FY 77-78 Research Report On The Impacts Of Ultra-Violet B Radiation On Biological Systems: A Study Related To Stratospheric Ozone Depletion

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FEBRUARY 28, 1978 FINAL REPORT

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CONTENTS

UV-B RADIATION MEASUREMENTS, INSTRUMENTATION AND METHODOLOGY

Solar UV-B Irradiance

Detailed spectral analyses of the UV radiation reaching the ground are of utmost importance to studies of the type covered by this report because of the pronounced wavelength dependence of most biological and natural photochemical reactions. Ultraviolet radiation shorter than 320nm to natural cut-off levels was the area of experimentation under consideration. Changes in spectral irradiance for this portion of the spectrum (280-320nm, comonly denoted as UV-V*) are analytically expressed as a function of solar angle and various atmospheric parameters, including atmospheric ozone concentration. Thus, analytical analyses of the factors contributing to variations in spectral irradiance in this region accomodate solar angle, ozone layer thickness, aerosol density, ground albedo, elevation above sea level and cloudiness. Germane to this study is the ultraviolet radiation increases that would accompany a change in the ozone layer thickness as it would influence

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*Classically (Coblentz-Stair, cited in Meyer and Seitz, 1942), the UV-B consisted of range of wavelengths, 280-315nm. By common usage, the UV-B now ranges up to 320nm.

crop productivity. Critical to the experimentation on the effects of UV-B radiation on plants is a knowledge of the dose applied and the manner in which it is applied as related to the stage of growth and development of the organism. This section will deal with measurements of irradiance and methodology of exposing plants to UV-B radiation enhancement levels used in this study.

Dosimetry and Units of Measurements

For this report on the biological effects of the solar UV-radiation on plants, we have used International Standard (SI) radiometric units, and in those areas not well delineated, we have used the suggestions of Rupert (1974 that have been adopted for use by the Society of Photochemistry and Photobiology.

A brief description of some aspects of terminology and dosimetry germane to this report follows:

Terminology of Radiometry and Dosimetry

Force is the product of mass times acceleration (Newton's Second Law) if mass is constant. The unit of force is the Newton (MKS units = $kg \cdot m \cdot s^{-1}$). Energy (kinetic) is the space integral of force, or commonly, the product of force x distance. The unit of energy is the joule (MKS units = $N \cdot m$). Power is the rate at which energy is expended. The unit of power is the watt (1 watt = 1 joule s^{-1}).

The terminology of radiometry applies to all electromagnetic radiation. Terms relating to a beam of radiation passing through space (without regards to origin or destination) are radiant energy and is the total amount of energy in the beam (for as long as it persists); radiant energy flux, the power of the beam, or the rate of flow of energy; and radiant energy flux density, the power crossing a unit area normal to the beam. Terms relating to a source of radiation

are radiant intensity, the power emitted per steradian into space by the entire source; and radiance, the power emitted per steradian into space by a unit projected area of the source surface. A term relating to the object intercepting the radiation is the irradiance, the power striking the object per unit of the object, or the energy per unit area per unit time. In biological applications, irradiance is expressed in J m^{-2} s^{-1} or W m^{-2} (See Table 1).

The terminology of dosimetry as applied to biology is related to the organism irradiated. The integral dose is the total radiant energy incident on the object (e.g., ergs per bacterium). The dose is the amount of energy incident on a unit area of the object (e.g., ergs per mm^2). The dose rate (analogous to irradiance) is the power incident on the object per unit area, or the energy per unit area per unit time (e.g., erg mm^{-2} sec^{-1}). Energy "incident upon" an object, does not imply that the energy is "absorbed by the object. Dosimetry quantities related to that actually absorbed are energy x $mass^{-1}$ in physical dimensions (see Table 2).

Instrumentation

Gamma Scientific Spectroradiometer

A model 2900 spectroradiometer was purchased from Gamma Scientific, Inc., 3777 Ruffin Road, San Diego, CA 92123, in 1973 for use in Climatic Impact Assessment Program. The characteristic of the instrument has been described by Green et al. (1975). The only modification in the basic instrument has been the installation of a solar-blind filter between the monochromator and phototube and a helipot in the preamp circuit of the phototube to increase sensitivity. Both of these changes were under the direction of Mr. Karl H. Norris, Instrumentation Res. Laboratory AMRI, ARS, USDA, Beltsville, Maryland. The instrument was interfaced to a Hewlett-Packard model 2100 computer for monitoring solar UV-B radiation, calibrating other instruments and establishing conditions for

Table 1. Power and energy conversion factors.

Power (irradiance, energy fluence rate, dose rate)	Energy (1 Joule = 1 watt·second) (density of incident energy, energy fluence, dose)
$Erg.s^{-1}.mm^{-2} = 10^{-1}\ W.m^{-2}$	$Erg.mm^{-2} = 10^{-1}\ J.m^{-2}$
$Erg.s^{-1}.cm^{-2} = 10^{-3}\ W.m^{-2}$	$Erg.cm^{-2} = 10^{-3}\ J.m^{-2}$
$Erg.s^{-1}.m^{-2} = 10^{-7}\ W.m^{-2}$	$Erg.m^{-2} = 10^{-7}\ J.m^{-2}$
$W.mm^{-2} = 10^{6}\ W.m^{-2}$	$J.mm^{-2} = 10^{6}\ J.m^{-2}$
$W.cm^{-2} = 10^{4}\ W.m^{-2}$	$J.cm^{-2} = 10^{4}\ J.m^{-2}$
$W.m^{-2} = 1\ W.m^{-2}$	$J.m^{-2} = 1\ J.m^{-2}$
$mW.mm^{-2} = 10^{3}\ W.m^{-2}$	$mJ.mm^{-2} = 10^{3}\ J.m^{-2}$
$mW.cm^{-2} = 10^{1}\ W.m^{-2}$	$mJ.cm^{-2} = 10^{1}\ J.m^{-2}$
$mW.m^{-2} = 10^{-3}\ W.m^{-2}$	$mJ.m^{-2} = 10^{-3}\ J.m^{-2}$
$\mu W.mm^{-2} = 1\ W.m^{-2}$	$\mu J.mm^{-2} = 1\ J.m^{-2}$
$\mu W.cm^{-2} = 10^{-2}\ W.m^{-2}$	$\mu J.cm^{-2} = 10^{-2}\ J.m^{-2}$
$\mu W.m^{-2} = 10^{-6}\ W.m^{-2}$	$\mu J.m^{-2} = 10^{-6}\ J.m^{-2}$
Equivalent Power Terms on a λ basis per nanometer	$W.h.mm^{-2} = 3.6 \times 10^{9}\ J.m^{-2}$
	$W.h.cm^{-2} = 3.6 \times 10^{7}\ J.m^{-2}$
	$W.h.m^{-2} = 3.6 \times 10^{3}\ J.m^{-2}$
$mW.m^{-3}.nm^{-1} \times 10^{-3} = W.m^{-2}.nm^{-1}$	$mW.h.mm^{-2} = 3.6 \times 10^{6}\ J.m^{-2}$
$W.m^{-2}.um^{-1} \times 10^{-3} = W.m^{-2}.nm^{-1}$	$mW.h.cm^{-2} = 3.6 \times 10^{4}\ J.m^{-2}$
$mW.m^{-2}.nm^{-1} \times 10^{-3} = W.m^{-2}.nm^{-1}$	$mW.h.m^{-2} = 3.6\ J.m^{-2}$
$\mu W.cm^{-2}.(10nm)^{-1} \times 10^{-3} = W.m^{-2}.nm^{-1}$	
$Erg.sec^{-1}.cm^{-2}.nm^{-1} \times 10^{-3} = W.m^{-2}.nm^{-1}$	$\mu W.h.mm^{-2} = 3.6 \times 10^{3}\ J.m^{-2}$
	$\mu W.h.cm^{-2} = 3.6 \times 10^{1}\ J.m^{-2}$
	$\mu W.h.m^{-2} = 3.6 \times 10^{-3}\ J.m^{-2}$

Table 2. Summary of Dosimetric Quantities

Source: Adapted from Rupert, 1974

Physical dimensions	Units	Suggested name	Suggested symbol
energy x area^{-1}	joule per square meter (J m^{-2})	energy fluence	F
area^{-1}	per square meter (m^{-2})	photon fluence	P
energy x area^{-1} x time^{-1}	joule per square meter and second (J m^{-2} s^{-1})	energy fluence rate	dF/dt or $\dot{F}$
area^{-1} x time^{-1}	per square meter and second (m^{-2} s^{-1})	photon fluence rate	dP/dt or $\dot{P}$
energy x mass^{-1}	joule per kilogram (J kg^{-1})	absorbed dose	D_a
energy x mass^{-1} x time^{-1}	joule per kilogram and second (J kg^{-1} s^{-1})	absorbed dose rate	dD_a/dt or $\dot{D}_a$

the field irradiator. For use in environmental control chambers and the greenhouse, the protocol outlined in Table 3 and 4 were used.

When the Gamma Scientific Spectroradiometer was interfaced to the computer, the "UV" set of programs were designed to control the Gama Scientific spectroradiometer and to collect, convert and analyze the ultraviolet global spectrum from 280 to 340 namometers. Options were available to record the original data on paper tape for later analysis. Program UVRD was designed for this later analysis. A real time analysis option (Program UVBT) was also available to convert to milliwatts per square meter per nanometer through conversion values (R values) stored on disc files. An update on the calibration was obtained through Program CALIB which was used in conjunction with the spectroradiometer and the tungsten-halogen standard radiance source (See Calibration Standards p.7).

The measured data was quadratically interpolated to even wavelengths with Hewlett-Packard software. The source signal was then converted to flux units and an integration was performed from 295 nm to 340 nm using the Simpson Method to give the total UV flux in W/m^2. The converted signal was then modified by a weighting function (see Table 10):

$$DNA = \exp - \left[(\lambda - 265)/21\right]^2$$

and another integration was performed from 295-340nm.

Provide the instrument was turned on and set up properly as outlined below, the programs could be activated from and the date returned to, any remote terminal via a telephone.

The raw data (wavelength transducer and photomultiplier output) were sampled by an H.P. Digital Voltmeter. An initial wavelength search was made by triggering the monochrometer grating motor through the relay board until the initial starting wavelength (289nm) is located. The scan was then initiated and controlled through the relay board to step approximately 1 nanometer at a time. A 500 millisecond delay was required before reading each signal to allow

Table 3. Protocol for use of the Gamma Scientific Spectroradiometer at locations other than in the solar scanning tower automated with the Hewlett-Packard computer.

The following procedure and attached data taking form (Table 4) should aid in making the UV light measurements in the greenhouses and growth chambers. Anyone using the instruments for the first time should be instructed on proper use.

1) Do not turn unit on yet.
2) Set range switch to "auto".
3) Turn HV "course" extreme counterclockwise.
4) Close slits.
5) Set response to S(slow) M(medium) or F(fast).
6) Turn unit on.
7) With function switch on "HV" adjust for 350 volts with course and fine.
8) With function switch on "operate" depress zero button and adjust zero.
9) Turn function switch back to "HV" and maintain 350 throughout.
10) Set range switch to "-1" (Mixie bulb is out, count 2 turns counterclockwise).
11) Attach fluke meter and switch box to monochromator. Put fluke on 2 volt range.
12) Turn wavelength to 200nm, open slits and readjust zero knob until fluke meter is zeroed.
13) Close slits and take another reading. (repeat steps 12 and 13 periodically).
14) Open slits and take data as required on attached forms.
15) Calculate DNA weighted flux from the following equation:

$$DNA = \sum_{e=1}^{9} Cal(\lambda i) * Sig(\lambda i)$$

16) Calculate $UV\text{-}B_{seu}$
17) Take a sun burn meter reading
18) Repeat data taking for 5, 10, 20, 30, 40, 50 and 100cm, also do one with light out. For 30cm distance take data every nanometer from 290-340nm.
19) Construct a graph of $UV\text{-}B_{seu}$ vs distance and extrapolate for deduction of intermediate distances.
20) Return equipment to the horticultural unit solar scanning tower by 7:30AM.

Table 4. Sample of the data recording sheet to be used with the Gamma Scientific Spectroradiometer for determining UV-B_{seu} in greenhouses &growth chambers

ROBERTSON METER= _____ DISTANCE= _____

NM	SIG	CAL	CALxSIG
290		3.000	
295		1.545	
300		0.751	
305		0.302	
310		0.114	
315		0.038	
320		0.012	
325		0.004	
330		0.001	
200		SUM	

ROBERTSON METER= _____ DISTANCE= _____

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320		0.012	
325		0.004	
330		0.001	
200		SUM	

UVB_{seu} = Sum/21.0

for stablization of the electronics and to allow for "scan motor flyby." This essentially limited the speed of the scan to approximately 2 nm/sec. Data from 280nm to 285nm was assumed to be dark current and scattered light generated signals and was used for correction by subtration from the entire spectrum. The sun-burn UV radiometer output was sampled immediately before and after each scan. Also, it was sampled separately every 5 minutes and recorded by a potentiometric strip chart recorder. (This portion of the grant was under the direction of Dr. Jon Bartholic).

Every half hour from 9 am to 4 pm a scan was made of the natural solar UV-B influx and a mean UV-B flux for the day computed. The mean natural UV-B flux for each crop was arrived at by averaging the daily fluxes while the crop was growing.

Optronics Model 741 Spectroradiometer

A model 741 of the specifications outlined in Table 5 was purchased from Optronics Laboratories, Inc., 7676 Fenton Street, Silver Springs, MD 20910. It was equipped with a Hewlett-Packard 9815A calculator. The instrument was originally calibrated against the secondary standard owned by Optronics Laboratories, Inc. A comparison of this secondary source with the secondary standard lamp we have used for calibration agreed within $\pm$ 2%. An inter-comparison between measurements made with the Optronics Model 741 spectroradiometer, the Gamma Scientific spectroradiometer and a spectroradiometer in Mr. Karl Norris' laboratory, AMRI, ARS, USDA, Beltsville, MD all agreed within $\pm$ 4%.

Optronics Model 725 Radiometer

A model 725 radiometer of the specifications outlined in Table 6 was supplied by Optronics Laboratories Incorporated. It was calibrated by Mr. Karl Norris for a UV-B irradiance of 2.6 W/m^2 to give a full scale deflection using 5 mil Cellulose Acetate filtered UV-B irradiance from an FS-40 lamp

Table 5. Specifications for Optronics Laboratories, Inc. Model 741 UV-B Spectroradiometer.

MODEL 741 UV-B SPECTRORADIOMETER

Preliminary Specifications

Wavelength Range	250 to 400 nm with option to extend to 800 nm
Bandpass	2 nm ± 0.5 nm
Scanning Time	1 and 5 nm/sec
Response Time	1 and 10 sec (0 to 99%)
Wavelength Accuracy (dial reading)	± 0.5 nm
Wavelength Precision (cam pulse)	± 0.2 nm
Spectroradiometric Accuracy	± 3%
Repeatability	± 1%
Stray Light	10^{-4} at 285 nm*
HV Power Regulation	0.1%
Angular Response	Input optics with cosine response to within ± 5% at 45°
Dynamic Range	10^7
Irradiance Range	10^{-10} to 10^{-3} W/cm^{2}nm
Noise Equivalent Irradiance	10^{-10} W/cm^2 nm at 280 nm
Readout	4 digit display of log amperes
Recorder Output	0 to 7 V with 1 volt per decade
Data Acquisition Interval	1 nm interval sync pulse
Digital Output	4 digit BCD, Hold and control signals
Size: Optics	4 x 7 x 8 inch
Electronics	4-1/2 x 8 x 11 inch
Weight: Optics	Less than 10 lbs.
Electronics	Less than 10 lbs.
Operating Environment:	
Temperature	10 - 37° C
Humidity	to 80%
Electrical Requirements	105 to 125 V, 60 Hz

* measured with a xenon source and a 0.5 mm cellulose acetate filter

Table 6.

OPTRONIC LABORATORIES, INC.

Emphasizing Precision and Accuracy

Preliminary Bulletin 51

MODEL 725 UV-B RADIOMETER

The Model 725 is a portable, battery operated radiometer specifically designed for measuring the ultraviolet irradiance of artifical sunlight which is used in many growth chambers, greenhouses, field plots, etc.

The design and selection of components are optimized for the UV-B spectral region. A peak response at 300 nm is obtained using a filtered, solar-blind diode. A dome-shaped teflon diffuser serves as an unusally effecient uv cosine receptor. The electronics and the removeable optical sensor is housed in an attractive wooden box suitable for laboratory or field use. The optical sensor is small and light weight allowing placement of the sensor into growth chambers with a minimum of disturbance to growing plants.

The electronics consists of a single-stage operational amplifier, a calibration trim-pot, and a battery test pushbutton switch. The readout consists of a single range analog display and a BNC recorder output which provides an analog signal equivalent to the voltage displayed on the panel meter. The unit is calibrated to read "UV-B" watt/cm^2 using the BZ type lamp standard.

SPECIFICATIONS

Peak Wavelength Response	300 ± 5 nm
Response at 280 and 320 nm	Down less than 70%
Response at 500 nm	Less than .01% of peak
Stability	±3%/6 months
Accuracy	± 2%
Readout	0-1 Volt analog panel meter external recorder output
Response Time	1 sec.
Power Requirement	Internal battery pack or 105-125 VAC
Continous Battery Operation	200 hours
Recharge Time	14-16 hours
Size	9 x 3 x 4

Price $350.00

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that would be equivalent to 5 UVBSE when "weighted" by $A\Sigma 9$ as described by the equation of Carns et al. (1977). Figure 1 demonstrates an intercomparison between measurements using the model 725 radiometer meter reading and the Gamma Scientific spectroradiometer with FS-40 Westinghouse "sun lamps" and a 5 mil Cellulose Acetate filter. The read-out on the latter is both W/m^2 and "weighted" mW/m^{-2} (see page 9 for description of latter). It should be noted that the radiometer cannot be used to adequately describe a "weighted" or total irradiance. Radiometers are very useful as monitoring devices once calibrated conditions have been established but should not be used for characterizing UV-B irradiance conditions.

Sun-Burn UV Meter

A sun-burn, UV radiometer supplied to investigators associated with the Climatic Impact Assessment Program was available for monitoring solar radiation and experimental test systems. The instrument has been well described in the CIAP monograph 5, Chapter 2. However, because of its built-in weighting function, it was only used as a monitoring radiometer.

2145 Type RV meter

A small hand-held 2145 UV meter modified by installing a filter over the radiation detector of a General Electric type 214 illumination meter, was used to monitor the FS-40 Westinghouse "sun lamps." It was supplied by Drs. Lowel E. Campbell and Richard W. Thimijan, Agricultural Equipment Laboratory, PPHI, ARS, USDA as part of the overall program.

Calibration Standards

A standard lamp was purchased from Gamma Scientific, Inc. april 11, 1973. It was rechecked for spectral irradiance by Optronic Laboratories in July 1977

Figure 1

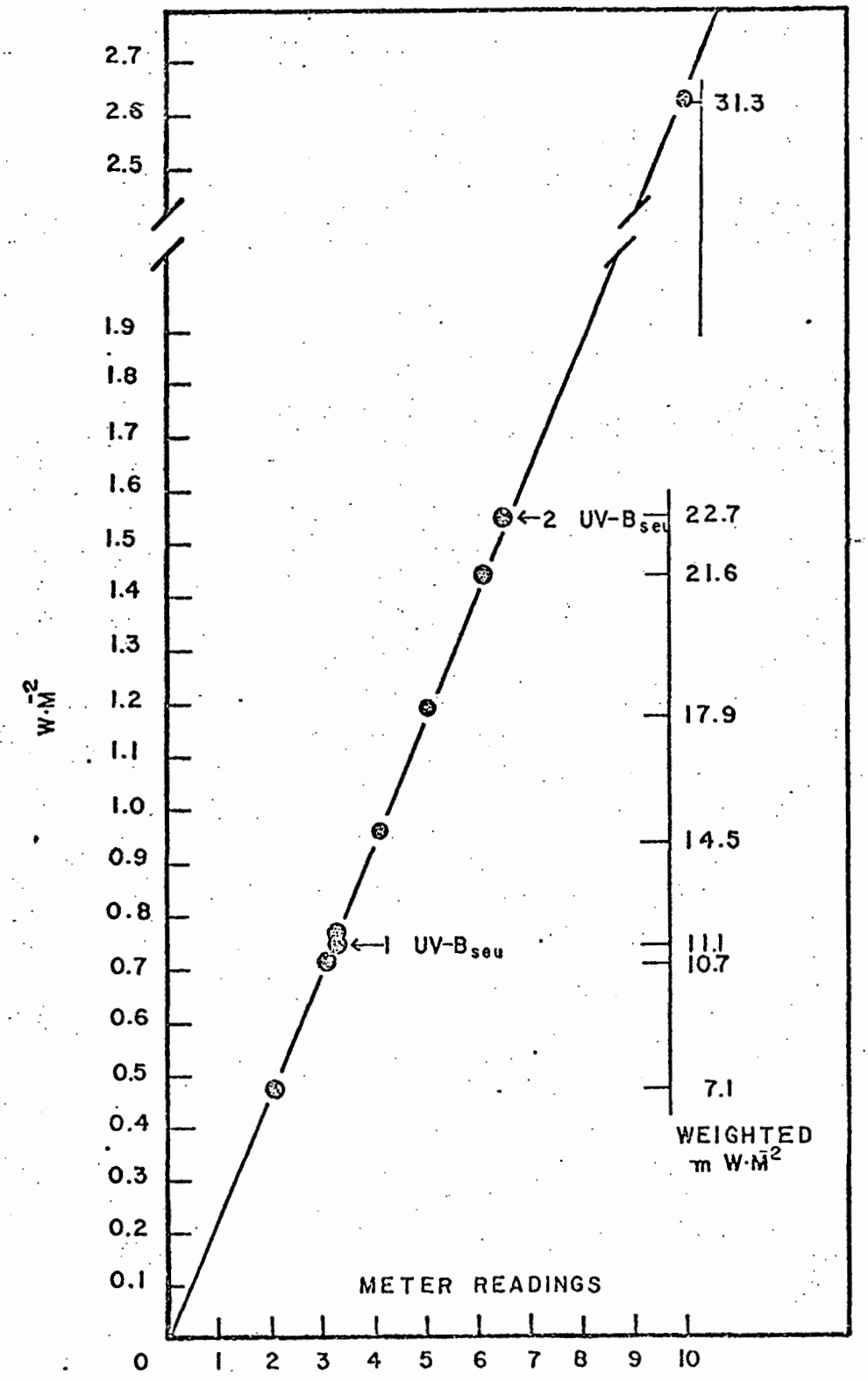


Fig. 1. Calibration of the Optronic 725 radiometer with the Gamma Scientific spectroradiometer showing the relationship between Optronic 725 meter readings and the total W/m^2 and weighted mW/m^2 as determined with the spectroradiometer and computer. The source of irradiance was an FS-40 lamp filtered with 5 mil C.A.

and found to vary by less than 2% from the initial calibration report. The standard was a 1000-watt quartz-halogen, tungsten coiled-coil filament lamp, designated by model 230, type SN-99. When operated at 8.3 amperes at a distance of 50 cm, the irradiance per 5nm of wavelength was rated in calibration as shown in Figure 2.

In reality, the calibration values traceable to the National Bureau of Standards, were given only at 280, 290, 300, 320 and 350 nanometers. For other wavelengths, the calibration values were interpolated through an approximation to the Blackbody Function, i.e.,

$$I = \frac{I_o \, C^{-\frac{c}{\lambda}}}{\lambda^5} \qquad \text{where } I = \frac{I_o}{\lambda^5} \times \frac{1}{(e^{\frac{c}{\lambda}} - 1)}$$

A second standard was purchased from the National Bureau of Standards for use in the 280-230 nm range. This was a 20-watt fluorescent lamp. The operating condition and output are shown in Table 7.

A Solar Reference Day

On April 28, 1977 a number of measurements were made every 30 minutes during the day with a Gamma Scientific Spectroradiometer. The day was chosen because it was a clear one during approximately the mid-point of the spring vegetable growing season. Data of Figure 3 demonstrates the irradiance per nanometer of wavelength from 290-340nm. Total irradiant flux for a 295 to 340 nm band width for 15 measured and 6 interpolated values are shown in Table 8. Total flux was calculated to be 126.557 W/m^2 of total irradiance. This was taken to be the solar reference day and is the solid line plotted on Figure 3 which is labelled "calculated value." A check for the calculated curve was an actual measured solar spectrum out of the several that had a total irradiance

Figure 2

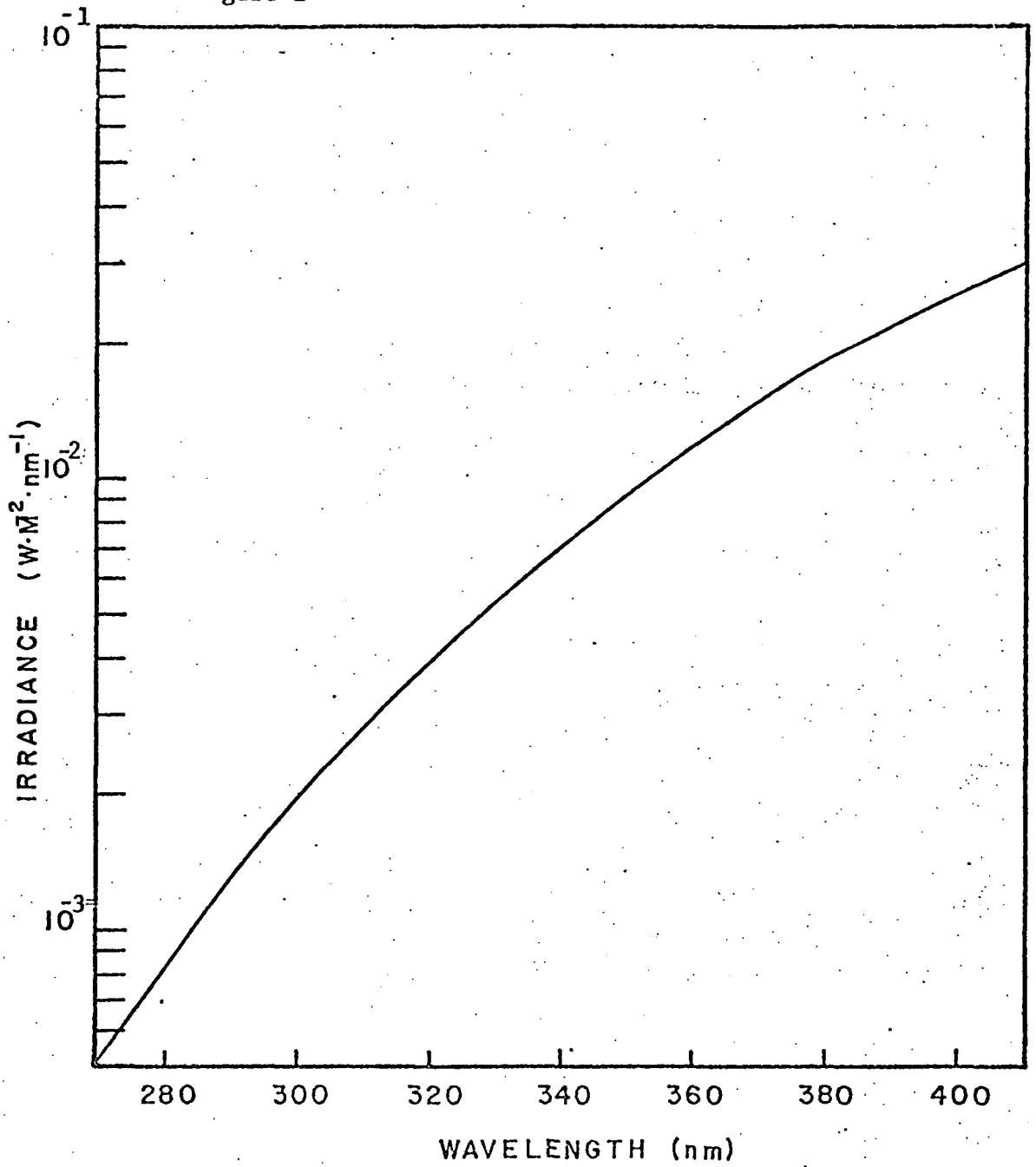


Fig. 2. Calibration curve for the SN-99 1000 watt quartz-halogen, tungsten coiled-coil filament standard lamp.

Figure 3

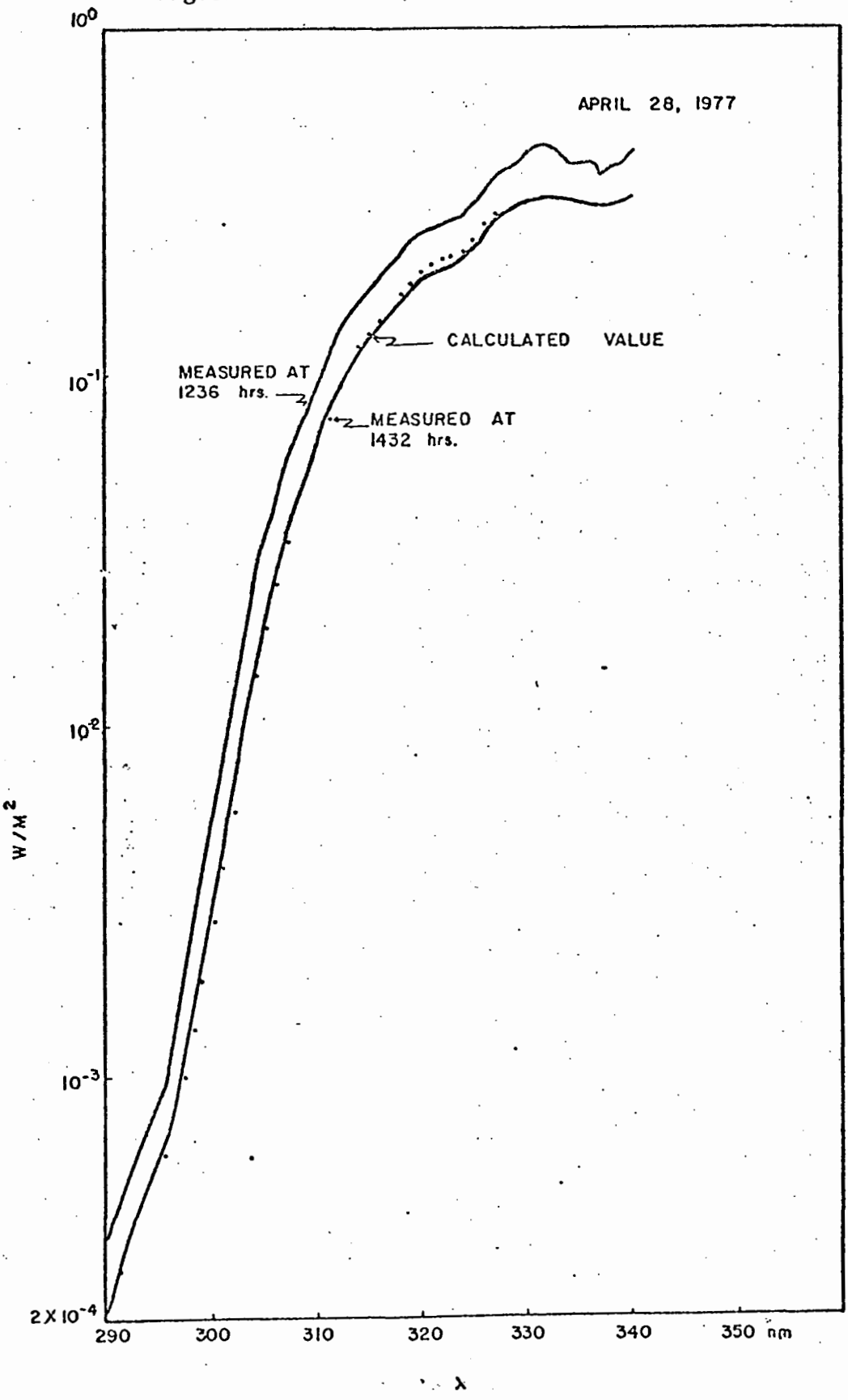


Fig. 3. Two measured solar UV-B irradiance spectra and a calculated reference solar spectrum (see text for method of calculation of reference spectrum).

Table 7. Spectral irradiance of Lamp No. BZ 11 when operated at a voltage of 0.250 RMS.

Wavelength (nm)	Spectral Irradiance (W/cm^3)
280	0.00508
282	0.01420
284	0.03490
286	0.08170
288	0.17400
290	0.333
292	0.591
294	0.974
300	2.930
304	4.520
306	5.190
308	5.660
318	5.170
320	4.700
322	4.210
324	3.740
326	3.290
328	2.890
330	2.530
338	1.500
340	1.320
342	1.160
344	1.010
346	0.891
348	0.778
350	0.684

Table 8. Total irradiance and weighted irradiance for April 28, 1977 which was a clear day at Gainesville, Florida.

Time (EST)	Total Irradiance 295-340nm(W/m^2)	Weighted Irradiance 295-340nm (mW/m^2)
0705	0.800[1]	0.400[1]
0735	1.726	1.336
0805	2.565	2.288
0835	3.652	3.663
0905	4.808	5.618
0935	5.900[1]	7.850[1]
1005	7.003	10.070
1035	7.767	12.261
1105	8.560	14.070
1135	9.308	16.366
1205	9.665	17.212
1235	9.796	17.478
1305	9.658	17.044
1335	8.922	15.390
1405	8.500	13.450
1435	7.667	11.226
1505	6.660	9.288
1535	5.330[1]	7.120[1]
1605	4.000[1]	5.150[1]
1635	2.800[1]	3.250[1]
1705	1.470[1]	1.200[1]
	126.557[2]	191.730[3]

[1]Interpolated values.

[2]Equals 227,803 $W \cdot sec/m^2$.

[3]Equals 345,114 $mW \cdot sec/m^2$.

value and a weighted value (see next section) close to the calculated one. This was the scan at 1432 hours with a total flux of 7.667 W/m^2 irradiance. As a further point of reference for April 28, 1977, the 1236 hr. EST scan was plotted. Ths UV-B portion of the spectrum was 7 minutes after the sun had passed the meridian and was at 17.4^{o} from Zenith. Fig. 4 demonstrates the calculated total flux of the solar reference day and weighted flux when the curve is extrapolated to cover irradiance from dawn to dusk. Table 9 is the accumulated irradiance by nm of wavelength from 0705 to 1402 hrs Est. for April 28, 1977.

Rating 280 to 320nm for Biological Effectiveness

Because of the high reactivity of the 280-320 nm wavelength radiation with biological materials, attention has been given to determining the proper function to apply to have equal effectiveness in a dose-response analysis of a biological reaction in this spectral region. We have found that the "weighted function" described by the following formula as "curve fitted" to a DNA absorption spectra, had good utility for our research.

$$\hat{y} = e^{-x};\ x = \left(\frac{\lambda - 265}{21}\right)^2;$$

$$\text{Then: } \hat{\hat{y}} = e^{-\left(\frac{\lambda - 265}{21}\right)^2}$$

This was a "weighting function" suggested by Carns et al. (1977) at an EPA/USDA sponsored workshop at the USDA/ARS Laboratories, Beltsville, MD in Feb. 1977, and will be referred to as AΣ21. It was agreed that this would be a portion of the protocol for this one-year, short-term study. As will be recognized by biologists, this formula is based on a Poisson distribution.

In many biological phenomena, the responses noted can be described by a mathematical expression known as the Poisson Distribution. With rare kinds of events occurring and the n is large, the binomial distribution is noticeably

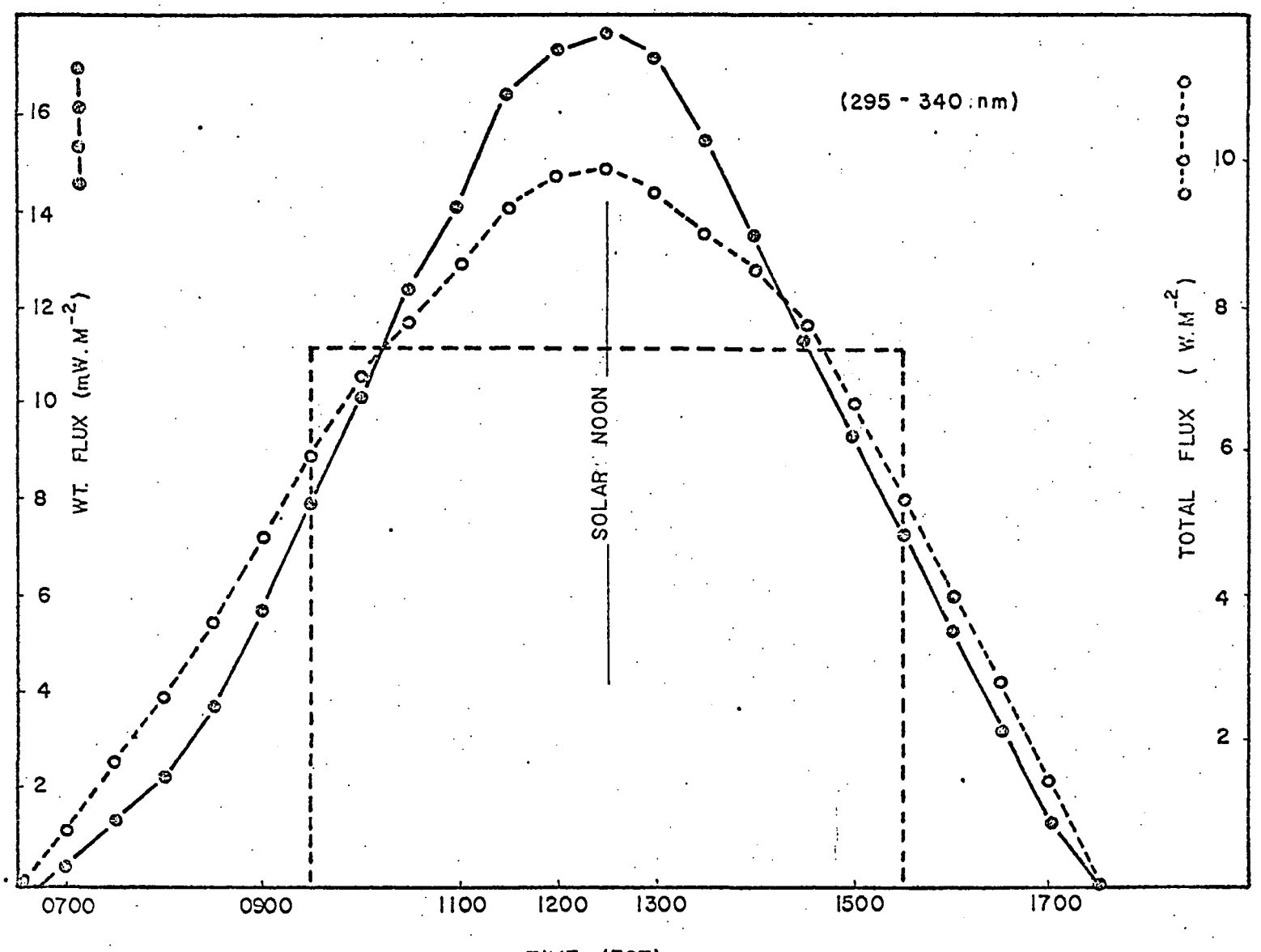


Fig. 4. Total (W/m^2) and weighted (mW/m^2) irradiance curves for 295-240 nm wavelengths for every 30 minutes during April 28, 1977. The data points of measured and interpolated values are recorded in Table 8. The dotted square illustrates the reference solar standard with the vertical lines indicating irradiance levels that went into establishing the horizontal reference line.

Table 9. Total solar UV-B radiation for each Wavelength from 290 - 340 nm on April 28, 1977.[1]

λ	mW/m^2	λ	mW/m^2	λ	mW/m^2	λ	mW/m^2	λ	mW/m^2
290	.247	291	.281	292	.357	293	.450	294	.533
295	.615	296	.784	297	1.123	298	1.179	229	2.267
300	3.448	301	4.965	302	7.245	303	11.179	304	16.135
305	22.352	306	28.954	307	37.177	308	46.986	309	56.087
310	67.507	311	81.623	312	97.936	313	111.457	314	122.067
315	134.470	316	147.559	317	159.609	318	171.37	319	186.611
329	200.596	321	209.987	322	214.346	323	220.434	324	230.912
325	248.732	326	266.296	327	297.419	328	304.282	329	315.030
330	326.219	331	333.356	332	334.585	333	331.361	334	329.629
335	397.109	336	320.450	337	318.272	338	325.757	339	328.020
340	339.665								

[1]Daily Means for Each 290 to 340 nm expressed in mW/m^2 from 0805 - 1502 hrs EST.

skewed and the normal approximation is unsatisfactory. Poisson's Distribution, a limited form of the binomial distribution, is a better approximation when n tends to be infinite and p tends to be zero at the same time in such a way that $\mu = np$ is constant. This seems to describe the events occurring with UV-B radiation and plant tissues, particularly if the targets are large molecules and are repairable or replaced. The Poisson distribution can also be developed by reasoning quite unrelated to the binomial. It is analagous to the classical example where signals are being transmitted and the probability that a signal reaches a given point in a small time-interval t is λt, irrespective of whether previous signals arrived recently or not. Then the number of signals arriving in a finite time interval may be shown to follow a Poisson Distribution.

This formula for comparing biological effectiveness and for matching natural solar irradiance to experimental test conditions has had good utility for the following reasons:

1. It is a functional analytical equation that has found much application in analyzing environmental factors as related to plant responses.

2. To the present time, action spectra of specific biological responses in this region of the spectrum have been shown to require some adjustments with most weighting functions. Even the one specifically designed for erythema has to be modified for specific cases of "redding". Figure 5 is a $\log_{10}$ plot of the nummerical biological effectiveness factors vs wavelength of several well described ones. Note the relationship of $A\Sigma$ 21 to the others and its position somewhat as an "average".

3. This mathematical treatment of biological effectiveness is based on DNA absorbtion. DNA is the basic cellular molecule that is the pivotal point for cellular damage by UV-B radiation. There are

Figure 5

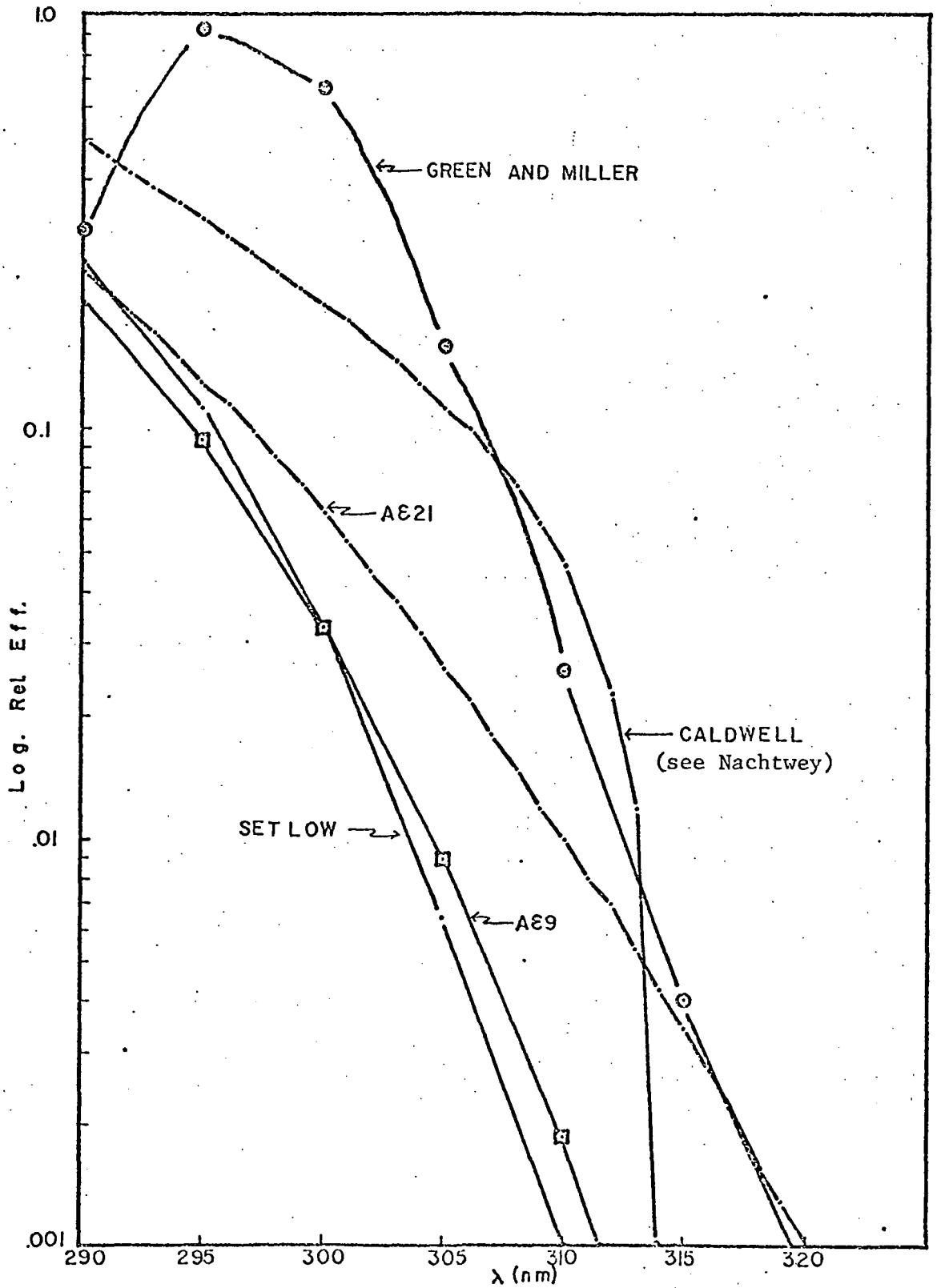


Fig 5. Comparison of biological effectiveness "weighting" of UV-B radiation by several investigators. The AΣ21 was used in this report (see references for others).

other reactions but this component will more than likely play a role in most plant systems. It is a point of reference and the mathematical interfacing to biology is fairly straightforward with a seemingly sound logical basis when compared to other biological events with statistical probabilities.

The data in Table 10 demonstrates the use made of the A Σ 21 for biological weighting. The measured irradiance at each wavelength from 290 to 340 nm at 1432 hours on April 28, 1977 is multiplied by the e^{-x} to yield a biological "weighted" mW/m^2, illustrated by the last column. To give some utility to use of the biological effectiveness weighting for establishing experimental conditions to test the effect of UV-B radiation on plants, a standard reference condition had to be chosen. We chose to analyze one clear day during the growing season at Gainesville FL and to use this in addition to other factors in arriving at a solar reference condition. Figure 3 demonstrates measured solar irradiance at 1236 and 1432 hours and an "average" calculated spectral scan for 290 to 340nm. The "average" was based on solar irradiance of approximately 7.08 W/m^2 with a biological effectiveness based on the A Σ 21 of 11.12 mW/m^2. This value of 11.12 mW/m^2 was then used to establish experimental conditions for UV-B irradiation conditions. Figure 4 illustrates a comparison between the total irradiance and "weighted" irradiance used and demonstrates the "on and off" characteristic of applying the "average" irradiance. Whether the trapazoid or the Simpson rule of totaling is applied, The total and biologically weighted irradiance was a little over 7.08 W/m^2 and 11.12 mW/m^2, respectively. This was chosen empirically to be 1 unit of biologically effective UV-B radiation, the UV-B solar equivalent unit, abbreviated $UV\text{-}B_{seu}$. If a total of actual and biologically weighted irradiance is made for the entire day at band-width 295 to 340 nm it would be approximately 10.55 W/m^2 and 15.98 mW/m^2, respectively. We chose not to use the total

Table 10. Solar radiation at ground level as measured with a gamma spectroradiometer on April 28, 1977 at 1432 hr at Gainesville, Florida

λ	e^{-x}	mW/m^2	$WtmW/m^2$
290	0.242	0.2	0.0484
291	0.217	0.3	0.0651
292	0.192	0.3	0.0576
293	0.170	0.5	0.0850
294	0.150	0.5	0.0750
295	0.130	0.6	0.0720
296	0.113	0.8	0.0904
297	0.098	1.1	0.1078
298	0.085	1.4	0.1190
299	0.073	1.9	0.1387
300	0.062	2.9	0.1798
301	0.053	4.3	0.2279
302	0.045	6.6	0.2970
303	0.038	10.1	0.3838
304	0.032	15.0	0.4800
305	0.026	20.7	0.5382
306	0.022	27.2	0.5984
307	0.018	35.1	0.6318
308	0.015	44.9	0.6735
309	0.012	54.6	0.6552
310	0.010	65.3	0.6530
311	0.008	80.8	0.6464
312	0.007	97.9	0.6853
313	0.0054	112.9	0.6297
314	0.0043	124.8	0.5366
315	0.0034	138.2	0.4699
316	0.0027	151.1	0.4080
317	0.0022	163.7	0.3601
318	0.0016	176.8	0.2829
319	0.0013	193.7	0.2518
320	0.0010	208.0	0.2080
321	0.00082	219.2	0.1800
322	0.00063	224.5	0.1414
323	0.00049	230.2	0.1130
324	0.00037	238.9	0.0883
325	0.00028	256.7	0.0718
326	0.00022	282.8	0.0622
327	0.00016	309.5	0.0495
328	0.00012	318.2	0.0382
329	0.00009	329.7	0.0297
330	0.00009	343.4	0.0309
331	0.00005	351.2	0.0176
332	0.00004	354.5	0.0114
333	0.00003	350.7	0.0105
334	0.00002	346.9	0.0069
335	1.5×10^{-5}	345.3	0.0036
336	1.1×10^{-5}	338.5	0.0034
337	0.8×10^{-5}	337.6	0.0027
338	0.6×10^{-5}	343.7	0.0002
339	0.4×10^{-5}	346.3	0.0002
340	0.3×10^{-5}	359.3	0.0002

irradiance for the day but to modify the reference spectrum on the basis of solar angles of approximately 50^{o} for the AM and 45^{o} for the PM from the zenith. The rational was that a certain level of UV-B irradiance was beneficial. There is no a priori basis for choice of this level. We chose to use the point where the irradiance level at 300nm was approximately 1×10^{-3} W/m^2.

When the solar reference conditions of the $UV\text{-}B_{seu}$ solar spectrum is compared to Bener's measurements to approximate a 0.32 atms · cm ozone column and Green et al. (1975)mathematical model based on Bener's measurements, it matches within $\pm$ 5% the curve descriptive of a 0.32 atms · cm ozone column with a solar zenith angle of 30^{o}. This is illustrated by Fig. 6 and Table 11. Applying the same rules to this curve as to the solar reference spectrum, the total flux from 295 to 340 nm is 7.24 W/m^2 with a weighted flux of 11.52 W/m^2.

Based on these comparison's, the empirically arrived at 11.12 W/m^2 was used to adjust FS-40 Westinhouse"sum Lamps" and filters for enhancement level.

In studying the biological effectiveness curves (Fig. 5) and the attenuation of UV-B radiation by ozone, the major atmospheric attenuator, (Fig.7 and8), it becomes obvious that the critical factor in establishing conditions for UV-B experimentation is the level of 290 to 300nm radiation. Notice the change in slope of the 297.5 vs the 320 nm radiation. Adjusting distances to a radiating source along with changing attentuation with filters is the method used in this study with particular care to filter attenuate for this is a most critical factor. The "biological effectiveness weighting" is a mathematical adjustment between what can be accomplished with lamps, pulleys, filters and Timers and what is natural or what is expected.

Figure 6

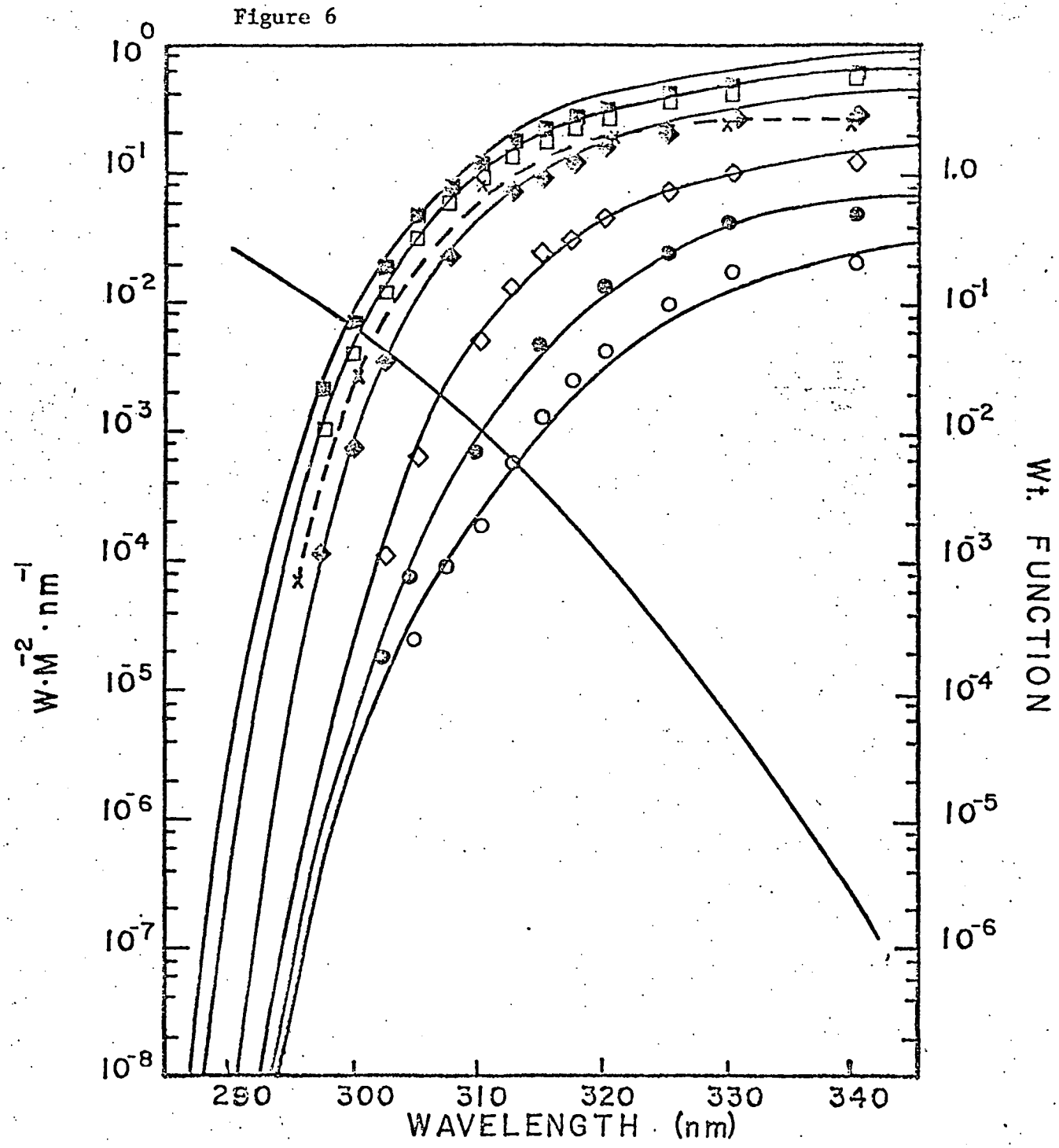


Fig. 6. Downward global flux for an ozone thickness of 0.32 cm. All points except the X--X are Bener's (1972) results for solar zenith angles of 0, 30, 50, 70, 80, and 85° in order of decreasing magnitude of the fluxes. The solid lines are the corresponding theoretical calculations of Shettle and Green. The X points and dotted line are the reference solar spectrum (see text) and the solid line referenced to the weighted function is the A Σ 21 described in the text.

Figure 7.

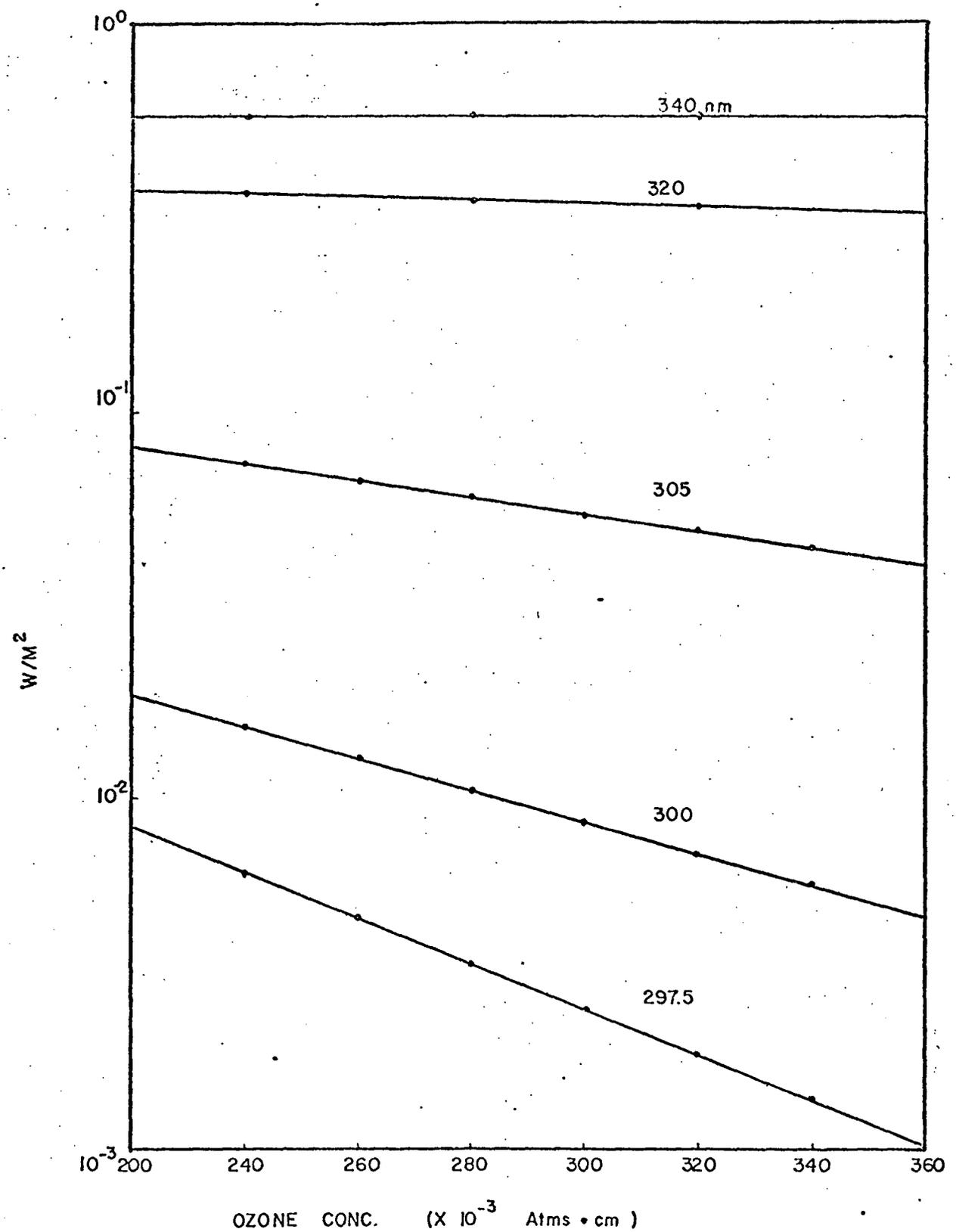


Fig. 7. Solar UV fluxes as adapted from Bener's data, based on attenuation by various ozone depths. The units are W/m^2 at the designated nm.

Figure 8

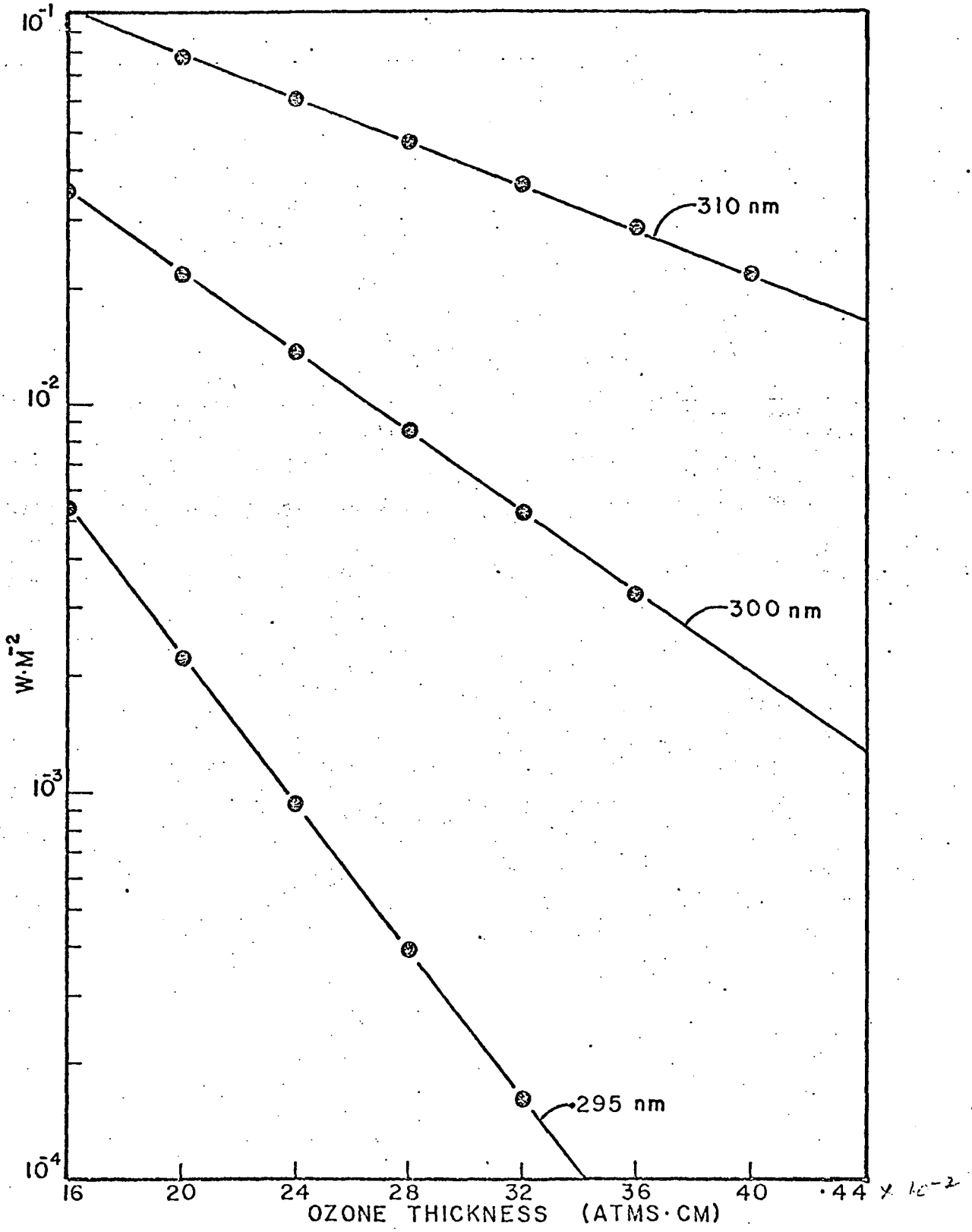


Fig. 8. Solar UV fluxes based on Green et al.'s (1975) analytical treatment of Bener's data. The units are W/m^2 at the designated nm of wavelength.

TABLE 11. Global UV Radiation at a Solar Elevation Angle of 60° as a Function of Wavelength for Ozone Thicknesses of 0.32 cm. (From Shettle and Green, 1974).

Wavelength (nm)	0.32-cm ozone thickness Global radiation
	$\frac{W}{m^2.nm}$
340	6.40×10^{-1}
330	4.99×10^{-1}
325	4.15×10^{-1}
320	3.19×10^{-1}
315	2.13×10^{-1}
310	1.10×10^{-1}
305	3.63×10^{-2}
300	5.20×10^{-3}
295	1.63×10^{-4}
290	3.06×10^{-7}
285	3.16×10^{-12}
280	2.10×10^{-21}

Establishing Conditions for UV-B Radiation Enhancement In Controlled Environmental Chambers, Greenhouse and Field Experimentation

The basic arrangement for UV-B radiation enhancement was to use FS-40 Westinghouse fluorescent "sun lamps" with a filter of 0.005 mil (0.20 mm Mylar, type S, for the control and different thicknesses of cellulose acetate to simulate different solar equivalent conditions. The irradiative nature of the FS-40 lamp has been well characterized and illustrations of spectral output (Fig. 9) and aging (Fig. 10) are included for reference.

A very critical parameter for UV-B radiation enhancement is the use of proper filters to attenuate the spectral distribution of UV-B radiation. Fig. 11 will demonstrate the cut-off characteristics of different thicknesses of cellulose acetate. The films were purchased from Transilwrap, 2616 McCall Place, Atlanta, GA 30340 in thousand-foot rolls to lessen problems inherent with different lots of film. Using the absorption properties of the different thicknesses of cellulose acetate in conjunction with distance from one to several lamps a given $UV\text{-}B_{seu}$ was established for the enhancement conditions. Table 12 demonstrates typical $UV\text{-}B_{seu}$ conditions in "C" type environmental control chambers at the Duke University Phytotron with 4 FS-40 lamps at equal distance but with different mil thicknesses of cellulose acetate. Figure 12 demonstrates the relation between distance to a 5 mil cellulose acetate filtered FS-40 lamp and irradiance when it is totalled on the basis of 290 to 320, 290 to 340, or 295 to 340nm

The most practical protocol to use at the present time with our present level of technology of measuring spectra in the 290-320nm region and sources of irradiance with filter combinations is to use a radiometer for monitoring that is periodically calibrated against a well calibrated spectroradiometer.

Figure 9

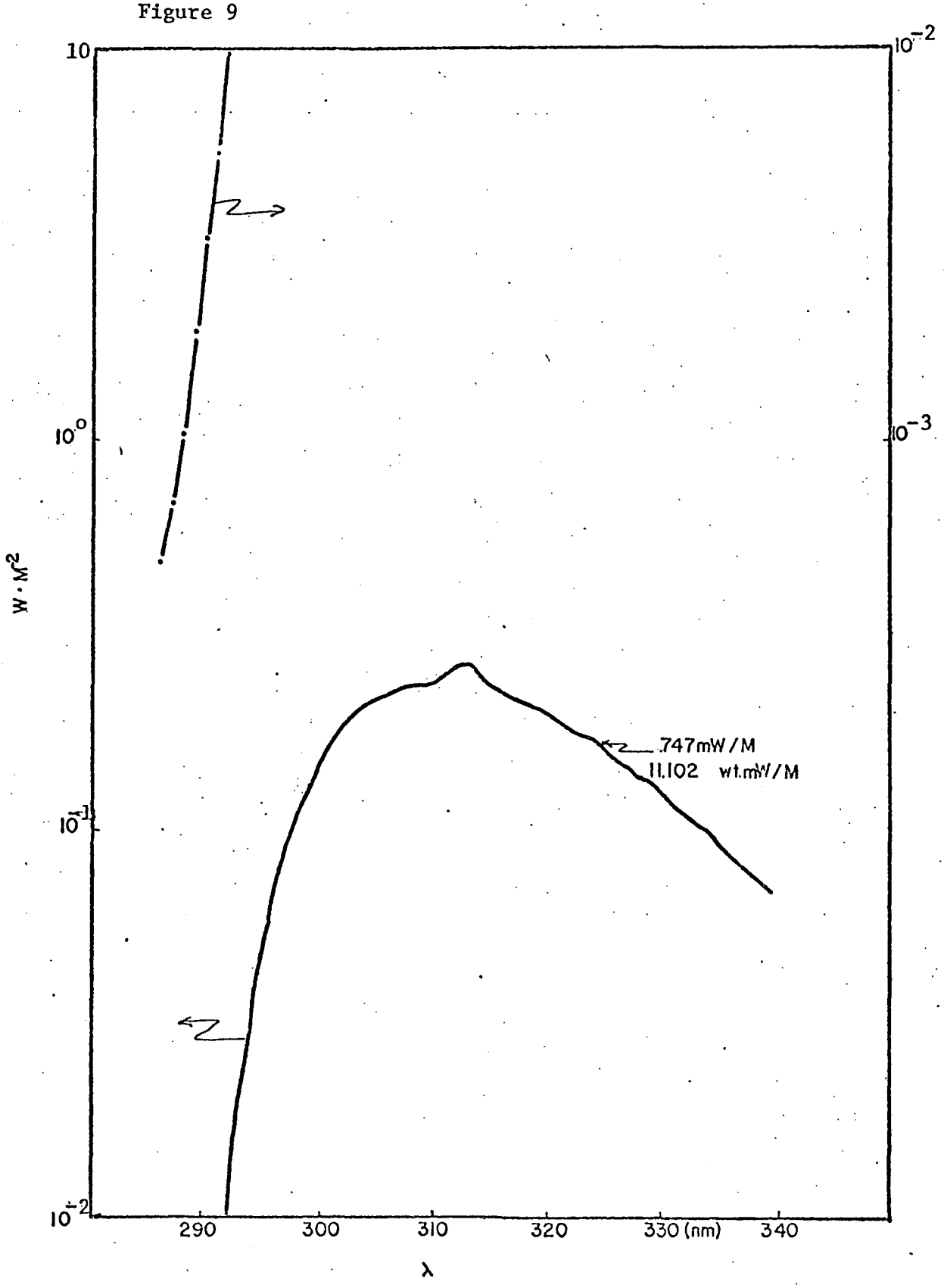


Fig. 9. UV-B irradiance from 2 FS-40 Westinghouse "sun lamps" filtered by 5 mil Cellulose Acetate. The distance to the lamp + filter combination was adjusted to yield close to 1 UV-B_{seu}($7.08W/m^2$ with a weighted value of $11.12mW/m^2$) vs $0.747W/m^2$ with a weighted value of $11.10mW/m^2$.

Figure 10

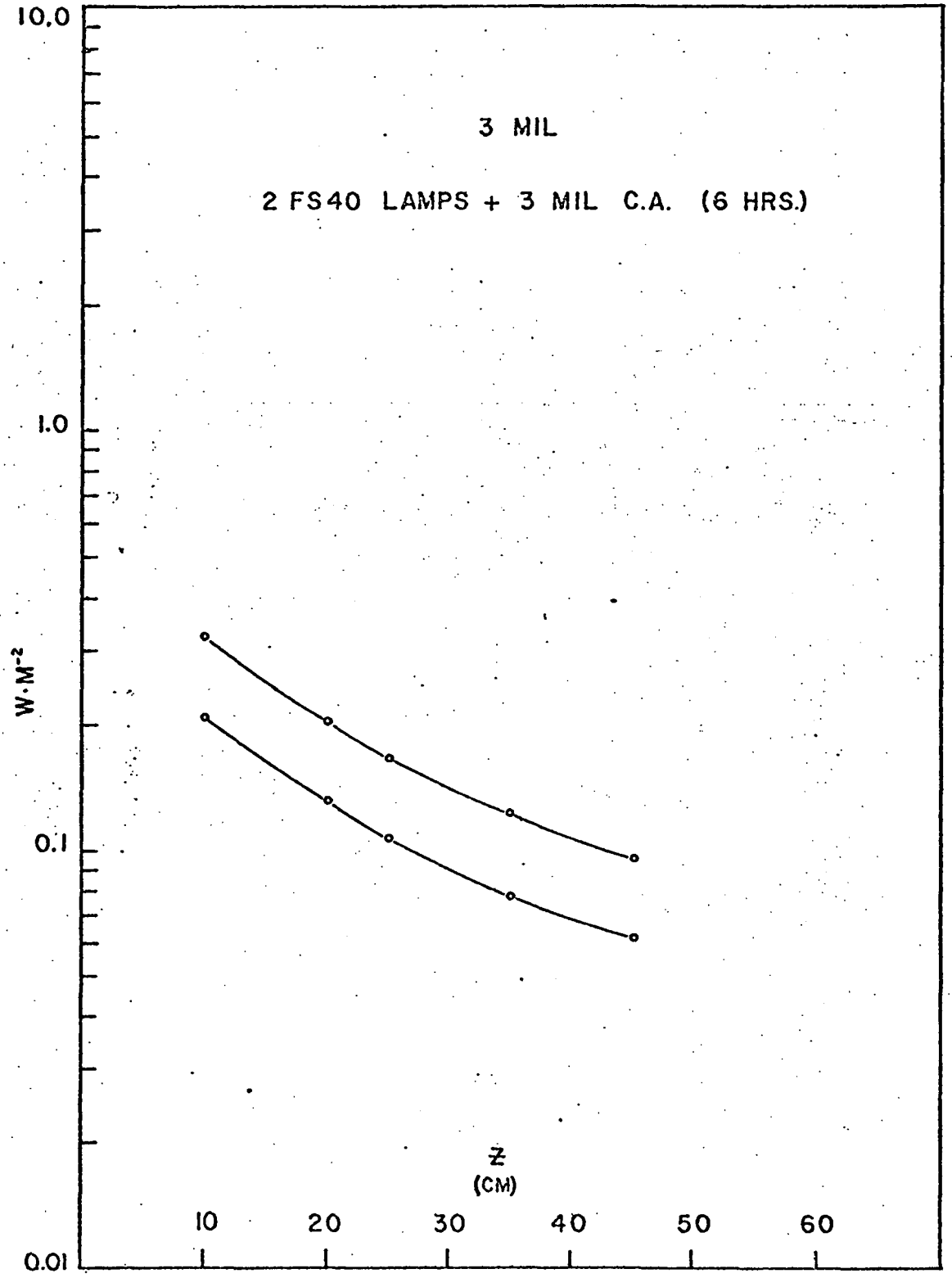


Fig. 10. Relation of UV-B irradiance to distance from 2 FS-40 "sun lamps" filtered with 3 mil cellulose acetate as a result of solarization of the film in 6 hrs. The top curve is C.A. non-exposed; the bottom exposed 6 hrs. Each data point is total UV irradiance from 290-340nm

Figure 11

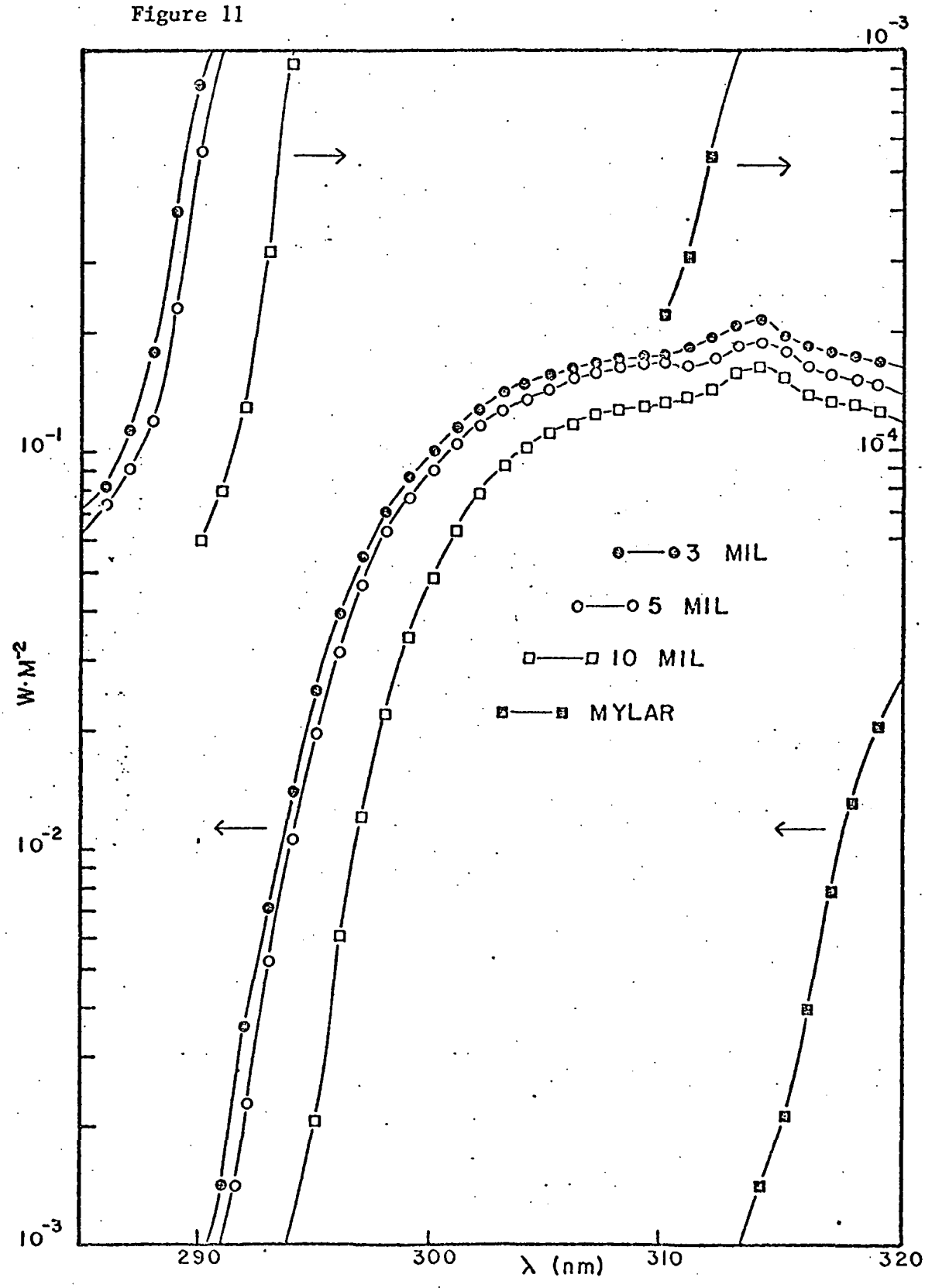


Fig. 11. Relation of filters and thickness to UV irradiance at each λ′ from 285 to 320nm from 2 FS-40 "sun lamps" with all conditions the same except changing the filters.

Figure 12

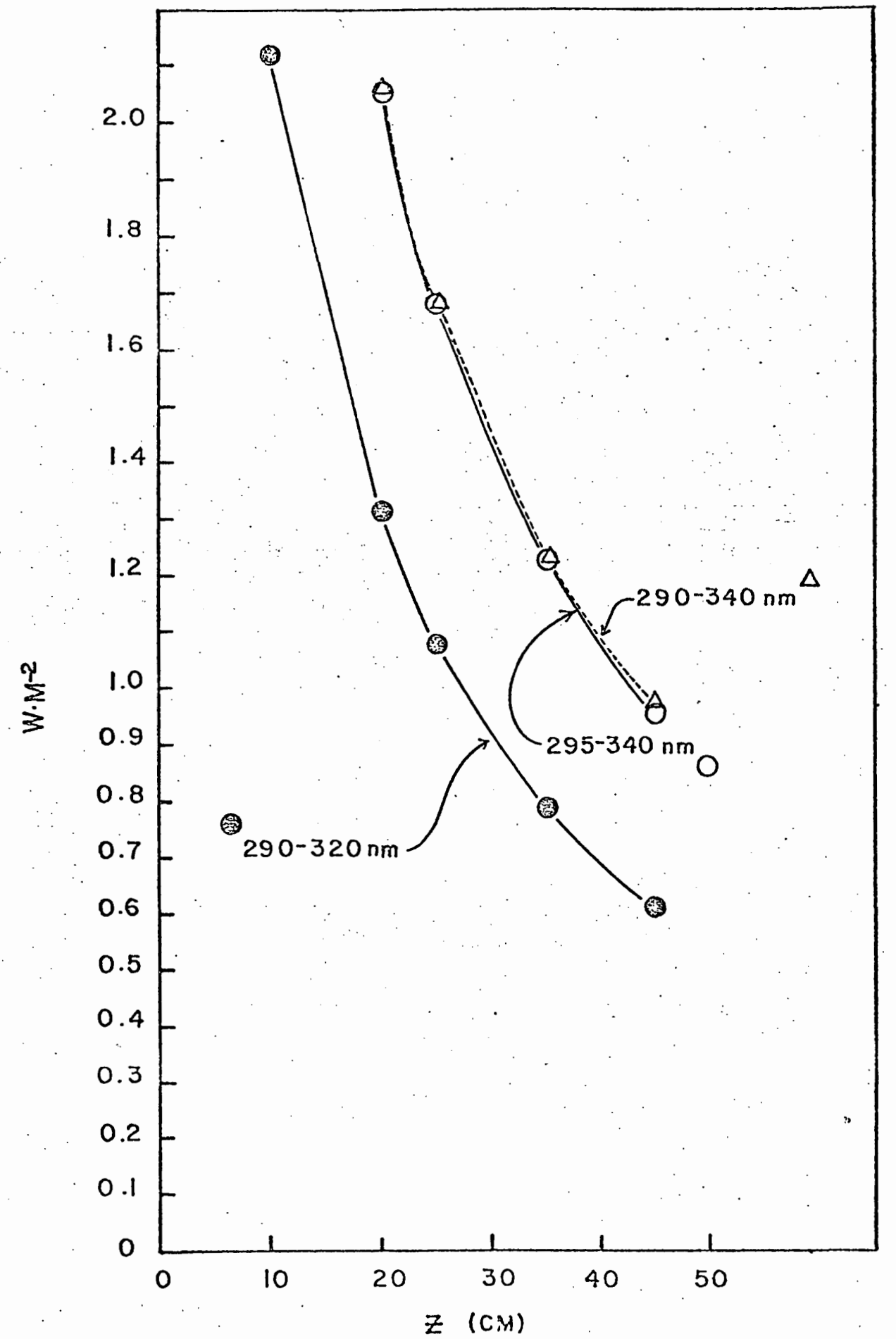


Fig. 12. Relation of total UV irradiance from either the 290-320nm, 295-340nm or 290-340nm band-width from 2 FS-40 "sun lamps" filtered with 5 mil cellulose acetate.

In addition to knowing the amount of error inherent with the measuring instruments against standard irradiance sources, the comparative calibrations have to be done under the system that is used to irradiate the organisms, i.e. in the field in each controlled environmental chamber, and for each greenhouse laboratory set-up. Ideally, monitoring with a spectroradiometer would be best but availability, economics and convenience are all limiting factors. The latter is very much related to time involved in obtaining measurements and maintaining precision in measurements.

Controlled Environmental Chambers

Use was made of both the Gamma Scientific 2900 and Optronics 741 spectroradiometers and the Optronics 725 and the sun-burn radiometers in establishing conditions in the "C" type, reach-in controlled environmental chambers at the Duke University Phytotron. For the UV-B radiation enhancement portion of irradiance, the best arrangement found was the mounting of 4 FS-40 Westinghouse "sun lamps" directly in the chambers (Appendix I-5). Because of the high reflectivity of the side walls of the chambers which are constructed of special-treated, highly polished aluminum, there was good distribution of irradiance flux in the chambers. This can be ascertained from the data of Fig. 13 and 14. Table 12 contains the data for rating the chambers as to UV-B solar equivalent values on the basis of measured $UV\text{-}B_{seu}$. For ease of keeping up with the data, the treatment of $UV\text{-}B_{seu}$ levels were given a code of 0,1,2,3, 4, and 5 for mylar, 0.5, 1.0, 1.5, and 2.0 $UV\text{-}B_{seu}$ level of irradiance. Actual levels are shown in the table for each chamber. The photosynthetically active radiation portion of the spectrum was produced by a bank of 15 cool white fluorescent lights in combination with 6 incandescent lamps.

In addition to the regular practices of fertilizing once daily with a half-strength Hoagland's solution and watering with distilled water, normal

Figure 13

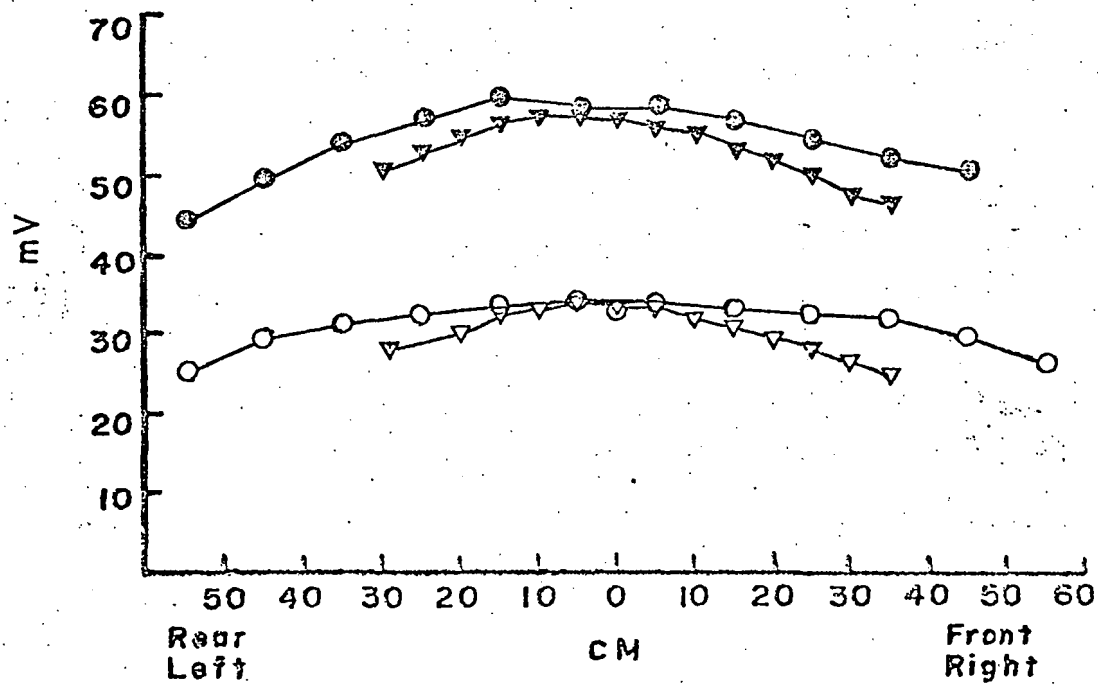


Fig. 13. Relative UV-B irradiance in the "C" type controlled environment chambers at the Duke Phytotron with 4 FS-40 sun lamps. Upper curves were measured with 4 lamps (● ▽ left to right, centered front to rear), lower curves are with 2 lamps (○ ▽ left to right, centered front to rear).

Figure 14

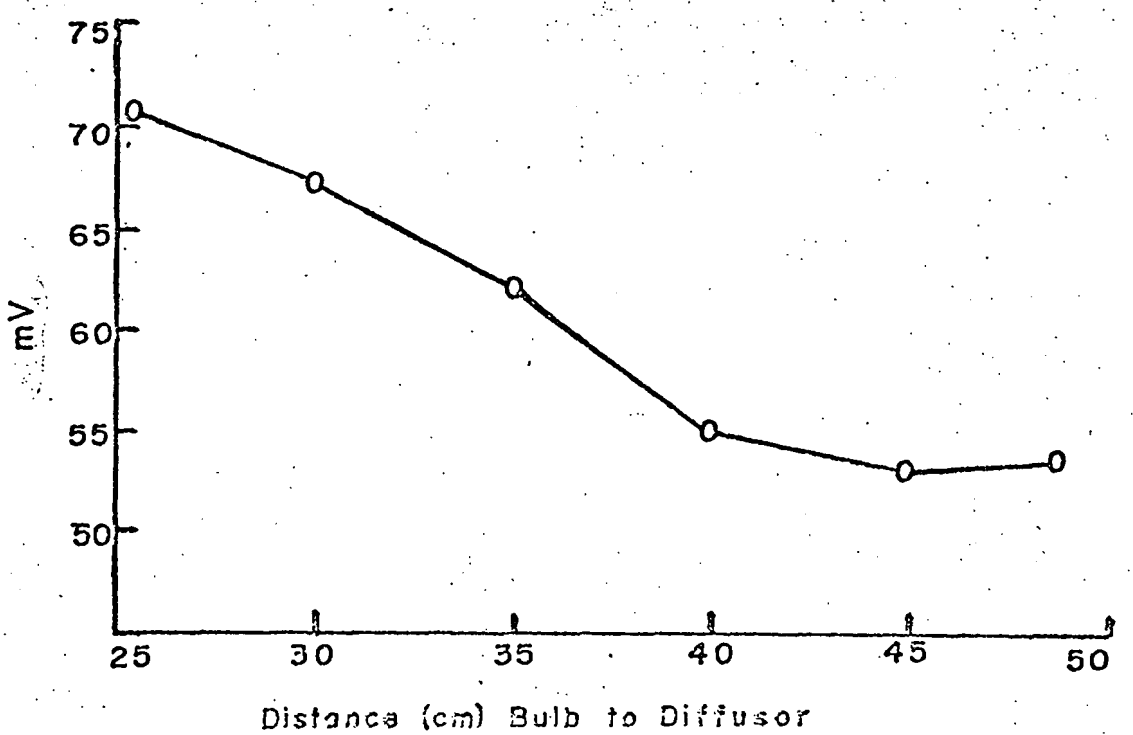


Fig. 14. Relative UV-B irradiance with distance of 4 FS-40 sun lamps in the "C" type controlled environment chambers at the Duke Phytotron. Note the change in slope at 40cm as distance to lamp is increased due to wall reflectance.

Table 12. Relationship between Gamma Scientific Spectroradiometer and Optronics 725 radiometer readings and actual UV-B_{seu} in the Duke University Phytotron controlled environment "C" chambers.

Chamber No.	UV-B_{seu} Code	FS-40 Filter	Actual UV-B_{seu}	Gamma Scientific Wavelength mW/m^2 295	300	310	Optronics 725 Value
4	0	Mylar[1]	0.036	0.15	0.07	0.00	0.6
9	0	Mylar	0.007	0.00	0.00	0.00	0.6
15	0	Mylar	0.003	0.00	0.00	0.00	0.6
17	0	Mylar	0.005	0.00	0.00	0.00	0.6
7	0.5	10+10[2]	0.496	0.46	3.50	2.02	2.4
8	0.5	10+10	0.536	0.46	3.20	2.00	2.8
6	1.0	10	1.12	2.50	8.60	3.20	4.6
10	1.0	10	1.01	3.09	7.20	2.70	
13	1.0	10	1.07	2.60	8.30	3.10	6.4
16	1.0	10	0.99	2.80	7.40	2.80	6.8
1	1.5	3+5	1.46	5.30	10.40	3.70	5.8
2	1.5	3+5	1.57	5.10	11.40	3.90	4.9
12	1.5	3+5	1.47	4.80	11.30	3.80	7.0
18	1.5	3+5	1.59	8.18	11.70	3.30	7.7
3	2.0	5	2.05	6.50	15.10	4.20	5.5
5	2.0	5	2.08	10.50	15.40	4.40	6.2
11	2.0	5	2.16	10.40	15.60	4.60	
14	2.0	5	2.09	10.20	15.30	4.30	7.6

[1]Mylar, Type S, .005 mil.

[2]Cellulose acetate, numbers designate mil thickness

chamber maintenance and procedures were followed.

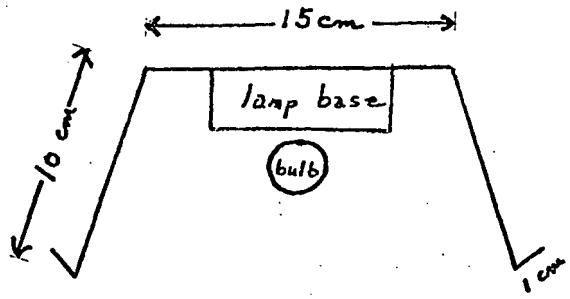
UV-B irradiance and PAR light during the photoperiod were continuously monitored by a radiometer coupled to a strip chart recorder for each chamber. Filters were changed after 18 hours of exposure to radiation from the FS-40 lamps to lessen the problems associated with solarization of the filters. Conceptulization of the physical condition for plant treatment can be aided by viewing photographs in Appendix I-5, 23).

Greenhouse Irradiator

As with establishing the conditions for UV-B enhancements in controlled environmental chambers, spectroradiometers were used to measure irradiance at set-up and initiation of the experiment, at periodic check times and at the time of termination of each experiment. Routine monitoring was accomplished by use of the Optronic 725 radiometer. Filter changes and lamp checks were made after each 18 hours of burn-time on the FS-40 lamps. Protocol was established to keep total weighted UV-B radiation within $\pm$ 10% in between the filter changes and lamp checks by raising and lowering the bank of lamps. The arrangement on the greenhouse irradiators at the Duke University Phytotron and at Gainesville FL can be seen in photographs on pages 1, 35 and 37 of Appendix I. In addition to movement of the bank of lamps up and down by pulley arrangement, each lamp could be moved laterally independently of other lamps. This allowed lateral adjustments in any direction to help establish an irradiance flux within specified levels.

The Field UV-B Irradiator

The irradiator for the field was basically a single aluminum reflector 20 meters in length with 6 x FS-40 Westinghouse "sun lamps" mounted end to end. A special highly posished aluminum reflector was extruded as a single crimped piece with cross-sectional dimensions as shown in the following diagram:



The one-cm fold on the sides allowed a place for attachment of the cellulose acetate films. Twelve of these units were built and mounted over specially constructed beds in the field (see Section IV for description of the plant beds, irrigation system, and control of the field area). The reflectors were reinforced on the side opposite the lamps by a single strip of 2.5 x 2.5 cm aluminum channel. The lamp base was chosen because of its small size and having a self-contained transformer of the rapid start type. These lamp fixtures were mounted on the underside of the reflector and the depth of base plus lamp was 7.8cm. The design was to give a single line source of irradiance. The reflector/lamp combinations were mounted on pulleys and chains (Appendix I-1) at each end and the center so height adjustments could be made as the plants grew. A UV-B irradiance gradient was established by maintaining a 12^{o} angle on the irradiation unit. Filters were changed, lamps checked and irradiances measured on the gradient twice a week, namely Monday and Thursday. During the growing of the first 3 crops of tomatoes, potatoes and corn, the gradient was established using 5 mil cellulose acetate filters and lamp heights to yield a 0.8 $UV\text{-}B_{seu}$ level at mid-lamp on the first meter to less than 0.02

$UV\text{-}B_{seu}$ at mid-lamp on the lowest enhancement meter. During the growing of the second three crops of Southern pea, 'Florunner" peanuts and upland rice, 'Star Bonnet', the irradiance gradient was from 1.5 $UV\text{-}B_{seu}$ at midpoint of the first lamp at the highest enhancement level to less than 0.02 UV-B at midpoint of the meter under the lowest enhancement level. For crops of squash, mustard and 'Red Globe' radish, the filter material was changed to 3 mil cellulose acetate and the gradient from 3.1 $UV\text{-}B_{seu}$ to 0.02 $UV\text{-}B_{seu}$. An example of the measured gradient for these three crops is shown in Fig. 15. The gradient for the other crops had a similar shaped curve but at lower UV-B irradiance levels.

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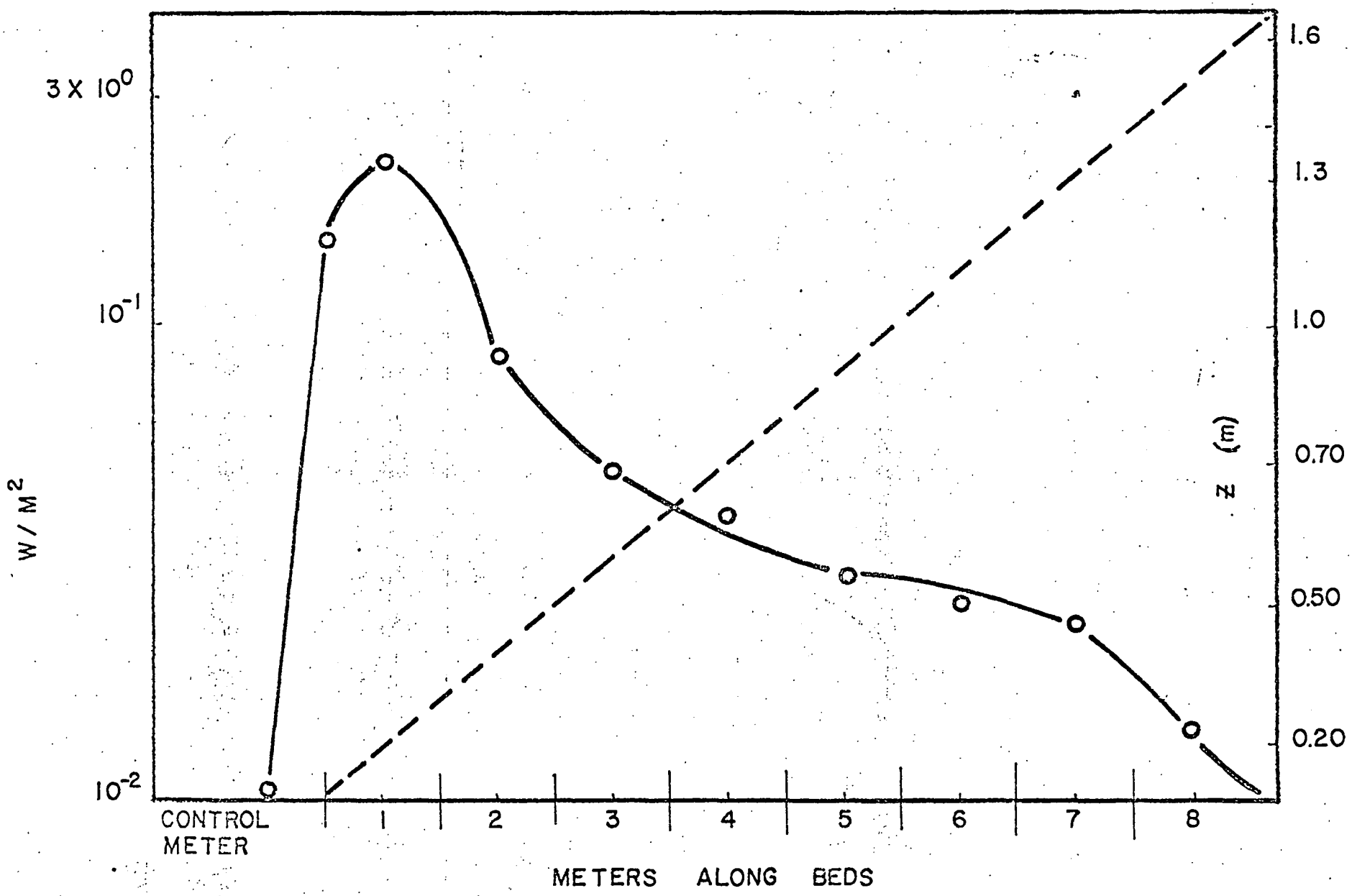

Fig. 15. An actual measured UV-B irradiance gradient in W/m^2 (Σ 295-340nm) at plant height down the planting bed in the field irradiator. This was the gradient used for squash, mustards and radish.

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EFFECTS OF ULTRAVIOLET-B RADIATION ENHANCEMENTS ON EIGHTY-TWO DIFFERENT AGRICULTURAL SPECIES

Abstract

Eighty-two different agricultural species were grown for 4 to 11 weeks in growth chambers at the Duke University Phytotron under 4 to 5 different UV-B irradiance regimes. Twelve replicates (plant/pot) for each species for each chamber were repeated in 2 or 4 chambers (plots) and data taken for each replicate included: 1) leaf fresh and 2) dry weight, 3) stem fresh and 4) dry weight, 5) root fresh and 6) dry weight, 7) leaf area, 8) leaf density 9) root: shoot ratio 10) total fresh and 11) dry weight biomass 12) % leaves, 13) % stems and 14) % roots. Monocots were measured weekly for height and at harvest the total number of leaves, number of chlorotic leaves and % chlorotic leaves was determined.

The most universal response to UV-B irradiation was dwarfing, a stunting of plant organs and shortening in stature. Other effects included marginal and interveinal chlorosis, concave and convex leaf cupping, leaf wrinkling, red pigment formation, darker green color of leaves, epinasty of leaves, lessening of vine characteristics and loss of apical dominance.

Each species was treated for response to UV-B radiation as indicated by the leaf, stem and root dry weight increases or decreases when compared to the controls. Sixteen were favored, showing increase in biomass, 10 were resistant, biomass being ± 5% of the controls, 24 were moderately susceptible, showing 5-25% decrease in biomass, 15 were sensitive, showing 25-50% decrease in biomass and 17 were highly sensitive showing greater than 50% reduction in biomass. The Gramineae tended to be the most resistant or favored and the Cruciferae were the most highly susceptible. Leaf density increased on favored

and resistant species. Biomass partitioning shifted to a larger % in leaves at the expense of stems and roots for dicots but the pattern was not strong in the Gramineae where it was often the reverse of this. Conifers were moderately susceptible but leaf density was altered by the UV-B enhancement levels used.

Introduction

To evaluate young seedling response and vigor to enhanced levels of UV-B radiation, 82 different agricultural species and varieties were grown for 4 to 11 weeks in growth chambers at the Duke University Phytotron (Table 1). There included 42 vegetable, 30 agronomic and 7 forest crops.

Materials and Methods

The plants were grown and treated in 18 "C" chambers with highly reflective polished aluminum walls (Appendix I-5). In each of 4 chambers per UV-B light regime the soil surface was set at the appropriate distance from cellulose acetate or mylar filtered FS-40 Westinghouse sun lamps to obtain a UV-B irradiance approximating 0, 0.5, 1.0, 1.5 and 2.0 $UV\text{-}B_{seu}$ as described in Section I of this report (Table 2). With 4 FS-40 lamps in a "C" type chamber filtered with 5 mil cellulose acetate at a distance of 60 cm from plant height, the weighted 11.12 mW/m^2 equalled 0.71 W/m^2 of unweighted flux. A bank of 15 cool white and 4 incandescent lights in each chamber maintained a 16-hour photoperiod of approximately 200 microeinsteins $m^{-2}sec^{-1}$. Photosynthetically active radiation was measured in microeinsteins $m^{-2}sec^{-1}$ with and without the FS-40 lamps (Table 2). UV-B irradiance was measured with a Gamma Scientific spectroradiometer equipped with a solar blind filter. Irradiance levels are expressed as $UV\text{-}B_{seu}$ where 1 $UV\text{-}B_{seu}$ under FS-40 lamps equal a weighted flux of 11.1^2 mW/m^2. Daily UV-B radiation from the filtered FS-40 lamps was for a 6-hour period in the center of the 16-hour photoperiod. Mylar and cellulose acetate of 10+10 mil, 10 mil, 3+5 mil, and 5 mil filters (Transilwrap Comp., 3616 McCall Place, Atlanta, GA

30340) were used in combination with height adjustments on the FS-40 lamps to obtain the appropriate UV-B levels (Table 2). Filters were changed every 3 to 4 days. Only 2 chambers were available for 0. 5 $UV\text{-}B_{seu}$ but 4 chambers were used for the other treatments.

In the first series of tests, the temperature in 10 of the chambers, 2 for each of the 5 light regimes, was programmed for 19° during the day and 15° for the 8-hour dark period. Twenty-one species were grown in these chambers (Table 1). In the remaining 8 chambers, 2 for each UV-B irraidance regime, omitting the 0.5 $UV\text{-}B_{seu}$ trt. The temperature was programmed for 21°C day and 17°C night. Twenty two species were grown in these 8 chambers. In the second series of tests all 18 chambers were used and 39 species grown under a 26°/22°C day/night temperature regime. For each species, 12 pot replications were made, 6 per chamber in the first series of tests (chamber replicates for each UV-B irradiance regime) and 3 per chamber in the second test series of 4 chamber replicates per irradiance regime.

Six to 12 seeds[1] were planted in each pot which was 7 cm in diameter and 325 ml in volume. The potting mix was a gravel/vermiculite standard medium. This media was chosen because of past successes of getting good germination and because it could be removed from the roots of the plant easier than most. Plants were watered twice daily with a modified half-strength Hoaglands solution. After germination, the dicots were thinned for uniformity to 2 plants per pot.

Nineteen different parameters were evaluated on the plants in the present study. Height was measured on each monocot plant and a Duncan's Multiple Range test made on the data taken after 2 (Table 3, 4) 3 (Table 5, 6) and 4 (Tables

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[1]Seed of various species were contributed by the Florida Seed Foundation, Tallahassee, Weyerhauser Company, Centralia, Wash., Agricultural Seed Laboratory, Phoenix, Arizona and other seed was purchases locally. We thank the various suppliers for their immediate help on this one-year project.

7, 8) weeks. At harvest, the monocots were evaluated for total number of leaves (Tables 9, 10), number of chlorotic leaves (Tables 11, 12) and % of leaves showing chlorosis or tip burn (Tables 13, 14) and a Duncan's Multiple Range test run on the 12 pot means for each UV-B irradiance. Dicots were evaluated for chlorosis and other visual symptoms.

After the final height measurements and non-destructive evaluations were made, all 82 species were harvested on a container (pot) basis and a Duncan's Multiple Range test for significant changes and rankings was made on data for each measured parameter. Data taken for each pot included: 1) leaf fresh weight, 2) stem fresh weight, 3) root fresh weight (roots water washed and all vermiculite removed), 4) leaf dry weight (Tables 15, 16), 5) stem dry weight (Tables 17, 18), 6) root dry weight (Tables 19, 20) 7) total dry weight biomass (Table 21, 22), 8) % leaves (Tables 23, 24), 9) % stems (Tables 25, 26), 10) % roots (Tables 27, 28), 11) leaf area (Tables 29, 30), 12) leaf specific thickness or density (Tables 31, 32), and 13) root:shoot ratio (Tables 33, 34). A photographic record was made of each species grown under each UV-B irradiance regime (Appendix I-6 to 22). Six sensitivity ratings were used for evaluating each species. These were based on leaf, stem and root biomass production in relation to control plants. Species with increases in biomass were rated as "favored" (+) and those showing ± 5% biomass changes were classified as "resistant" (0). Species with biomass reductions of 5 to 25%, 25 to 50% and 50% or greater were classified as moderately susceptible (1), susceptible (2) and highly susceptible (3), respectively.

Increases or decreases in leaf density from the Mylar control were grouped as 0-5%, 5-10%, 10-15% and 15-20%. Changes in % leaf biomass partitioning were grouped as 3-10%, 10-15% etc., increasing by 5% increments. Percent root increase or decreases from the control were highly variable and grouped 0-25%,

25-50% and 50-75%, increasing by 25% increments.

Individual parameters for each species and the relevant statistical analyses can be found in Tables 3 to 34 and should be referred to for detailed study.

Results

1. Cruciferae - Appendix I-6,7,8,9,10[1]

All but 2 of the crucifers (mustard and radish) were rated as highly susceptible (Tables 35, 36). At 1 UV-B_{seu} the mustard was moderately susceptible but at 1.5 or 2.0 it was highly susceptible. The radish was favored at 0.5 and 1.0 UV-B_{seu}, showing increases in biomass. It was moderately susceptible at the other enhancement levels. The crucifers showed pronounced concave leaf cupping, leaf wrinkling, marginal chlorosis, stunting and reduction in leaf area. Leaf density was decreased in broccoli, kale and kohlrabi.

While the other crucifers, especially mustard and rutabega, increased in leaf density (Tables 31, 32). Biomass partitioning was not altered in brussel sprouts and slightly increased in leaves and stem for mustards. Radish showed the most increase in partitioning into the vegetative portion (up to 25% more than the controls), and broccoli was in the 10-15% increase groups. The other crucifers partitioned 3-10% more biomass into the vegetative above ground portions of the plant. The 3-10% increases for leaf and stem biomass were accompanied by % decreases in root biomass of 25-50% or more, and even the radish and mustard were lower (Tables 23-28).

II. Chenopodiaceae - Appendix I-7.

Chard in this experiment was very susceptible (Tables 35, 36) in biomass

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[1]These Appendices referals are for the photographic records.

reductions (Tables 21, 22) but the % leaf and stem dry weight was unaltered (Tables 23-26). Visual symptoms were the same as in the crucifers. Percent root allocation was variable but increased under 1 and 2 $UV\text{-}B_{seu}$ and decreased under 1.5 (Tables 27, 28). Leaf density increased an average of 9% over that of the control (Tables 31, 32).

III. Compositae - Appendix I-1,8,22

Artichoke and sunflower were favored by UV-B radiation while lettuce was moderately susceptible (Tables 35, 36). Sunflowers appeared fairly normal and the artichoke, being slow to germinate, also appeared normal except for the slightly smaller size. Leaf density was decreased 15-20% for artichoke and lettuce and 10-15% on sunflower (Tables 31, 32). The biomass found in leaves and stems was increase 3-10% in lettuce and sunflower but was down 10-15% for artichoke (Tables 23-26). Correspondingly, root biomass was increased in artichoke and sunflower but decreased 15-20% in lettuce (Tables 27, 28).

IV. Cucurbitaceae - Appendix I-12,13

Only watermelon and early summer squash were rated highly susceptible in this family (Tables 35, 36). Pumpkin was moderately susceptible and the other cucurbits were susceptible. Stunting and interveinal chlorosis were found as well as convex cupping of the leaves. In general leaf density decreased, up to 10% but early summer squash leaf densities decreased to 32% (Tables 31, 32). Cucumber leaf density increased to 29% and watermelon to 46%. Biomass partitioning into leaves was markedly increased in the cantelopes and squash (up to 51% for both) but somewhat less in pumpkin (up to 14%) and watermelon (up to 28%) (Tables 23, 24). Percent biomass in stems was decreased 35-40% in the squash, 44-53 in the melons, 40% in cucumber, 37% in watermelon and 10% in pumpkin (Tables 25, 26). The decrease in root biomass was also high for honeydew

cantelope (up to 43%) and cucumber (up to 50%) with the other species showing less reductions (Tables 27, 28).

V. Gramineae - Appendix I-17, 18

Pensacola, Bahia, Bermuda and Carpet grass were susceptible to moderately susceptible (Tables 35, 36). Stunting and tip chlorosis were the most obvious UV-B symptoms (Tables 3-8 and 11-14). Leaf-density increased with exposure to UV-B radiation (Tables 31, 32) and there was little change in biomass partitioning for % leaves (Tables 23, 24). Percent roots increased on Pensacola grass (up to 67% and the others decreased (Tables 27, 28).

Chufas, Sudangrass and oats were favored by UV-B radiation and showed increases in biomass (Tables 15-22). At least at the lower $UV\text{-}B_{seu}$ regimes, leaf density was increased for oat and Chufas but decreased on Sudangrass (Tables 31, 32). No change in leaf biomass partitioning was found, or % roots on Chufas, but oat and Sudangrass showed variable increases and decreases in % roots at the different UV-B levels (Tables 23, 24, 27, 28). Final height was increased to 1-14% in oats, 17% in Sudangrass and 19% in Chufas (Tables 7, 8). Up to 45% and 55% increases in leaf chlorosis were found in Sudangrass and oats, respectively, and 186% in Chufas (Tables 13, 14). However, the total number of leaves was decreased in oats, up to 26%, and increased in sudangrass, and Chufas, up to 31% and 58%, respectively (Tables 9, 10).

Rye and sorghum were moderately susceptible (Tables 35, 36), showing only small variations in biomass partitioning (Tables 23-28). The total number of leaves was higher (Tables 9, 10) with a greater density than the control in rye and the opposite in sorghum (Tables 31, 32).

The two millets were moderately susceptible (Tables 35, 36) with opposite responses in biomass partitioning (Tables 23-28) and leaf density

(Tables 31, 32). Starr Pearl millet had decreased leaf density (Tables 31, 32) and % leaves (Tables 23, 24) but increased % roots (Tables 27, 28). Both were reduced in height 10-20% (Tables 7, 8), both had increased numbers of leaves (Tables 9, 10) and increased percentages of the leaves showing chlorosis (Tables 13, 14). The three barley varieties responded similarly to UV-B radiation although Hembar was altered more and was rated susceptible and Belle and Arivat barleys were moderately susceptible (Tables 35, 36). Leaf density was less for all three (Tables 31, 32). Height was reduced 25-50% below the controls for Belle and Arivat and 50-75% for Hembar (Tables 7, 8). Increased chlorosis was observed in Belle barley but Arivat and Hembar barley showed increased chlorosis only for 1 UV-B_{seu} and decreased chlorosis at the higher UV-B levels (Tables 11-14). Biomass partitioning was unaltered in Arivat barley and the % biomass in leaves and stems was decreased with the % roots increased in Belle and Hembar barley (Tables 23-28).

Corn varieties were susceptible, except Coker 71 which was highly susceptible, to UV-B radiation (Tables 35, 36). Silverqueen and Hybrid XL 380 corn were resistant to 1 UV-B_{seu} but not the other levels. Leaf density was increased 5-10% in all but the Coker variety which showed a pronounced decrease in leaf density (Tables 31, 32). Biomass partitioning did not change in Silverqueen corn but the % leaves increased in Tobelle and the Hybrid drastically decreased in the slightly susceptible Coker variety (Tables 23-28). Percent roots was variable except in the Coker variety where it increased (Tables 27, 28). Height was reduced 21-30% in Silverqueen and Coker corn but only 11-20% in the other two (Tables 7, 8). All 4 varieties had over 25% more of the leaves chlorotic and some decrease in the number of leaves, except for Silverqueen where the numbers were similar to the control (Tables 13, 14).

Brazos and LaBelle rice were resistant and Lebonnet ., Bluebett and Star Bonnet rice varieties were moderately susceptible to UV-B radiation (Tables 35, 36). Biomass partitioning was essentially the same as in the controls with slight decreases in the % roots of Lebonnet and Bleubet (Tables 23, 28). Leaf density was highly reduced at all levels for Lebonnet rice but less so for the others (Tables 31, 32). Height was reduced about the same % in all varieties, reaching a maximum of 19% at 1.5 UV-B_{seu} in Star Bonnet rice (Tables 7, 8). Lebonnet had a decrease in the amount of leaf chlorosis while the other 4 had increases of 25-50% over than of the control (Tables 13, 14). Total number of leaves was slightly increased in Labelle rice, the same in Brazos and decreased up to 15% in the other 3 rice varieties (Tables 9, 10).

VI. Leguminosae - Appendix I-14, 15, 16, 22.

Beans were all moderately susceptible (Tables 35, 36) with biomass reductions up to 25% of the controls (Tables 21, 22). Stunting, leaf wrinkling, release from apical dominance and a lessening of vine characters were general legume symptoms. Leaf density was increased 11-12% on garden bean, pinto bean and Tennessee Flat bean, but 78% on Lima bean (Tables 31, 32). Biomass partitioning was the same as the controls for leaves, and stems except a 17% decrease in stems for the garden bean (Tables 23-26). A slight increase in root biomass detected in garden and pinto bean at 0.5 and 1.0 UV-B_{seu} while the rest of the levels had up to 25% decreases in root biomass (Tables 27, 28). Only Lima beans showed an increase in roots, up to 20% at 1 UV-B_{seu}.

Butterpea was moderately sensitive (Tables 35, 36) with a large increase (up to 174%) in leaf density (Tables 31, 32). No difference was

found in biomass partitioning for leaves and stems (Tables 23-26), although roots showed a decrease of up to 28% (Tables 27, 28). Blackeye peas were highly sensitive (Tables 35, 36) and also showed an increase in leaf density up to 27% (Tables 31, 32). Similar amounts of biomass were partitioned into the leaves as in the controls (Tables 23, 24) but apparently more into stems with reduction in root biomass (Tables 25-28). English peas were favored by UV-B radiation at the lower UV-$B_{seu's}$ (Tables 35, 36). Leaf density increased up to 376% above that of the control (Tables 31, 32) and more biomass was partitioned into leaves (Tables 23, 24) with reductions in roots (Tables 27, 28).

Clover was highly sensitive (Tables 35, 36), with increases in leaf density (Tables 31, 32) and biomass proportions in leaves (Tables 23, 24). Partitioning into stems and roots was highly variable but did increase for roots at the 1.5 and 2.0 UV-B_{seu} levels (Tables 26-28).

Soybean was susceptible (Tables 35, 36) with up to a 114% increase in leaf density (Tables 31, 32). Biomass partitioning was not strongly altered by UV-B radiation and there was some increase in the % roots (Tables 23-28). Leaf bronzing, chlorosis wrinkling and development of a deeper green leaf color occurred under higher UV-$B_{seu's}$.

Peanuts were favored by UV-B radiation (Tables 35, 36). There was up to 6% increase in dry weight (Tables 21, 22) that was apparently due to increased leaf and stem dry weights (Tables 15-18) because root dry weight was lower than corresponding controls (Tables 19, 20). Leaf density was only slightly increased (8%) (Tables 31, 32).

VII. Liliaceae - Appendix I-21.

Both asparagus and onion were resistant to UV-B radiation (Tables 35, 36). Leaf density tended to decrease for asparagus (Tables 31, 32) and

there was some increases in percent roots (Tables 27, 28). Onion responses for most parameters were highly variable UV-B enhancement treatments.

VIII. Malvaceae - Appendix I-22.

Cotton was resistant to UV-B radiation (Tables 35, 36) and showed increases in weight of leaves stems and roots at the 0.5 UV-B_{seu} (Tables 15-18). The plants appeared normal except for red pigmentation along the petioles. At higher levels biomass was slightly decreased (Tables 21, 22). Leaf density remained similar to the controls (Tables 31, 32) and there was a slight increase in biomass partitioning into leaves with reduction in stems and roots (Tables 23-28). Okra was susceptible (Tables 35, 36), but with no change in leaf density (Tables 31, 32) or biomass partitioning into leaves (Tables 23, 24). Percent stems (Tables 25, 26) was increased and the roots (Tables 27, 28) correspondingly decreased under the higher UV-B irradiance levels.

IX. Pinaceae - Appendix I-19, 20.

The conifers were moderately susceptible (Tables 35, 36) to UV-B, with the exceptions of white fir which was favored and Douglas-fir which was resistant. Leaf dry weights were reduced 8 to 22% and roots 9 to 25% below the controls (Tables 15, 16). The effects were less pronounced at 0.5 UV-B_{seu}. White fir had well over twice as much leaf and root biomass (Tables 15, 16, 19, 20) as the controls and leaf density was increased 44% at 1 UV-B_{seu} (Tables 31, 32). The % leaves was unaltered by UV-B (Tables 23, 24) and the % roots was increased in slash and loblolly pine and white fir but decreased 3 to 9% in lodgepole and ponderosa pine and noble fir (Tables 27, 28). Leaf dry weight increased in Douglas-fir by 7% (Tables 15,16) but root dry weights, were variable depending on the UV-B level

(Tables 19, 20). Leaf density in Douglas-fir increased by 10% over the controls (Tables 31, 32). Around 16% less biomass was partitioned into roots (Tables 27, 28).

X. Polygonaceae - Appendix I-9.

Rubarb was highly susceptible to UV-B radiation (Tables 35, 36) and showed increased leaf densities up to 226% greater than the controls (Tables 31, 32). Visual symptoms were similar to the Cruciferae. About 5% more biomass was in leaves (Tables 23, 24) with corresponding decreases in stem and root dry weights (Tables 25-28).

XI. Solanaceae - Appendix I-21.

Bell pepper plants were resistant to 0.5 $UV\text{-}B_{seu}$ (Tables 35, 36), with a 47% increase in total dry weight (Tables 21, 22). At the higher UV-B level it had decreases in biomass (Tables 21, 22). Leaf density (Tables 31, 32) was unaltered and biomass was increased 6% in leaves (Tables 23, 24), 10% in stems (Tables 25, 26) and decreased in roots (Tables 27, 28).

Eggplant was favored by UV-B at the lower levels (Table 35, 36) and biomass was not decreased until the 2.0 $UV\text{-}B_{seu}$ treatment (Tables 21, 22). Leaf density was not altered (Tables 31, 32) and biomass partitioning showed around 18% increase in leaves (Tables 23, 24) and 5% increase in roots (Tables 27, 28), but a 28% decrease in stem dry weights (Tables 25, 26).

Tomatoes were highly susceptible (Tables 35, 36). Leaf density was decreased 10% below the controls (Tables 31, 32). The percent biomass in leaves was increased 18% over controls (Tables 23, 24) and the stems and roots decreased 15% and 29%, respectively (Tables 25-28).

XII. Umbelliferae

Carrots and celery were favored by UV-B radiation (Tables 35, 36), showing increases in total dry weight biomass, especially at 0.5 and 1.0 $UV\text{-}B_{seu}$ for celery (Tables 21, 22). Leaf-stem dry weights (Tables 15-18) as well as root dry weights (Tables 19, 20) were increased. Leaf density was increased up to 26% for carrots and averaged 22% for celery above the respective controls (Tables 31, 32). However, an average of 2 to 4% less biomass was partitioned into leaves in these two species (Tables 23, 24) with the main increase in the % roots (averaging 14% for carrot and 23% for celery) (Tables 27, 28).

Parsnip was a resistant species (Tables 35, 36) which did not change in leaf density (Tables 31, 32). Slightly more (6%) biomass was in leaves than in roots (Tables 23, 24, 27, 28).

Discussion

Taxonomic groups with some measured component increasing, i.e., dry weight, as a result of UV-B radiation included 6 different families and 16 species or varieties. An additional 2 families and 10 species were classified as resistant to UV radiation (Tables 35, 36). For the Gramineae, favored and resistant species included wheat, oats, rice, chufas and sudangrass. Within the dicots, favored and resistant species included sunflower, radish, peanuts, English peas, onion and cotton. Douglas-fir and white fir of the Pinaceae were also included here. There are 7 species included in these 2 categories which were slow to gernimate and thus, were not exposed to enhanced UV-B levels for very long before they were harvested. The seven were: artichoke, eggplant, carrots and celery of the favored category, and asparagus, bell pepper and parsnip of the resistant category. Since detri-

mental UV-B effects at the irradiance levels used are probably cumulative and were not pronounced after only 1 or 2 weeks of growth, one should be cautious in interpreting the data for these 7 species.

Except for radish and mustard, the Cruciferae were the most sensitive group, followed by Solanaceae, Cucurbitaceae, Chenopodiaceae, Polygonaceae and some Leguminosae and Gramineae. Tomato was the most sensitive of the 82 species. Biomass reductions on plants for which the leaf or stem are the marketable product represent direct effects on yield. Changes in leaf density may also alter quality of the leafy product.

Although monocot plants have usually performed better than dicots under UV-B radiation, the Coker 71 corn was a highly sensitive variety and the other 3 corn varieties were classified as sensitive. Hence, corn did not follow the usual pattern for grasses.

In rating the species for sensitivity to UV-B radiation certain family or generic groups tended to fall within the same rating (Tables 35, 36). For example, all except 2 of the Cruciferae were highly sensitive and 5 of the 6 Pinaceae were moderately sensitive. However, in families where several genera were represented, the genera sorted out into different ratings and this was sometimes evident for species within genera, although in the latter case the ratings were not widely diverse.

Leaf density, with few exceptions, increased or stayed the same for favored and resistant species (Table 36). Species within any given susceptible category did not follow a pattern for increasing or decreasing leaf density according to the sensitivity rating. However, within a genus or family there was often some uniformity in leaf density response. All 11 Leguminosae species and 6 of 7 wheat varieties showed increases in leaf density and 7 of 9 Cucurbitaceae showed decreases in leaf density. Each

genus or species with varieties within the Gramineae also tended to follow a general pattern of increased leaf density. The leaf density response then, was consist for plants resistant or favored by UV-B radiation, and variety, species, genus or family related for those classified in a susceptible category; i.d. showing decreases in biomass below the control with exposure to treatment.

As a general rule, when biomass was reduced, there was a higher % biomass found in leaves and a lower % in stems and roots, particularly for the dicots. This shift was not as pronounced in the Gramineae and in 5 of the 7 wheat varieties, the opposite was true, % roots increasing with % biomass decreasing in leaves and stems. Rice was very stable in relation to biomass partitioning.

Symptoms of UV-B treated plants grown in controlled environment chambers under controlled, but low photosynthetically active radiation levels, are exaggerated examples of what might be observed under field conditions. Star Bonnet rice, Silverqueen corn, Walter tomato, Florunner peanuts, Red Globe radish and mustard grown in the field in 1977 were of the same seed lot as those grown in the phytotron study. Increases and decreases in biomass and changes in yield, quantity and quality of products were observed under field conditions. Vegetative changes that would logically affect yields as found under field conditions were also observed in the phytotron. Leaf chlorosis and wrinkling symptoms observed in the phytotron were also evident in the field but to a much lesser extent. Thus, knowledge of symptoms produced under controlled environment conditions may allow growers of individual crops to recognize UV-B effects in the field when crops are being grown under optimal cultural conditions. Investigators developing vegetable varieties especially for areas of high natural UV-B flux, may be able to recognize these symptoms

in various lines they are propagating since vegetables tended to show leaf effects. However, agronomists and foresters working with Gramineae and Pinaceae species will have less opportunity to identify sensitive plants under field conditions since stunting was the major visual symptom in these families.

However, caution must be taken in extrapolating effects on crop yield from controlled environment chamber observations as related to UV-B radiation, especially since photorepair at high PAR levels may show as much variation as UV-B effects at low PAR intensities. Thus, actual comparative analyses, such as underway with some crops, should be done to verify the effects of UV-B radiation under field conditions. The controlled environmental chamber testing is invaluable in demonstrating the crops that are sensitive to increased UV-B irradiance and the type of responses expected.

Table 1. Species and length of time grown in the "C" chamber at the Duke Univ. Phytotron under 16 hr photoperiod and the designated day/night temperatures.

19°/15°C

	Common Name	Scientific Name	# Weeks
1.	asparagus, 'Mary Washington'	Asparagus officinalis L.	5
2.	carrots, 'gold king'	Dacus carota L.	5
3.	celery, 'golden self-blanching'	Apium graveolens L.	5
4.	radish, 'red globe'	Raphanus sativus L.	4
5.	lettuce, 'iceberg'	Lactuca sativa L.	4
6.	onion, 'white Bermuda'	Allium cepa L.	4
7.	parsnip, 'long smooth'	Pastinaca sativa L.	5
8.	peas, 'little marvel English'	Pisum sativum L.	4
9.	wheat, 'wakeland'	Triticum aestivum	4
10.	wheat, 'Cocorit'	Triticum spp.	4
11.	wheat, 'Cajeme'	Triticum spp.	4
12.	wheat, 'Crane'	Triticum spp.	4
13.	wheat, ' Inia 56R'	Triticum spp.	4
14.	wheat, 'Jori'	Triticum spp.	4
15.	wheat, 'Super X'	Triticum spp.	4
16.	pine, slash	Pinus elliottii Engelm.	11
17.	pine, loblolly	Pinus taeda L.	11
18.	pine, lodgepole	Pinus contorta Dougl.	11
19.	pine, ponderosa	Pinus ponderosa Laws.	11
20.	fir, noble	Abies procera Rehd. [Abies nobilis (Dougl) Lind.]	11
21.	fir, white	Ablies concolor (Gord. and Glend.) Lindl.	11

Table 1 Con't.

21°/17°C

	Common Name	Scientific Name	# Weeks
22.	barley, 'Belle'	Hordium vulgare L.	4
23.	barley, 'Arivat'	Hordium vulgare L.	4
24.	barley, 'Hembar'	Hordium vulgare L.	4
25.	broccoli	Brassica oleracea L. var. botrytis	4
26.	brussel sprouts, 'Long Island Improved'	Brassica oleracea L. var. gemmifera	4
27.	cabbage	Brassica oleracea L. var. capitata	4
28.	cauliflower, 'snowball'	Brassica Oleracea L. var. italica	4
29.	chard	Beta vulgaris L. var. cicia	4
30.	collards	Brassica oleracea L. var. acephala	4
31.	kale 'Dwarf blue Scotch'	Brassica oleracera L. var. acephala	4
32.	Kohlrabi	Brassica oleracera L. var. gongylodes	4
33.	mustard	Brassica juncea var. crispifolia	4
34.	rutabega	Brassica napobrassica (L.) Mill	4
35.	corn 'silverqueen'	Zea mays L. var. saccharate	4
36.	corn 'Tiobelle'	Zea Mays L.	4
37.	corn, hybrid XL 380	Zea Mays L.	4
38.	corn, 'coker 71'	Zea Mays L.	4
39.	grass, 'Pensacola'	Paspalum sp.	4
40.	grass, 'Arg. Bahia'	Paspalum notatum	4
41.	grass, 'Bermuda'	Cynodon dactylon	4
42.	grass, 'carpet'	Axonopus affinis	4
43.	soybean, 'Hardee'	Glycine max L.	4

Table 1 Con't.

26°/22°C

	Common Name	Scientific Name	# Weeks
44.	artichoke, 'green globe'	Cynara scolymus L.	4
45.	bean, lima, 'Jackson wonder'	Phaseolus lunatus L.	3
46.	bean, garden	Phaseolus vulgaris L.	3
47.	bean, pinto	Phaseolus vulgaris	3
48.	bean, 'Tennessee flat'	Phaseolus vulgaris L.	3
49.	bell pepper	Capsicum annum L.	5
50.	butterpea, 'white Dixie'	Phaseolus lunatus L.	3
51.	cantelope, 'Hales best jumbo'	Cucumis melo var. reticulatis L.	4
52.	cantelope, 'honeydew'	Cucumis melo var. inodorous L.	4
53.	chufas	Cyperus esculentus L.	4
54.	clover, 'alyceclover'	Alysicargus vaginalis L.	5
55.	cotton	Gossipium hirsutum L.	4
56.	cucumber, 'pointsett'	Cucumis sativus L.	4
57.	cowpeas, 'blackeye No. 5'	Vigna unguiculata L.	3
58.	eggplant	Solanum melongena L.	4
59.	millet, 'starr pearl'	Pennisetum glaucum L.	4
60.	millet, 'brown top'		
61.	oats, Fl. 501	Avena sativa L.	4
62.	okra, 'clemson spineless'	Hibiscus esculenta L.	4
63.	peanuts, 'florunner'	Arachis hypogaea L.	4
64.	peas, 'blackeye'	Vigna unguiculata L.	3
65.	pumpkin, 'king of mammoth'	Cucurbita moschata L.	4
66.	rice, 'lebonett'	Oryza sativa L.	4
67.	rice, 'brazos'	Oryza sativa L.	4
68.	rice, 'bluebett'	Oryza sativa L.	4
69.	rice, 'labelle'	Oryza sativa L.	4
70.	rice, 'star bonnet'	Oryza sativa L.	4
71.	rubarb, 'Myatt Victoria'	Rheum rhaponticum L.	4
72.	rye, 'wress abruzzi'	Secale cerale L.	4
73.	sorghum, hybrid grain	Sorghum bicolor Moench	4
74.	squash, 'early summer'	Cucurbita maxima L.	4
75.	squash, 'prolific straight'	Cucurbita pepo L.	3
76.	squash, 'clefine' zucchini	Cucurbita pepo L.	3
77.	squash, 'acorn'	Cucurbita pepo L.	3
78.	sudangrass, hybrid sorghum SX17	Sorghum sudaness L.	4
79.	tomato, 'Walter'	Lycospersicum esculentum Mill	4
80.	watermelon, 'congo'	Citrullus vulgaris L.	4
81.	Douglas-fir	Pseudotsuga mensiesii(Mirb.)Franco	6
82.	sunflower, 'African'	Hellianthus annuus L.	4

Table 2. Light quality in the "C" chambers at the Duke University Phytotron.

UV-B_{seu}[1]	mil CA Filter[2]	Photosynthetically Active Radiation[3] Cool White Lights Only	Cool White + FS-40
0.036	M	200	200
0.007	M	240	245
0.003	M	195	235
0.005	M	210	215
0.540	10+10	235	240
0.500	10+10	240	245
1.120	10	225	230
1.010	10	235	240
1.070	10	230	235
0.990	10	195	200
1.460	3+5	180	185
1.570	3+5	230	235
1.480	3+5	215	220
1.590	5	170	175
2.050	5	235	240
2.080	5	210	215
2.160	5	250	255
2.090	5	250	255

1/ UV-B_{seu} as defined in section I. UV-B weighted by DNA-21.

2/ C.A. = cellulose cecetate filter; M = 5 mil myler type 5.

3/ Microeinsteins m^{-2} sec^{-1}.

Table 3. Comparison of the 5 UV-B radiation treatments for height (mm) after 2 weeks as to means, mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

UV-B Treatments[1], Means, and % Differences[2]

	Species	1	2	%	3	%	4	%	5	%	Σ %	$\bar{x}$%
9.	wheat, 'Wakeland'	165	146	-12	133	-19	122	-26	121	-27	-84	-20.9
10.	wheat, 'CoCorit'	129	119	- 8	112	-13	107	-17	110	-15	-53	-13.2
11.	wheat, 'Cajeme'	114	108	- 5	104	- 9	103	-10	94	-18	-41	-10.3
12.	wheat, 'Crane'	122	112	- 8	105	-14	101	-17	104	-15	-54	-13.5
13.	wheat, 'Inia 66R'	152	145	- 5	130	-15	124	-18	127	-16	-54	-13.5
14.	wheat, 'Jori'	157	149	- 5	162	3	152	- 3	150	- 5	-10	- 2.4
15.	wheat, 'Super-X'	127	124	- 2	118	- 7	110	-13	113	-11	-34	- 8.5
22.	barley, 'Belle'	184	-	-	157	-14	133	-28	141	-23	-66	-21.8
23.	barley, 'Arivat'	157	-	-	131	-16	115	-27	140	-11	-54	-18.0
24.	barley, 'Hembar'	163	-	-	140	-14	126	-23	133	-18	-55	-18.4
35.	corn, 'Silverqueen'	142	-	-	139	- 1	110	-23	125	-12	-36	-12.0
36.	corn, 'Tobelle'	163	-	-	136	-17	112	-31	134	-18	-66	-21.9
37.	corn, 'Hybrid XL380'	164	-	-	155	- 6	118	-28	154	- 6	-40	-13.3
38.	corn, 'Coker 71'	150	-	-	146	- 3	90	-40	130	-14	-56	-18.7
53.	chufas	114	-	-	96	84	87	77	98	86	248	82.5
59.	millet,'Starr Pearl'	165	157	- 5	302	83	120	-27	150	- 9	42	10.5
60.	millet, 'Brown Top'	78	-	-	75	- 4	60	-23	71	- 9	-36	-12.0
61.	oats	204	69	-66	219	7	231	13	205	1	-45	-11.3
66.	rice, 'Lebonett'	122	92	-25	133	9	108	-12	126	3	-24	- 5.9
67.	rice, 'Brazos'	132	102	-23	148	12	121	- 8	144	9	-10	- 2.5
68.	rice, 'Bluebett'	91	73	-20	101	11	72	-21	99	9	-21	- 5.2
69.	rice, 'Labelle'	122.33	109	-11	121	- 1	99	-19	123	1	-30	- 7.4
70.	rice, 'Star Bonnet'	113	94	-17	108	- 4	84	-26	119	5	-42	-10.4
72.	rye	237	207	-13	211	-11	198	-17	218	- 8	-48	-12.0
73.	sorghum	193	58	-70	156	-19	156	-19	141	-27	135	-33.8
78.	sudangrass	160	119	-26	190	19	152	- 5	192	20	8	2.0

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in Section I.

Table 4. Duncan's Multiple Range Test on Monocots for 2 week height differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
9.	wheat,'Wakeland'	A	B	C,B	C	C
10.	wheat,'CoCorit'	A	B	C,B	C	C,B
11.	wheat,'Cajeme'	A	B,A	B,A	B,A	B
12.	wheat,'Crane'	A	B	C,B	C	C,B
13.	wheat,'Inia 66R'	A	A	B	B	B
14.	wheat,'Jori'	A	A	A	A	A
15.	wheat,'SuperX'	A	A	B,A	B	B
22.	barley,'Belle'	A	-	B	C	C
23.	barley,'Arivat'	A	-	B,C	C	B,A
24.	barley,'Hembar'	A	-	B	C	C,B
35.	corn,'Silverqueen'	A	-	A	B	B,A
36.	corn, 'Tobelle'	A	-	B	B	B
37.	corn, Hybrid XL	A	-	A	B	A
38.	corn,'Coker 71'	A	-	B,A	C	B
54.	clover	A	-	A	A	A
60.	millet,'Browntop'	B	B	A	B	B
61.	oats	A	-	B,A	B	B,A
62.	okra	B	C	B,A	A	B
67.	rice,'Brazos'	B,A	C	A	B,C	B,A
68.	rice,'Bluebett'	B,A	C	A	B,C	A
69.	rice,'Labelle'	B,A	B	A	B	A
70.	rice,'Star Bonnet'	A	B,A	A	B	A
71.	rhubarb	B,A	B,C	B,A	C	A
73.	sorghum	A	B	B	B	B,A
75.	squash,'Prolific'	A	C	B,A	B,A	B
80.	watermelon	B,C	D	B,A	C	A

[1/] Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 5. Comparison of the 5 UV-B radiation treatments for height (mm) after 3 weeks as to means, mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

UV-B Treatments[1], Means, and % Differences[2]

	Species	1	2	%	3	%	4	%	5	%	Σ %	$\bar{x}$%
9.	wheat, 'Wakeland'	241	-32	202	189	-22	174	-28	165	-16	-97	-24.3
10.	wheat, 'CoCorit'	210	-17	182	179	-15	165	-21	174	-13	-67	-16.7
11.	wheat, 'Cajeme'	186	-20	172	168	-10	203	9	148	- 8	-29	- 7.1
12.	wheat, 'Crane'	204	-23	169	173	-15	162	-21	158	-17	-76	-18.9
13.	wheat, 'Inia 66R'	226	-26	198	182	-20	186	-18	168	-12	-75	-18.8
14.	wheat, 'Jori'	232	-13	206	261	13	212	- 9	203	-11	-20	- 5.0
15.	wheat, 'Super-X'	192	-15	188	180	- 6	166.2	-14	163.2	- 2	-37	- 9.2
22.	barley, 'Belle'	282	-	-	226	-20	207	-27	211	-25	-72	-23.9
23.	barley, 'Arivat'	232	-	-	207	-11	171	-26	192	-17	-54	-18.1
24.	barley, 'Hembar'	316	-	-	239	-24	252	-20	249	-21	-66	-21.9
35.	corn, 'Silverqueen'	327	-	-	287	-12	229	-30	245	-25	-67	-22.4
36.	corn, 'Tobelle'	325	-	-	269	-17	224	-31	250	-23	-71	-23.8
37.	corn, 'Hybrid XL380'	313	-	-	271	-13	212	-32	259	-17	-63	-21.0
38.	corn, 'Coker 71'	295	-	-	271	- 8	166	-44	222	-25	-77	-25.5
53.	chufas	242	-	-	226	- 7	202	-17	204	-16	-39	-12.9
59.	millet,'Starr Pearl'	300	311	4	350	17	228	-24	280	- 7	-10	- 7.6
60.	millet, 'Brown Top'	182	-	-	153	-16	123	-32	151	-17	-65	-21.8
61.	oats	353	258	-27	340	- 4	338	- 4	329	- 7	-42	-10.4
66.	rice, 'Lebonett'	278	237	-15	277	0	236	-15	252	- 9	-40	- 9.9
67.	rice, 'Brazos'	276	256	- 7	283	3	246	-11	284	3	-13	- 3.2
68.	rice, 'Bluebett'	222	187	-16	218	- 2	171	-23	206	- 7	-48	-11.9
69.	rice, 'Labelle'	273	241	-12	238	-13	222	-19	243	-11	-54	-13.6
70.	rice, 'Star Bonnet'	233	201	-14	218	- 6	183	-22	227	- 3	-44	-11.1
71.	rubarb	333	292	-12	300	-15	283	- 8	306	-12	-48	-11.9
72.	rye	335	193	-42	297	-11	246	-27	247	-26	-107	-22.6
78.	sudangrass	304	212	-30	340	12	284	- 7	332	9	-16	- 3.9

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in Section I.

Table 6. Duncan's Multiple Range Test on Monocots for 3 week height differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
9.	wheat,'Wakeland'	A	B	C,B	C,B	D
10.	wheat,'CoCorit'	A	B	B	B	B
11.	wheat,'Cajeme'	A	A	A	A	A
12.	wheat,'Crane'	A	B	B	B	B
13.	wheat,'Inia 66R'	A	B	C	C	D
14.	wheat,'Jori'	A	B	B,A	B	B
15.	wheat,'SuperX'	A	A	B,A	B,C	C
22.	barley,'Belle'	A	-	B	B	B
23.	barley,'Arivat'	A	-	B,A	C	B,C
24.	barley,'Hembar'	A	-	B	B	B
35.	corn,'Silverqueen'	A	-	B,A	C	B,C
36.	corn, 'Tobelle'	A	-	B	C	C,B
37.	corn,'Hybrid XL'	A	-	B	C	B
38.	corn,'Coker 71'	A	-	A	C	B
54.	clover	A	-	A	A	A
60.	millet,'Browntop'	B,A	B,A	A	B	B
61.	oats	A	-	B,A	B	B,A
62.	okra	A	B	A	A	A
67.	rice,'Brazos'	A	B	A	B	B,A
68.	rice,'Bluebett'	B,A	B,A	A	B	A
69.	rice,'Labelle'	A	B,A	A	B	B,A
70.	rice,'Star Bonnet'	A	B	B	B	B
71.	rhubarb	A	B,A	B,A	B	A
73.	sorghum	A	B	B	B	B
75.	squash,'Prolific'	A	C	B,A	B,C	B,C
80.	watermelon	B,C	D	A	C	B,A

[1/] Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 7. Comparison of the 5 UV-B radiation treatments for final height (mm) of monocots) as to means, mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

UV-B Treatments[1], Mean Weights and % Differences[2]

	Species	1	2	%	3	%	4	%	5	%	Σ%	x̄%
9.	wheat 'Wakeland'	282	234	-17	226	-20	219	-22	200	-29	88	-22.1
10.	wheat, 'CoCorit'	240	220	- 8	216	-10	214	-11	208	-13	42	-10.6
11.	wheat, 'Cajeme'	229	211	- 8	215	- 6	226	- 1	191	-17	32	- 8.0
12.	wheat, 'Crane'	258	219	-15	224	-13	216	-16	204	-21	66	-16.4
13.	wheat, 'Inia 66R'	253	223	-12	232	- 8	227	-10	201	-21	51	-12.7
14.	wheat, 'Jori'	251	234	- 7	244	- 3	238	- 5	238	- 5	20	- 5.0
15.	wheat, 'Super-X	253	246	- 3	241	- 5	215	-15	214	-15	38	- 9.5
22.	barley, 'Belle'	325	-	-	273	-16	277	-15	270	-17	48	-16.0
23.	barley, 'Arivat'	286	-	-	252	-12	232	-19	256	-10	41	-13.7
24.	barley, 'Hembar'	316	-	-	239	-24	252	-20	249	-21	65	-21.7
35.	corn, 'Silverqueen'	561	-	-	462	-18	417	-26	439	-22	66	-22.0
36.	corn, 'Tobelle'	518	-	-	423	-18	388	-16	423	- 8	42	-14.0
37.	corn, 'Hybrid XL'	462	-	-	394	-15	327	-29	392	-15	59	-19.7
38.	corn, 'Coker 71'	494	-	-	384	-22	304	-38	378	-23	83	-27.7
53.	chufas	392	-	-	361	-8	334	-15	319	-19	-41	-13.8
59.	millet, 'Starr Pearl'	409	329	-20	385	-6	319	-22	386	- 6	-53	-13.3
60.	millet, 'Brown	281	-	-	223	-21	207	-26	248	-12	-59	-19.5
61.	oats	408	350	-14	383	-6	384	-6	373	- 9	-35	- 8.7
66.	rice, 'Lebonett'	378	333	-12	397	5	340	-10	344	-9	-26	- 6.5
67.	rice, 'Brazos'	368	351	- 5	381	4	327	-11	363	- 1	-14	- 3.4
68.	rice, 'Bluebett'	316	265	-16	299	-5	261	-17	280	-11	-50	-12.6
69.	rice, 'Labelle'	362	319	-12	346	-4	316	-13	321	-11	-40	-10.1
70.	rice, 'Star Bonnet'	330	290	-12	317	-4	278	-19	3k6	-4	-39	- 9.8
71.	rhubarb	389	341	-12	352	-10	323	-17	351	-10	-49	-12.1
72.	rye	457	316	-31	431	-6	351	-23	345	-25	-84	-21.1
78.	sudangrass	397	463	17	439	11	371	-7	437	10	31	7.7

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in Section I.

Table 8. Duncan's Multiple Range Test on Monocots for 4 week height differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
9.	wheat,'Wakeland'	A	B	B	C,B	C
10.	wheat,'Co Corit'	A	B	B	B	B
11.	wheat,'Cajeme'	A	B,A	A	A	B
12.	wheat,'Crane'	A	B	B	B	B
13.	wheat,'Inia 66R'	A	B	B,A	B	C
14.	wheat,'Jori'	A	A	A	A	A
15.	wheat,'SuperX'	A	A	A	B	B
22.	barley,'Belle'	A	-	B	B	B
23.	barley,'Arivat'	A	-	B	B	B,A
24.	barley,'Hembar'	A	-	B	B	B
35.	corn,'Silverqueen'	A	-	B	B	B
36.	corn, 'Tobelle'	A	-	B	B	B
37.	corn,'Hybrid XL	A	-	B	C	B
38.	corn,'Coker 71'	A	-	B	C	B
54.	clover	A	-	B,A	B,A	B
60.	millet,'Browntop'	A	A	B,A	B	B,A
61.	oats	A	-	B,C	C	B,A
62.	okra	A	C	B	B	B
67.	rice,'Brazos'	B,A	C	A	C	B,C
68.	rice,'Bluebett'	A	B,A	A	B	B,A
69.	rice,'Labelle'	A	A	A	A	A
70.	rice,'Star Bonnet'	A	B	B,A	B	B
71.	rhubarb	A	B,A	A	B	A
73.	sorghum	A	C,B	B	C	B
75.	squash,'Prolific'	A	B	A	B	B
80.	watermelon	B,C	A	B,A	C	B,A

[1/] Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 9. Comparison of the 5 UV-B radiation treatments for total # of leaves per plant of monocots as to means, mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

UV-B Treatments[1], Mean Weights and % Differences[2]

	Species	1	2	%	3	%	4	%	5	%	Σ%	x̄%
9.	wheat 'Wakeland'	29	36	24	38	31	30	3	32	10	69	17.2
10.	wheat, 'Coorit'	26	27	4	31	19	25	-4	28	8	27	6.7
11.	wheat, 'Cajeme'	26	29	12	35	35	29	12	28	8	65	16.3
12.	wheat, 'Crane'	27	26	-4	30	11	25	-7	25	-7	- 7	- 1.9
13.	wheat, 'Inia 66R'	29	29	0	30	3	28	-3	30	3	3	0.9
14.	wheat, 'Jori'	26	27	4	31	19	26	0	30	15	38	9.6
15.	wheat, 'Super-X'	23	25	9	27	17	23	0	24	4	30	7.6
22.	barley, 'Belle'	26			25	-4	26	0	25	-4	- 8	- 2.7
23.	barley, 'Arivat'	22			23	5	22	0	23	5	10	3.3
24.	barley, 'Hembar'	27			26	-4	26	-4	26	-4	-12	- 4.0
35.	corn, 'Silverqueen'	11			11	0	11	0	10	-9	- 9	- 5.3
36.	corn, 'Tobelle'	12			11	-8	12	0	12	0	- 8	- 2.7
37.	corn, 'Hybrid XL380'	12			11	-8	11	-8	12	0	-16	- 5.3
38.	corn, 'Coker 71'	12			11	-8	11	-8	12	0	-16	- 5.3
53.	chufas	24			32	33	38	58	33	38	129	43.1
59.	millet, 'Starr Pearl'	28	30	7	33	18	31	11	33	18	54	13.4
60.	millet, 'Brown Top'	40			47	18	44	10	45	13	40	13.3
61.	oats	27	20	-26	25	-7	26	-4	26	-4	-41	-10.2
66.	rice, 'Lebonett'	24	21	-13	23	-4	22	-8	21	-13	-38	- 9.4
67.	rice, 'Brazos'	24	24	0	25	4	23	-4	24	0	0	0
68.	rice, 'Bluebett'	20	17	-15	20	0	17	-15	20	0	-30	- 7.5
69.	rice, 'Labelle'	21	21	0	22	5	23	10	22	5	19	4.8
70.	rice, 'Star Bonnet'	23	22	-4	22	-4	21	-9	22	-4	-22	- 5.4
72.	rye	55	59	7	56	2	61	11	54	-2	18	4.5
73.	sorghum	27	23	-15	26	-4	25	-7	26	-4	-30	- 7.4
78.	sudangrass	26	34	31	30	15	31	19	29	12	77	19.2

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in Section I.

Table 10. Duncan's Multiple Range Test on Monocots for Total Number of Leaves differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
9.	wheat,'Wakeland'	C	B,A	A	C	B,C
10.	wheat,'Coorit'	B	B,A	A	B	B,A
11.	wheat,'Cajeme'	B	B	A	B	B
12.	wheat,'Crane'	B,A	B	A	B	B
13.	wheat,'Inia 66R'	A	A	A	A	A
14.	wheat,'Jori'	B	B	A	B	B,A
15.	wheat,'SuperX'	B	B,A	A	B	B
22.	barley,'Belle'	A	-	A	A	A
23.	barley,'Arivat'	A	-	A	A	A
24.	barley,'Hembar'	A	-	A	A	A
35.	corn,'Silverqueen'	A	-	A	A	A
36.	corn, 'Tobelle'	A	-	A	A	A
37.	corn,'Hybrid XL380'	B,A	-	B,A	B	A
38.	corn,'Coker 71'	A	-	B,C	C	B,A
54.	clover	B	-	B,A	A	B,A
60.	millet,'Browntop'	A	A	A	A	A
61.	oats	A	-	A	A	A
62.	okra	A	B	A	A	A
67.	rice,'Brazos'	A	B	B,A	B,A	B
68.	rice,'Bluebett'	A	A	A	A	A
69.	rice,'Labelle'	A	A	A	A	A
70.	rice,'Star Bonnet'	A	A	A	A	A
71.	rhubarb	A	A	A	A	A
73.	sorghum	A	A	A	A	A
75.	squash,'Prolific'	A	A	A	A	A
80.	watermelon	C	A	B	B	B

[1/] Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 11 . Comparison of the 5 UV-B radiation treatments for number of chlorotic leaves as to means, mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

		UV-B Treatments[1], Means, and % Differences[2]										
	Species	1	2	%	3	%	4	%	5	%	Σ %	$\bar{x}$ %
9.	wheat, 'Wakeland'	8.3	10.6	28	11.3	36	12.8	54	22.8	175	293	73.2
10.	wheat, 'CoCorit'	15.3	11.9	-22	12.9	-16	13.2	-14	22.2	45	-7	-1.6
11.	wheat, 'Cajeme'	6.9	12.6	83	11.3	64	18.2	164	20.5	197	507	126.8
12.	wheat, 'Crane'	11.9	8.3	-30	10.5	-12	13.6	14	17.9	30	23	5.7
13.	wheat, 'Inia 66R'	9.4	11.2	19	12.1	29	16.7	78	23.3	148	273	68.4
14.	wheat, Jori'	13.8	12.0	-13	15.4	12	17.2	25	23.7	72	95	23.7
15.	wheat. 'Super-X'	10.3	12.0	17	14.3	39	16.1	26	17.3	68	180	44.9
22.	barley, 'Belle'	16.2	--	--	20.0	24	14.7	9	16.1	1	14	4.5
23.	barley, 'Arivat'	14.0	--	--	17.4	24	12.0	-14	12.5	-11	-1	0
24.	barley, 'Hembar'	15.3	--	--	19.8	29	13.5	-12	12.3	-20	-2	-1
35.	corn, 'Silverqueen'	4.4	--	--	7.2	64	5.3	21	5.0	14	98	32.6
36.	corn, 'Tobelle'	4.6	--	--	8.6	87	5.2	13	4.2	-9	91	30.4
37.	corn, 'Hybrid XL380'	2.8	--	--	7.3	161	4.8	71	4.4	57	289	96.4
38.	corn, 'Coker 71'	5.3	--	--	8.1	53	4.7	-11	5.8	9	51	17.0
53.	chufas	7.7	19.9	158	16.6	116	17.0	121	--	--	395	131.6
59.	millet, 'Starr Pearl'	17.1	18.7	9	17.2	1	17.3	1	15.7	-8	3	.7
60.	millet, 'Browntop'	18.8	12.5	-34	7.5	-60	13.4	-29	--	--	-122	-40.8
61.	oats	13.3	18.1	36	18.5	39	19.7	49	15.7	18	141	35.3
66.	rice, 'Lebonett'	9.2	7.1	-23	3.0	-67	7.5	-19	3.5	-62	-171	-42.7
67.	rice, 'Brazos'	4.5	8.7	93	4.5	0	7.5	67	4.5	0	160	40.0
68.	rice, 'Bluebett'	5.4	6.6	22	5.5	2	8.8	63	3.0	-44	43	10.6
69.	rice, 'Labelle'	6.1	8.6	41	4.7	-23	15.6	156	4.3	-30	144	36.1
70.	rice, 'Star Bonnet'	7.3	10.2	40	5.0	-32	9.1	25	3.8	-48	-15	-3.8
71.	rhubarb	29.3	30.2	3	24.3	-17	28.7	-2	33.3	14	-2	-.6
72.	rye	10.0	16.8	68	17.4	74	19.7	97	9.8	-2	237	59.3
78.	sudangrass	15.4	20.0	30	15.4	0	12.8	-17	29.2	90	103	25.6

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in SectionI.

Table 12. Duncan's Multiple Range Test on Monocots for Number of Chlorotic Leaf differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
9.	wheat,'Wakeland'	B	B	B	B	A
10.	wheat,'CoCorit'	B	B	B	B	A
11.	wheat,'Cajeme'	C	B	C,B	A	A
12.	wheat,'Crane'	B	B	B	B,A	A
13.	wheat,'Inia 66R'	C	C	C,B	B	A
14.	wheat,'Jori'	C,B	C	C,B	B	A
15.	wheat,'SuperX'	C	B,C	B,A	A	A
22.	barley,'Belle'	B	-	A	B	B
23.	barley,'Arivat'	B,A	-	A	B	B
24.	barley,'Hembar'	B	-	A	B	B
35.	corn,'Silverqueen'	B	-	A	B	B
36.	corn, 'Tobelle'	B	-	A	B	B
37.	corn,'Hybrid XL380'	C	-	A	B	B
38.	corn,'Coker 71'	B	-	A	B	B
54.	clover	B	-	A	A	A
60.	millet,'Browntop'	A	A	A	A	A
61.	oats	A	-	A	A	A
62.	okra	B	B,A	B,A	B,A	A
67.	rice,'Brazos'	A	B,A	B,A	B	B,A
68.	rice,'Bluebett'	B	B	A	B	B,A
69.	rice,'Labelle'	B,A	B	B,A	B,A	A
70.	rice,'Star Bonnet'	A	A	A	A	A
71.	rhubarb	A	A	A	A	A
73.	sorghum	A	A	A	A	A
75.	squash,'Prolific'	B,C	C	B,A,C	B,A	A
80.	watermelon	C,B	A	B	C,B	C

[1/] Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 13. Comparison of the 5 UV-B radiation treatments for % chlorotic leaves as to means, mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

UV-B Treatments[1], Mean Weights and % Differences[2]

	Species	1	2	%	3	%	4	%	5	%	Σ%	x̄%
9.	wheat 'Wakeland'	28	31	11	30	7	47	68	69	146	232	58.0
10.	wheat, 'CoCorit'	60	44	-27	43	-28	55	-8	78	30	- 33	- 8.3
11.	wheat, 'Cajeme'	29	43	48	33	14	64	121	75	159	341	85.3
12.	wheat, 'Crane'	44	33	-25	36	-18	55	25	71	61	43	10.8
13.	wheat, 'Inia 66R'	34	38	12	41	21	59	74	76	124	229	57.4
14.	wheat, 'Jori'	53	45	-15	50	-6	66	25	81	53	57	14.2
15.	wheat, 'Super-X'	44	49	11	54	23	70	59	75	70	164	40.9
22.	barley, 'Belle'	63			80	27	58	-8	64	2	21	7.0
23.	barley, 'Arivat'	65			77	18	54	-17	56	-14	- 13	- 4.3
24.	barley, 'Hembar'	58			77	33	51	-12	47	-19	- 2	- 0.7
35.	corn, 'Silverqueen'	41			67	63	49	20	48	17	100	33.3
36.	corn, 'Tobelle'	38			76	100	43	13	36	-5	108	36.0
37.	corn, HybridXL380	25			65	150	44	76	38	52	288	96.0
38.	corn, 'Coker 71'	43			74	72	42	-2	48	12	81	27.1
53.	chufas	22			63	186	43	95	53	141	423	140.9
59.	millet 'StarrPearl'	62	53	-15	57	-8	56	-10	51	-18	- 50	-12.5
60.	millet, 'Browntop'	47			32	-32	17	-64	25	-47	-143	-47.5
61.	oats	51	79	55	75	47	72	41	76	49	192	48.0
66.	rice, 'Lebonett'	38	17	-55	31	-18	14	-63	37	- 3	-139	-34.9
67.	rice, 'Brazos'	20	19	- 5	35	75	22	10	32	60	140	35.0
68.	rice, 'Bluebett'	27	17	-37	34	26	31	15	42	56	59	14.8
69.	rice, 'Labelle'	31	21	-32	38	23	20	-35	107	245	200	50.0
70.	rice, 'Star Bonnet'	35	19	-46	45	29	28	-20	42	20	- 17	- 4.3
72.	rye	52	56	8	53	2	43	-17	52	0	- 8	- 1.9
73.	sorghum	37	42	14	66	78	62	69	74	100	259	64.9
78.	sudangrass	60	87	45	69	15	50	-17	45	-25	18	4.6

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in Section I.

Table 14. Duncan's Multiple Range Test on Monocots for %Chlorotic Leaf differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
9.	wheat,'Wakeland'	B	B	B	B	A
10.	wheat,'CoCorit'	B	B	B	B	A
11.	wheat,'Cajeme'	B	B	B	A	A
12.	wheat,'Crane'	B,C	C	B,C	B,A	A
13.	wheat,'Inia 66R'	B	B	B	A	A
14.	wheat,'Jori'	C,B	C	C	B	A
15.	wheat,'SuperX'	C	C	B,C	B,A	A
22.	barley,'Belle'	B	-	A	B	B
23.	barley,'Arivat'	B,A	-	A	B	B
24.	barley,'Hembar'	B	-	A	B	B
35.	corn,'Silverqueen'	B	-	A	B	B
36.	corn, 'Tobelle'	B	-	A	B	B
37.	corn,'Hybrid XL380'	C	-	A	B	B
38.	corn,'Coker 71'	B	-	A	B	B
54.	clover	B	-	A	A	A
60.	millet,'Browntop'	A	A	A	A	A
61.	oats	A	-	B,A	B	B,A
62.	okra	B	A	A	A	A
67.	rice,'Brazos'	A	B,A	B,A	B	A
68.	rice,'Bluebett'	A	A	A	A	A
69.	rice,'Labelle'	B,A	B	B,A	B,A	A
70.	rice,'Star Bonnet'	A	A	A	A	A
71.	rhubarb	A	A	A	A	A
73.	sorghum	A	A	A	A	A
75.	squash,'Prolific'	B	B	A	A	A
80.	watermelon	B,A	A	B,A	B	B

[1/]Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 15. Comparison of the 5 UV-B radiation treatments for leaf dry weight(g) as to means, mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

UV-B Treatments[1], Mean Weights and % Differences[2]

	Species	1	2	%	3	%	4	%	5	%	Σ%	x̄%
1.	asparagus	0.07	0.06	-14	0.07	0	0.07	0	0.07	0	-14	-3.6
2.	carrots	0.55	0.58	5	0.71	29	0.56	2	0.58	5	42	10.5
3.	celery	0.39	0.65	67	0.46	18	0.35	-10	0.41	5	79	19.9
4.	radish	0.25	0.31	24	0.50	100	0.23	- 8	0.28	12	128	32.0
5.	lettuce	0.21	0.15	-29	0.17	-19	0.12	-43	0.08	-62	-152	-38.1
6.	onion	0.10	0.10	0	0.11	10	0.08	-20	0.09	-10	- 20	- 5.0
7.	parsnip	0.45	0.42	- 7	0.42	- 7	0.46	2	0.48	7	- 4	- 1.1
8.	English peas	0.36	0.66	83	0.49	36	0.77	114	0.38	6	239	59.7
9.	wheat,'Wakeland'	0.46	0.50	9	0.52	13	0.44	- 4	0.43	- 7	11	2.7
10.	wheat,'CoCorit'	0.47	0.45	- 4	0.49	4	0.44	- 6	0.42	-11	- 17	-43
11.	wheat,'Cajeme'	0.42	0.41	- 2	0.48	14	0.42	0	0.33	-21	10	2.4
12.	wheat,'Crane'	0.51	0.42	-18	0.50	- 2	0.41	-20	0.35	-31	- 71	-17.6
13.	wheat,'Inia 66R'	0.53	0.55	4	0.59	11	0.49	- 8	0.53	0	8	1.9
14.	wheat,'Jori'	0.63	0.63	0	0.74	17	0.63	0	0.70	11	29	7.1
15.	wheat,'Super-X'	0.42	0.46	10	0.53	26	0.46	10	0.39	- 7	38	9.5
16.	pine, slash	0.84	0.77	- 8	0.68	-19	0.53	-37	0.65	-23	- 87	-21.7
17.	pine, loblolly	1.22	1.18	- 3	1.05	-14	0.87	-29	1.04	-15	-61	-15.2
18.	pine, lodgepole	0.75	0.78	4	0.75	0	0.54	-28	0.68	- 9	-33	- 8.3
19.	pine, ponderosa	1.17	1.24	6	0.96	-18	0.82	-30	0.96	-18	-60	-15.0
20.	fir, noble	0.85	0.80	- 6	0.82	- 4	0.53	-38	0.68	-20	-67	-16.8
21.	fir, white	0.25	0.54	116	0.59	136	0.44	76	0.36	44	372	93.0
22.	barley,'Belle'	0.69	-	-	0.52	-25	0.57	-17	0.55	-20	-62	-20.7
23.	barley,'Arivat'	0.61	-	-	0.45	-26	0.48	-21	0.46	-25	-42	-24.0

Table 15 Cont'd

		1	2	%	3	%	4	%	5	%	Σ%	$\bar{x}$%
24.	barley,'Hembar'	0.81	-	-	0.47	-42	0.56	-31	0.54	-33	106	-35.4
25.	broccoli	0.54	-	-	0.23	-57	0.17	-69	0.17	-69	-194	-64.8
26.	brussels sprouts	0.41	-	-	0.22	-46	0.10	-76	0.15	-63	-185	-61.7
27.	cabbage	0.62	-	-	0.27	-56	0.23	-63	0.20	-68	-187	-62.3
28.	cauliflower	0.35	-	-	0.18	-49	0.13	-63	0.12	-66	-178	-59.3
29.	chard	0.28	-	-	0.11	-61	0.09	-68	0.07	-75	-204	-68.0
30.	collards	0.47	-	-	0.21	-55	0.26	-45	0.15	-68	-168	-56.0
31.	kale	0.48	-	-	0.26	-46	0.21	-56	0.18	-63	-165	-55.0
32.	kohlrabi	0.45	-	-	0.23	-49	0.16	-64	0.14	-69	-182	-60.7
33.	mustard	0.28	-	-	0.33	18	0.11	-61	0.09	-68	-111	-37.0
34.	rutabega	0.43	-	-	0.23	-47	0.18	-58	0.14	-67	-172	-57.3
35.	corn,'Silverqueen'	0.97	-	-	0.92	- 5	0.73	-25	0.70	-28	-58	-19.3
36.	corn, 'Tobelle'	1.20	-	-	0.87	-28	0.84	-30	0.81	-33	-90	-30.0
37.	corn, Hybrid XL	1.18	-	-	1.06	-10	0.77	-35	0.92	-22	-67	-22.3
38.	corn,'Coker 71'	2.02	-	-	0.89	-56	0.51	-75	0.77	-62	-193	-64.2
39.	grass,'Pensacola'	0.20	-	-	0.19	- 5	0.07	-65	0.11	-45	-115	-38.3
40.	grass,'Arg. Bahia'	0.16	-	-	0.13	-19	0.08	-50	0.10	-38	-107	-35.7
41.	grass,'Bermuda'	0.11	-	-	0.06	-45	0.18	64	0.14	27	-46	-15.3
42.	grass, carpet	0.11	-	-	0.04	-64	0.08	-27	0.08	-27	-118	-29.0
43.	soybean,'Hardee'	0.89	-	-	0.63	-29	0.58	-35	0.54	-61	-125	-41.7
44.	artichoke	0.38	-	-	0.41	8	0.48	26	0.33	-13	21	7.0
45.	bean, lima	0.96	-	-	0.89	- 7	0.82	-15	0.70	-27	-49	-16.3
46.	bean, garden	0.84	0.72	-14	0.80	- 5	0.58	-31	0.56	-33	-83	-20.8
47.	bean, pinto	0.97	-	-	0.87	-10	0.84	-13	0.90	- 7	-31	-10.3
48.	bean,'Tenn. Flat'	0.88	-	-	0.85	- 3	0.84	- 5	0.77	-13	-20	- 6.8
49.	bell pepper	0.47	0.69	47	0.49	4	0.50	6	0.51	9	66	16.5
50.	butterpea	0.77	-	-	0.70	- 9	0.69	-10	0.64	-17	-36	-12.1
51.	cantelope, 'Hales'	0.74	0.29	-61	0.35	-53	0.24	-68	0.28	-62	-243	-60.8
52.	cantelope, 'Honeydew'	0.78	0.26	-67	0.35	-55	0.31	-60	0.26	-67	-249	-62.2
53.	chufas	0.98	-	-	1.40	43	1.37	40	1.24	-27	109	36.4
54.	clover	0.14	-	-	0.09	-36	0.02	-86	0.05	-64	-186	-61.9
55.	cotton	0.83	0.92	11	0.84	1	0.91	10	0.81	- 2	19	4.8
56.	cucumber	1.00	0.79	-21	0.81	-19	0.68	-32	0.63	-37	-109	-27.3
57.	cowpeas	0.71	-	-	0.61	-14	0.60	-15	0.60	-15	-43	-14.3
58.	eggplant	0.19	-	-	0.29	53	0.27	42	0.21	11	105	35.1

Table 15 Cont'd

		1	2	%	3	%	4	%	5	%	Σ%	$\bar{x}$%
59.	millet,'Starr Pearl'	1.56	2.04	31	1.40	-10	1.11	-29	1.52	-3	- 11	- 2.7
60.	millet,'Browntop'	0.75	-	-	0.90	20	0.66	-12	0.75	0	8	2.7
61.	oats	0.91	0.54	-41	1.05	15	1.13	24	1.09	20	19	4.7
62.	okra	0.66	-	-	0.54	-18	0.44	-33	0.41	-38	- 89	-29.8
63.	peanuts	0.95	1.11	17	1.02	7	1.02	7	1.09	15	46	11.6
64.	peas, blackeye	1.21	0.56	-54	0.66	-45	0.47	-61	0.47	-61	-221	-55.4
65.	pumpkin	1.44	-	-	1.46	1	1.37	- 5	1.30	-10	- 13	- 4.4
66.	rice,'Lebonett'	0.65	0.56	-14	0.69	6	0.53	-18	0.51	-22	- 48	-11.9
67.	rice,'Brazos'	0.59	0.53	-10	0.71	20	0.53	-10	0.55	- 7	- 7	- 1.7
68.	rice,'Bluebett'	0.41	0.33	-20	0.37	-10	0.31	-24	0.36	-12	- 66	-16.5
69.	rice,'Labelle'	0.50	0.50	0	0.51	2	0.45	-10	0.50	0	- 8	- 2.0
70.	rice,'Star Bonnet'	0.46	0.42	- 9	0.47	2	0.38	-17	0.41	-11	- 35	- 8.7
71.	rhubarb	0.66	-	-	0.35	-47	0.27	-59	0.17	-74	-180	-60.1
72.	rye	1.31	1.28	- 2	1.23	- 6	1.31	0	1.21	- 8	- 16	- 4.0
73.	sorghum	2.20	0.65	-70	1.94	-12	1.90	-14	1.37	-38	-134	-33.4
74.	squash, Early Summer	1.61	0.95	-41	1.02	-37	0.88	-45	0.70	-57	-180	-44.9
75.	squash,'Prolific'	0.85	0.57	-33	0.72	-15	0.67	-21	0.68	-20	- 89	-22.4
76.	squash,'Zucchini'	1.03	-	-	0.96	- 7	0.83	-20	0.74	-28	- 55	-18.4
77.	squash, Acorn	0.59	-	-	0.59	0	0.57	- 3	0.42	-29	- 32	-10.7
78.	sudangrass	1.55	2.51	62	2.09	35	1.46	- 6	1.99	28	119	29.8
79.	tomato	0.52	0.05	-90	0.08	-85	0.07	-87	0.05	-90	-352	-88.0
80.	watermelon	0.69	0.32	-54	0.45	-35	0.28	-59	0.27	-61	-209	-52.2
81.	Douglas-fir	0.33	-	-	0.34	3	0.36	9	0.36	- 9	- 21	- 7.1
82.	sunflower	0.73	-	-	0.76	4	0.76	4	0.82	12	21	6.8

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in Section I.

Table 16. Duncan's Multiple Range Test for Leaf Dry Weight differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
1.	asparagus	A	A	A	A	A
2.	carrots	B	B	A	B	B
3.	celery	B	A	B	B	B
4.	radish	A	A	A	A	A
5.	lettuce	A	A	A	A	A
6.	onion	A	A	A	A	A
7.	parsnip	A	A	A	A	A
8.	English peas	B	A	B	B,A	B
9.	wheat,'Wakeland'	A	A	A	A	A
10.	wheat,'Co Corit'	A	A	A	A	A
11.	wheat,'Cajeme'	B,A	B,A	A	B,A	B
12.	wheat,'Crane'	A	B,A,C	B,A	B,C	C
13.	wheat,'Inia 66R'	A	A	A	A	I
14.	wheat,'Jori'	A	A	A	A	A
15.	wheat,'SuperX'	B	B,A	A	B,A	B
16.	pine, slash	A	B,A	B,A	B	B,A
17.	pine, loblolly	A	A	B,A	B	B,A
18.	pine, lodgepole	A	A	A	B	A
19.	pine, ponderosa	A	A	B	B	B
20.	fir, noble	A	A	A	C	B
21.	fir, white	C	A	A	B,A	B,C
22.	barley,'Belle'	A	-	B	B,A	B,A
23.	barley,'Arivat'	A	-	A	A	A
24.	barley,'Hembar'	A	-	B	B	B
25.	broccoli	A	-	B	B	B
26.	brussel sprouts	A	-	B	C	C
27.	cabbage	A	-	B	B	B
28.	cauliflower	A	-	B	B	B
29.	chard	A	-	B	B	B
30.	collards	A	-	B	B	B
31.	kale	A	-	B	B	B
32.	kohlrabi	A	-	B	C,B	C
33.	mustard	A	-	A	B	B
34.	rutabega	A	-	B	B	B
35.	corn,'Silverqueen'	A	-	A	A	A
36.	corn, 'Tobelle'	A	-	B	B	B
37.	corn,'Hybrid XL380'	A	-	B,A	C	B,C
38.	corn,'Coker 71'	A	-	B,A	B	B,A
39.	grass,'Pensacola'	A	-	A	A	A
40.	grass,'Arg. Bahia'	A	-	A	A	A
41.	grass,'Bermuda'	A	-	A	A	A
42.	grass, carpet	A	-	A	A	-
43.	soybean,'Hardee'	A	-	A	A	A
44.	artichoke	B,A	-	B,A	A	B

Table 16 Con't.

		Light Level				
	Species	1	2	3	4	5
45.	bean, lima	A	-	B,A	B	C
46.	bean, garden	A	B,A	A	B	B
47.	bean, pinto	A	-	B	B	B,A
48.	bean,'Tenn. Flat'	A	-	A	A	A
49.	bell pepper	B	A	B	B	B
50.	butterpea	A	-	A	A	A
51.	cantelope,'Hales'	A	B	B	B	B
52.	cantelope, 'Honeydew'	A	B	B	B	B
53.	chufas	A	-	A	A	A
54.	clover	A	-	B,A	B	B
55.	cotton	A	A	A	A	A
56.	cucumber	A	C,B	B	C,B	C
57.	cowpeas	A	-	B	C	C
58.	eggplant	A	-	A	A	A
59.	millet,'Starr Pearl'	B,A	A	B,A	B	B,A
60.	millet,'Browntop'	A	-	A	A	A
61.	oats	B	C	A	A	A
62.	okra	A	-	B,A	B	B
63.	peanuts	A	A	A	A	A
64.	peas, blackeye	A	C,B	B	C	C
65.	pumpkin	A	-	A	A	A
66.	rice,'Lebonette'	B,A	B,A,C	A	B,C	C
67.	rice,'Brazos'	B,A	B	A	B	B
68.	rice,'Bluebett'	A	A	A	A	A
69.	rice,'Labelle'	A	A	A	A	A
70.	rice,'Star Bonnet'	A	A	A	A	A
71.	rhubarb	A	-	B	B	B
72.	rye	A	A	A	A	A
73.	sorghum	A	C	B,A	B,A	B
74.	squash, early summer	A	B	B	C,B	C
75.	squash,'Prolific'	A	B	B	B	B
76.	squash,'Zuccini'	A	-	B,A	B,C	C
77.	squash, acorn	A	-	A	A	A
78.	sudangrass	B	A	B,A	B	B,A
79.	tomato	A	B	B	B	B
80.	watermelon	A	C,B	B	C	C
81.	Douglas-fir	A	-	A	A	A
82.	sunflower	A	-	A	A	A

1/ Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 17. Comparison of the 5 UV-B radiation treatments for stem dry weight (g) of dicots as to means, mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

UV-B Treatments[1], Mean Weights and % Differences[2]

Species	1	2	%	3	%	4	%	5	%	Σ%	x̄%
45. bean, lima	0.68			0.60	-12	0.64	- 6	0.51	-25	- 43	-14.2
46. bean, garden	0.44	0.40	- 9	0.40	- 9	0.33	-25	0.27	-39	- 82	-20.5
47. bean, pinto	0.59			0.54	- 8	0.51	-14	0.50	-15	- 37	-12.4
48. bean, 'Tenn.Flat.'	0.49			0.47	- 4	0.45	- 8	0.42	-14	- 27	- 8.8
49. bell pepper	0.17	0.31	82	0.17	0	0.20	18	0.15	-12	88	22.1
50. butter pea	0.67			0.43	-36	0.42	-37	0.40	-40	-113	-37.8
51. cantelope, 'Hales'	0.43	0.09	-79	0.10	-77	0.05	-88	0.06	-86	-330	-82.6
52. cantelope, 'Honeydew'	0.54	0.05	-91	0.10	-81	0.06	-89	0.05	-91	-352	-88.0
54. clover	0.04			0.02	-50	0.01	-75	0.01	-75	-200	-66.7
55. cotton	0.72	0.82	14	0.69	- 4	0.65	-10	0.58	-19	- 19	- 4.9
56. cucumber	0.66	0.25	-62	0.27	-59	0.18	-73	0.14	-79	-273	-68.2
58. eggplant	0.19			0.15	-21	0.11	-42	0.08	-58	-121	-40.4
62. okra	0.50			0.44	-12	0.36	-28	0.30	-40	- 80	-26.7
63. peanuts	0.95	1.21	27	1.05	11	1.09	15	1.01	6	59	14.7
64. peas	0.64	0.28	-56	0.35	-45	0.40	-38	0.28	-56	-195	-48.8
65. pumpkin	1.53			1.41	- 8	1.09	-29	1.06	-31	- 67	-22.4
71. rhubarb	0.30			0.13	-57	0.09	-70	0.06	-80	-207	-68.9
74. squash Early Sum.	1.69	0.51	-70	0.66	-61	0.39	-77	0.29	-83	-291	-72.5
75. squash 'Prolific'	0.61	0.15	-75	0.35	-43	0.27	-56	0.22	-64	-238	-59.4
76. squash 'Zucchini'	0.87			0.42	-52	0.28	-68	0.25	-71	-191	-63.6
77. squash, Acorn	0.33			0.20	-39	0.17	-48	0.11	-67	-155	-51.5
79. tomato	0.36	0.03	-92	0.05	-86	0.03	-92	0.02	-94	-364	-91.0
80. watermelon	0.40	0.11	-73	0.15	-63	0.08	-80	0.08	-80	-295	-73.8
82. sunflower	0.71			0.68	- 4	0.63	-11	0.70	- 1	- 17	- 5.6

[1]Means of plant replicates explained in methods section

[2]UV-B enhancement levels 1 to 5 defined in Section I.

Table 18. Duncan's Multiple Range Test for Stem Dry Weight differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
45.	bean, lima	A	-	A	A	B
46.	bean, garden	A	A	B,A	B,C	C
47.	bean, pinto	A	-	B,A	B	B
48.	bean,'Tenn. Flat'	A	-	A	A	A
49.	bell pepper	B	A	B	B	B
50.	butterpea	A	-	B	B	B
51.	cantelope, 'Hales'	A	B	B	B	B
52.	cantelope, 'Honeydew'	A	B	B	B	B
54.	clover	A	-	B,A	B	B
55.	cotton	B,A	A	B,A	B,A	B
56.	cucumber	A	B	B	C,B	C
58.	eggplant	A	-	A	A	A
62.	okra	A	-	B,A	B	B
63.	peanuts	B	A	B,A	B,A	B,A
64.	peas, blackeye	A	B	B	B	B
65.	pumpkin	A	-	A	B	B
71.	rhubarb	A	-	B	B	B
74.	squash, early summer	A	C,B	B	C,D	D
75.	squash,'Prolific'	A	C	B	C,B	C
76.	squash,'Zuccini'	A	-	B	C,B	C
77.	squash, acorn	A	-	B	C,B	C
79.	tomato	A	B	B	B	B
80.	watermelon	A	C,B	B	C	C
82.	sunflower	A	-	A	A	A

[1/] Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 19. Comparison of the 5 UV-B radiation treatments for root dry weight(g) as to means, Mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

UV-B Treatments[1], Mean Weights and % Differences[2]

	Species	1	2	%	3	%	4	%	5	%	Σ%	$\bar{x}$%
1.	asparagus	0.03	0.02	-33	0.02	-33	0.02	-33	0.03	0	-100	-25.0
2.	carrots	0.07	0.10	43	0.11	57	0.10	43	0.09	29	171	42.9
3.	celery	0.07	0.15	114	0.10	43	0.08	14	0.09	29	200	50.0
4.	radish	0.23	0.24	4	0.18	-22	0.13	-43	0.20	-13	- 74	-18.5
5.	lettuce	0.04	0.02	-50	0.02	-50	0.02	-50	0.03	-25	-175	-43.8
6.	onion	0.03	0.03	0	0.03	0	0.02	-33	0.05	67	33	8.3
7.	parsnip	0.09	0.08	-11	0.07	-22	0.09	0	0.08	-11	- 44	-11.1
8.	English peas	0.42	0.32	-24	0.30	-29	0.29	-31	0.31	-26	-110	-27.4
9.	wheat,'Wakeland'	0.28	0.44	57	0.49	75	0.43	54	0.47	68	254	63.4
10.	wheat,'CoCorit'	0.45	0.47	4	0.45	0	0.44	- 2	0.49	9	11	2.8
11.	wheat,'Cajeme'	0.36	0.41	14	0.55	53	0.44	22	0.38	6	94	23.6
12.	wheat,'Crane'	0.38	0.37	- 3	0.44	16	0.40	5	0.37	- 3	16	3.9
13.	wheat,'Inia 66R'	0.43	0.55	28	0.44	2	0.42	- 2	0.49	14	42	10.5
14.	wheat,'Jori'	0.51	0.58	14	0.67	31	0.60	18	0.65	27	90	22.5
15.	wheat,'Super-X'	0.35	0.36	3	0.47	34	0.44	26	0.38	9	71	17.9
16.	pine, slash	0.15	0.15	0	0.12	-20	0.12	-20	0.12	-20	-60	-15.0
17.	pine, loblolly	0.28	0.28	0	0.25	-11	0.22	-21	0.23	-18	-50	-12.5
18.	pine, lodgepole	0.22	0.24	9	0.22	0	0.15	-32	0.19	-14	-36	- 9.1
19.	pine, ponderosa	0.42	0.38	-10	0.31	-26	0.27	-36	0.29	-31	-102	-25.6
20.	fir, noble	0.20	0.17	-15	0.20	0	0.14	-30	0.13	-35	- 80	-20.0
21.	fir, white	0.16	0.15	-6	0.27	69	0.12	-25	0.07	-56	-18	-4.5
22.	barley,'Belle'	0.46	-	-	0.38	-17	0.44	- 4	0.42	- 9	- 30	-10.0
23.	barley,'Arivat'	0.65	-	-	0.46	-29	0.53	-18	0.41	-37	- 84	-28.0

Table 19 Cont'd

		1	2	%	3	%	4	%	5	%	Σ%	$\bar{x}$%
24.	barley,'Hembar'	0.59	-	-	0.41	-31	0.47	-20	0.39	-34	- 85	-28.3
25.	broccoli	0.13	-	-	0.03	-77	0.02	-85	0.02	-85	-247	-82.3
26.	brussels sprouts	0.06	-	-	0.02	-67	0.02	-67	0.03	-50	-184	-61.3
27.	cabbage	0.12	-	-	0.04	-67	0.05	-58	0.02	-83	-208	-69.3
28.	cauliflower	0.05	-	-	0.01	-80	0.01	-80	0.01	-80	-240	-80.0
29.	chard	0.02	-	-	0.01	-50	0.01	-50	0.01	-50	-150	-50.0
30.	collards	0.14	-	-	0.03	-79	0.02	-86	0.02	-86	-251	-83.7
31.	kale	0.09	-	-	0.04	-56	0.03	-67	0.03	-67	-190	-63.3
32.	kohlrabi	0.10	-	-	0.03	-70	0.02	-80	0.02	-80	-230	-76.7
33.	mustard	0.03	-	-	0.03	0	0.01	-67	0.01	-67	-134	-44.7
34.	rutabega	0.07	-	-	0.03	-57	0.02	-71	0.01	-86	-214	-71.3
35.	corn,'Silverqueen'	0.55	-	-	0.59	9	0.43	-22	0.39	-29	- 44	-14.5
36.	corn, 'Tobelle'	1.03	-	-	0.64	-38	0.50	-51	0.53	-49	-138	-46.0
37.	corn, Hybrid XL	1.05	-	-	1.12	7	0.62	-41	0.73	-30	- 65	-21.6
38.	corn,'Coker 71'	0.87	-	-	0.83	- 5	0.48	-45	0.60	-31	- 80	-26.8
39.	grass,'Pensacola'	0.03	-	-	0.05	67	0.01	-67	0.02	-33	- 33	-11.0
40.	grass,'Arg. Bahia'	0.04	-	-	0.02	-50	0.02	-50	0.03	-25	-125	-42.0
41.	grass,'Bermuda'	0.02	-	-	0.01	-50	0.03	50	0.01	-50	- 50	-17.0
42.	grass, carpet	0.03	-	-	0.01	-67	0.02	-33	0.02	-33	-133	-44.0
43.	soybean,'Hardee'	0.30	-	-	0.23	-23	0.24	-20	0.20	-33	- 76	-25.3
44.	artichoke	0.29	-	-	0.41	41	0.36	24	0.38	31	96	32.0
45.	bean, lima	0.30	-	-	0.32	7	0.27	10	0.25	-17	- 20	- 6.7
46.	bean, garden	0.34	0.33	-3	0.26	-24	0.19	-44	0.18	-47	-118	-29.4
47.	bean, pinto	0.48	-	-	0.44	- 8	0.34	-29	0.32	-33	- 71	-23.6
48.	bean,'Tenn. Flat'	0.37	-	-	0.34	- 8	0.31	-16	0.27	-27	- 51	-17.1
49.	bell pepper	0.19	0.23	21	0.13	-32	0.13	-32	0.14	-26	- 68	-17.1
50.	butterpea	0.28	-	-	0.20	-29	0.21	-25	0.19	-32	- 86	-28.6
51.	cantelope, 'Hales'	0.15	0.03	80	0.05	-67	0.03	-80	0.04	-73	-300	-75.0
52.	cantelope, 'Honeydew'	0.21	0.03	86	0.04	-81	0.03	-86	0.03	-86	-338	-84.5
53.	chufas	0.84	-	-	0.99	18	1.03	23	0.84	0	40	13.5
54.	clover	0.02	-	-	0.01	-50	0.004	-80	0.01	-50	-180	-60.0
55.	cotton	0.21	0.24	14	0.25	19	0.20	- 5	0.17	-19	10	2.4
56.	cucumber	0.31	0.11	65	0.16	-48	0.09	-71	0.07	-77	-261	-65.3
57.	cowpeas											
58.	eggplant	0.04	-	-	0.07	75	0.07	75	0.04	0	150	50.0

Table 19 Cont'd

		1	2	%	3	%	4	%	5	%	Σ%	$\bar{x}$%
59.	millet,'Starr Pearl'	0.53	0.57	8	0.55	4	0.53	0	0.50	- 6	6	1.4
60.	millet,'Brown	0.33	-	-	0.35	6	0.21	-36	0.26	-21	- 52	-17.2
61.	oats	0.37	0.20	-46	0.49	32	0.40	8	0.81	119	114	28.4
62.	okra	0.19	-	-	0.11	-42	0.07	-63	0.07	-63	-168	-56.1
63.	peanuts	0.62	0.45	-27	0.54	-13	0.52	-16	0.50	- 3	- 60	-14.9
64.	peas, blackeye	0.40	0.15	-63	0.18	-55	0.12	-70	0.14	-65	-253	-63.1
65.	pumpkin	0.26	-	-	0.34	31	0.23	-12	0.27	4	23	7.7
66.	rice,'Lebonett'	0.26	0.19	-27	0.26	0	0.19	-27	0.22	-15	- 69	-17.3
67.	rice,'Brazos'	0.22	0.20	- 9	0.27	23	0.19	-14	0.22	0	0	0
68.	rice,'Bluebett'	0.17	0.10	-41	0.14	18	0.16	- 6	0.14	-18	- 82	-20.6
69.	rice,'Labelle'	0.20	0.19	- 5	0.22	10	0.18	-10	0.22	10	5	1.3
70.	rice,'Star Bonnet'	0.18	0.17	- 6	0.20	11	0.13	-28	0.16	-11	- 33	- 8.3
71.	rhubarb	0.12	-	-	0.03	-75	0.02	-83	0.04	-67	-225	-75.0
72.	rye	0.55	0.57	4	0.50	0	0.55	0	0.55	0	- 5	- 1.4
73.	sorghum	1.18	0.31	-74	1.00	-15	0.95	-19	0.68	-42	-151	-37.7
74.	squash, Early Summer	0.32	0.13	-59	0.18	-44	0.10	-69	0.09	-72	-244	-60.9
75.	squash,'Prolific'	0.16	0.06	-63	0.10	-38	0.08	-50	0.10	-38	-188	-46.9
76.	squash,'Zucchini'	0.20	-	-	0.17	-15	0.13	-35	0.16	-20	- 70	-23.3
77.	squash, Acorn	0.14	-	-	0.11	-21	0.08	-43	0.07	-50	-114	38.1
78.	sudangrass	0.75	1.67	123	1.00	33	0.60	-20	1.16	55	191	47.7
79.	tomato	0.11	0.01	-91	0.01	-91	0.01	-91	0.01	-91	-364	-90.9
80.	watermelon	0.06	0.02	-67	0.03	-50	0.02	-67	0.02	-67	-250	-62.5
81.	Douglas-fir	0.07	-	-	0.07	0	0.05	-29	0.10	43	14	4.8
82.	sunflower	0.24	-	-	0.30	25	0.31	29	0.29	21	75	25.0

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in Section I.

Table20. Duncan's Multiple Range Test for Root Dry Weight differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
1.	asparagus	A	A	A	A	A
2.	carrots	A	A	A	A	A
3.	celery	B	A	B	B	B
4.	radish	B,A	A	B,A	B	B,A
5.	lettuce	A	A	A	A	A
6.	onion	B,A	B,A	B,A	B	A
7.	parsnip	A	A	A	A	A
8.	English peas	A	B	B	B	B
9.	wheat,'Wakeland'	A	A	A	A	A
10.	wheat,'CoCorit'	A	A	A	A	A
11.	wheat,'Cajeme'	B	B	A	B	B
12.	wheat,'Crane'	A	A	A	A	A
13.	wheat,'Inia 66R'	B	A	B	B	B,A
14.	wheat,'Jori'	B	B,A	A	B,A	A
15.	wheat,'SuperX'	C	C	A	B,A	B,C
16.	pine, slash	A	A	A	A	A
17.	pine, loblolly	A	A	A	A	A
18.	pine, lodgepole	A	A	A	B	B,A
19.	pine, ponderosa	A	B,A	B,C	C	B,C
20.	fir, noble	A	B,A	A	B	B
21.	fir, white	A	A	A	A	A
22.	barley,'Belle'	A	-	A	A	A
23.	barley,'Arivat'	A	-	B	B,A	B
24.	barley,'Hembar'	A	-	B	B	B
25.	broccoli	A	-	B	B	B
26.	brussel sprouts	A	-	B	B	B
27.	cabbage	A	-	B	B	B
28.	cauliflower	A	-	B	B	B
29.	chard	A	-	B	B	B
30.	collards	A	-	B	B	B
31.	kale	A	-	B	B	B
32.	kohlrabi	A	-	B	B	B
33.	mustard	A	-	A	B	B
34.	rutabega	A	-	B	B	B
35.	corn,'Silverqueen'	B,A	-	A	B,C	C
36.	corn, 'Tobelle'	A	-	B	B	B
37.	corn,'Hybrid XL380'	A	-	A	B	B
38.	corn,'Coker 71'	A	-	B,A	C	B,C
39.	grass,'Pensacola'	B,A	-	A	B	B,A
40.	grass,'Arg. Bahia'	A	-	A	A	A
41.	grass,'Bermuda'	A	-	A	A	A
42.	grass, carpet	A	-	B	B,A	-
43.	soybean,'Hardee'	A	-	B	B,A	B
44.	artichoke	B,A	-	B,A	A	B

Table 20 Con't.

	Species	Light Level 1	2	3	4	5
45.	bean, lima	B,A	-	A	B,A	B
46.	bean, garden	A	A	B,A	B	B
47.	bean, pinto	A	-	A	B	B
48.	bean,'Tenn. Flat'	A	-	B,A	B,A	B
49.	bell pepper	B,A	A	B	B	B,A
50.	butterpea	A	-	B	B	B
51.	cantelope,'Hales'	A	B	B	B	B
52.	cantelope, 'Honeydew'	A	B	B	B	B
53.	chufas	A	-	A	A	A
54.	clover	A	-	B,A	B	B
55.	cotton	B,A	A	A	B,A	B
56.	cucumber	A	C,B	B	C	C
57.	cowpeas	A	-	A	A	A
58.	eggplant	A	-	A	A	A
59.	millet,'Starr Pearl'	A	A	A	A	A
60.	millet,'Browntop'	A	-	A	A	A
61.	oats	B,A	B	B,A	B,A	A
62.	okra	A	-	B	B	B
63.	peanuts	A	A	A	A	A
64.	peas, blackeye	A	C,B	B	C	C,B
65.	pumpkin	B	-	A	B	B
66.	rice,'Lebonnet	A	A	A	A	A
67.	rice,'Brazos'	B,A	B,A	A	B	B,A
68.	rice,'Bluebett'	A	A	A	A	A
69.	rice,'Labelle'	A	A	A	A	A
70.	rice,'Star Bonnet'	A	A	A	A	A
71.	rhubarb	A	-	B	B	B
72.	rye	A	A	A	A	A
73.	sorghum	A	C	B,A	B,A	B,C
74.	squash, early summer	A	C,B	B	C	C
75.	squash,'Prolific'	A	B	B	B	B
76.	squash,'Zuccini'	A	-	B,A	B	B,A
77.	squash, acorn	A	-	B,A	B,C	C
78.	sudangrass	C,B	A	C,B	C	B
79.	tomato	A	B	B	B	B
80.	watermelon	A	C,B	B	C	C
81.	Douglas-fir	A	-	A	A	A
82.	sunflower	A	-	A	A	A

1/ Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 21. Comparison of the 5 UV-B radiation treatments for biomass or total dry weight (g) as to means, mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

UV-B Treatments[1], Mean Weights and % Differences[2]

	Species	1	2	%	3	%	4	%	5	%	Σ%	x̄%
1.	asparagus	0.09	0.08	-11	0.09	0	0.09	0	0.10	11	0	0
2.	carrots	0.62	0.67	8	0.82	32	0.65	5	0.67	8	53	13.3
3.	celery	0.46	0.80	74	0.56	22	0.43	- 7	0.50	9	98	24.5
4.	radish	0.48	0.56	17	0.68	42	0.36	-25	0.48	0	33	8.3
5.	lettuce	0.25	0.17	-32	0.19	-24	0.14	44	0.12	-52	-152	-38.0
6.	onion	0.13	0.13	0	0.14	8	0.10	-23	0.14	8	8	- 1.9
7.	parsnip	0.53	0.49	- 8	0.49	- 8	0.54	2	0.56	5	- 8	- 1.9
8.	English peas	0.78	1.98	154	0.79	1	1.06	36	0.69	-12	175	44.9
9.	wheat,'Wakeland'	0.74	0.94	27	1.00	35	0.86	16	0.90	22	100	25.0
10.	wheat,'CoCorit'	0.92	0.92	0	0.94	2	0.87	- 5	0.91	- 1	- 4	- 1.1
11.	wheat,'Cajeme'	0.78	0.82	5	1.04	33	0.86	10	0.72	- 8	41	10.3
12.	wheat,'Crane'	0.89	0.79	-11	0.94	6	0.80	-10	0.72	-19	- 35	- 8.7
13.	wheat,'Inia 66R'	0.95	1.10	16	1.02	7	0.91	- 4	1.01	6	25	6.3
14.	wheat,'Jori'	1.14	1.21	6	1.41	24	1.23	8	1.34	18	55	13.8
15.	wheat,'Super-X'	0.77	0.82	6	1.00	30	0.90	17	0.77	0	53	13.3
16.	pine, slash	0.99	0.92	- 7	0.80	-19	0.65	-34	0.77	-22	- 83	-20.7
17.	pine, loblolly	1.50	1.46	- 3	1.30	-13	1.09	-27	1.27	-15	- 59	-14.7
18.	pine, lodgepole	0.97	1.01	4	0.97	0	0.69	-29	0.88	- 9	- 34	- 8.5
19.	pine, ponderosa	1.59	1.62	2	1.27	-20	1.08	-32	1.25	-21	- 72	-17.9
20.	fir, noble	1.05	0.97	- 8	1.02	- 3	0.67	-36	0.81	-23	- 70	-17.4
21.	fir, white	0.31	0.69	123	3.32	971	0.55	77	0.43	39	1210	302.4
22.	barley,'Belle'	1.15	-	-	0.90	-22	1.01	-12	0.97	-16	- 50	-16.5
23.	barley,'Arivat'	1.26	-	-	0.91	-28	1.01	-20	0.87	-31	- 79	-26.2

Table 21. Cont'd

		1	2	%	3	%	4	%	5	%	Σ%	$\bar{x}$%
59.	millet,'Starr Pearl'	2.10	2.60	24	1.95	- 7	1.64	-22	2.02	- 4	- 9	- 2.3
60.	millet,'Browntop'	1.08	-	-	1.25	16	0.87	-19	1.00	- 7	- 11	- 3.7
61.	oats	1.28	0.74	-42	1.54	20	1.53	20	1.90	48	46	11.5
62.	okra	1.35	-	-	1.09	-19	0.86	-36	0.78	-42	- 98	-32.6
63.	peanuts	2.52	2.77	10	2.61	4	2.64	5	2.70	7	25	6.3
64.	peas, blackeye	2.25	1.00	-56	1.19	-47	0.89	-60	0.89	-60	-224	-55.9
65.	pumpkin	323	-	-	3.20	- 1	2.70	-16	2.63	-19	-36	-12.0
66.	rice,'Lebonett'	0.91	0.74	-19	0.95	4	0.72	-21	0.73	-20	- 55	-13.7
67.	rice,'Brazos'	0.80	0.73	- 9	0.98	23	0.71	-11	0.77	- 4	- 1	- 0.3
68.	rice,'Bluebett'	0.58	0.42	-28	0.51	-12	0,47	-19	0.50	-14	- 72	-18.1
69.	rice,'Labelle'	0.70	0.69	- 1	0.73	4	0.64	- 9	0.72	3	- 3	- 0.7
70.	rice,'Star Bonnet'	0.63	0.59	- 6	0.66	5	0.50	-21	0.57	-10	- 32	- 7.9
71.	rhubarb	1.07	-	-	0.51	-52	0.38	-64	0.28	-74	-191	-63.6
72.	rye	1.86	1.84	- 1	1.72	- 8	1.86	0	1.76	- 5	- 14	- 3.5
73.	sorghum	3.39	0.96	-72	2.94	-13	2.86	-16	2.04	-40	-140	-35.1
74.	squash, Early Summer	3.62	1.59	-56	1.86	-49	1.37	-62	1.08	-70	-237	-59.3
75.	squash,'Prolific'	1.62	0.78	-52	1.17	-28	1.01	-38	1.00	-38	-156	-38.9
76.	squash,'Zucchini'	2.10	-	-	1.55	-26	1.23	-41	1.14	-46	-113	-37.8
77.	squash, Acorn	1.07	-	-	0.90	-16	0.81	-24	0.60	-44	- 84	-28.0
78.	sudangrass	2.30	4.19	82	3.09	34	2.06	-10	3.15	37	143	35.8
79.	tomato	0.99	0.08	-92	0.13	-87	0.11	-89	0.07	-93	-361	-90.2
80.	watermelon	1.14	0.45	-61	0.62	-46	0.37	-68	0.36	-68	-242	-60.5
81.	Douglas-fir	0.40	-	-	0.41	3	0.40	0	0.46	15	18	5.8
82.	sunflower	1.67	-	-	1.74	4	1.70	2	1.81	8	14	4.8

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in Section I.

Table 21 Con't.

		1	2	%	3	%	4	%	5	%	Σ%	$\bar{x}$%
24.	barley,'Hembar'	1.41	-	-	0.88	-38	1.03	-27	0.93	-34	- 99	-32.9
25.	broccoli	0.67	-	-	0.26	-61	0.19	-72	0.19	-72	-204	-68.2
26.	brussels sprouts	0.47	-	-	0.24	-49	0.12	-74	0.17	-64	-187	-62.4
27.	cabbage	0.74	-	-	0.31	-58	0.27	-64	0.22	-70	-192	-64.0
28.	cauliflower	0.40	-	-	0.19	-53	0.14	-65	0.14	-65	-183	-60.8
29.	chard	0.30	-	-	0.12	-60	0.10	-67	0.07	-77	-203	-67.8
30.	collards	0.61	-	-	0.24	-61	0.28	-54	0.17	-72	-187	-62.3
31.	kale	0.57	-	-	0.30	-47	0.24	-58	0.21	-63	-168	-56.1
32.	kohlrabi	0.55	-	-	0.26	-53	0.18	-67	0.16	-71	-191	-63.6
33.	mustard	0.31	-	-	0.36	16	0.11	-65	0.10	-68	-116	-38.7
34.	rutabega	0.50	-	-	0.26	-48	0.20	-60	0.15	-70	-178	-59.3
35.	corn,'Silverqueen'	1.53	-	-	1.51	- 1	1.16	-24	1.09	-29	- 54	-18.1
36.	corn, 'Tobelle'	2.23	-	-	1.51	-32	1.34	-40	1.34	-40	-112	-37.4
37.	corn, Hybrid XL	2.22	-	-	2.18	- 2	1.39	-37	1.65	-26	-65	-21.6
38.	corn,'Coker 71'	2.89	-	-	1.72	-40	0.99	-66	1.38	-52	-158	-52.8
39.	grass,'Pensacola'	0.23	-	-	0.23	0	0.08	-65	0.13	-43	-109	-36.2
40.	grass,'Arg. Bahia'	0.20	-	-	0.15	-25	0.10	-50	0.13	-45	-120	-40.0
41.	grass,'Bermuda'	0.13	-	-	0.07	-46	0.21	62	0.15	15	-123	-41.0
42.	grass, carpet	0.14	-	-	0.05	-65	0.10	-29	0.10	-29	-123	-41.0
43.	soybean,'Hardee'	1.19	-	-	0.86	-28	0.82	-31	0.74	-38	- 97	-32.0
44.	artichoke	0.67	-	-	0.82	22	0.84	25	0.71	6	53	17.7
45.	bean, lima	1.94	-	-	1.81	-7	1.73	-11	1.45	-25	- 43	-14.3
46.	bean, garden	1.62	1.45	-10	1.46	-10	1.09	-33	1.00	-38	- 91	-22.8
47.	bean, pinto	2.04	-	-	1.85	- 9	1.69	-17	1.73	-15	- 42	-13.9
48.	bean,'Tenn. Flat'	1.74	-	-	1.65	- 5	1.60	- 8	1.46	-16	- 29	- 9.8
49.	bell pepper	0.83	1.22	47	0.79	- 5	0.83	0	0.80	- 4	39	9.6
50.	butterpea	1.72	-	-	1.33	-23	1.33	-23	1.23	-28	-74	-24.6
51.	cantelope, 'Hales'	1.32	0.41	-69	0.50	-62	0.32	-76	0.38	-71	-278	-69.5
52.	cantelope, 'Honeydew'	1.53	0.34	-78	0.49	-68	0.40	-74	0.34	-78	-297	-74.3
53.	chufas	1.81	-	-	2.38	31	2.41	33	2.08	15	80	26.5
54.	clover	0.20	-	-	0.12	-40	0.03	-85	0.06	-70	-195	-65.0
55.	cotton	1.76	1.98	13	1.79	2	1.77	1	1.57	-11	4	1.0
56.	cucumber	1.97	1.15	042	1.24	-37	0.95	-52	0.85	-57	-187	-46.8
57.	cowpeas											
58.	eggplant	0.42	-	-	0.51	21	0.44	5	0.33	-21	5	1.6

Table 22. Duncan's Multiple Range Test for Total Dry Weight differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
1.	asparagus	A	A	A	A	A
2.	carrots	B	B	A	B	B
3.	celery	B	A	B	B	B
4.	radish	A	A	A	A	A
5.	lettuce	A	A	A	A	A
6.	onion	A	A	A	A	A
7.	parsnip	A	A	A	A	A
8.	English peas	B	A	B	B,A	B
9.	wheat,'Wakeland'	B	B,A	A	B,A	B,A
10.	wheat,'Coorit'	A	A	A	A	A
11.	wheat,'Cajeme'	B	B	A	B	B
12.	wheat,'Crane'	A	B,A	A	B,A	B
13.	wheat,'Inia 66R'	B,A	A	B,A	B	B,A
14.	wheat,'Jori'	B	B,A	A	B,A	B,A
15.	wheat,'SuperX'	B	B	A	B,A	B
16.	pine, slash	A	B,A	B,A	B	B,A
17.	pine, loblolly	A	A	B,A	B	B,A
18.	pine, lodgepole	A	A	A	B	A
19.	pine, ponderosa	A	A	B	B	B
20.	fir, noble	A	A	A	B	B
21.	fir, white	A	A	A	A	A
22.	barley,'Belle'	A	-	B	B,A	B,A
23.	barley,'Arivat'	A	-	B	B,A	B
24.	barley,'Hembar'	A	-	B	B	B
25.	broccoli	A	-	B	B	B
26.	brussel sprouts	A	-	B	C	C,B
27.	cabbage	A	-	B	B	B
28.	cauliflower	A	-	B	B	B
29.	chard	A	-	B	B	B
30.	collards	A	-	B	B	B
31.	kale	A	-	B	B	B
32.	kohlrabi	A	-	B	C,B	C
33.	mustard	A	-	A	B	B
34.	rutabega	A	-	B	B	B
35.	corn,'Silverqueen'	A	-	A	A	A
36.	corn, 'Tobelle'	A	-	B	B	B
37.	corn,'Hybrid XL380'	A	-	A	B	B
38.	corn,'Coker 71'	A	-	B,A	B	B
39.	grass,'Pensacola'	A	-	A	A	A
40.	grass,'Arg. Bahia'	A	-	A	A	A
41.	grass,'Bermuda'	A	-	A	A	A
42.	grass, carpet	A	-	A	A	-
43.	soybean,'Hardee'	A	-	A	A	A
44.	artichoke	B,A	-	B,A	A	B

Table 22 Con't.

		Light Level				
	Species	1	2	3	4	5
45.	bean, lima	A	-	B,A	B	C
46.	bean, garden	A	A	A	B	B
47.	bean, pinto	A	-	B	B	B
48.	bean,'Tenn. Flat'	A	-	B,A	B,A	B
49.	bell pepper	B	A	B	B	B
50.	butterpea	A	-	B	B	B
51.	cantelope,'Hales'	A	B	B	B	B
52.	cantelope, 'Honeydew'	A	B	B	B	B
53.	chufas	A	-	A	A	A
54.	clover	A	-	B,A	B	B
55.	cotton	B,A	A	B,A	B,A	B
56.	cucumber	A	B	B	C,B	C
57.	cowpeas	A	-	A	A	A
58.	eggplant	A	-	A	A	A
59.	millet,'Starr Pearl'	A	A	A	A	A
60.	millet,'Browntop'	A	-	A	A	A
61.	oats	B,A	B	B,A	B,A	A
62.	okra	A	-	B,A	B	B
63.	peanuts	A	A	A	A	A
64.	peas, blackeye	A	B	B	B	B
65.	pumpkin	A	-	A	B	B
66.	rice,'Lebonette'	A	B	A	B	B,A
67.	rice,'Brazos'	B,A	B,A	A	B	B,A
68.	rice,'Bluebett'	A	A	A	A	A
69.	rice,'Labelle'	A	A	A	A	A
70.	rice,'Star Bonnet'	A	A	A	A	A
71.	rhubarb	A	-	B	B	B
72.	rye	A	A	A	A	A
73.	sorghum	A	C	B,A	B,A	B,C
74.	squash, early summer	A	C,B	B	C,D	D
75.	squash,'Prolific'	A	B	B	B	B
76.	squash,'Zuccini'	A	-	B	C	C
77.	squash, acorn	A	-	B	C,B	C
78.	sudangrass	C,B	A	B	C	B
79.	tomato	A	B	B	B	B
80.	watermelon	A	C,B	B	C	C
81.	Douglas-fir	A	-	A	A	A
82.	sunflower	A	-	A	A	A

1/ Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 23. Comparison of the 5 UV-B radiation treatments for biomass partitioning into % leaves as to means, mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

UV-B Treatments[1], Mean Weights and % Differences[2]

	Species	1	2	%	3	%	4	%	5	%	Σ%	x̄%
1.	asparagus	76	73	- 4	76	0	74	- 3	72	- 5	- 12	- 3.0
2.	carrots	88	86	- 2	87	- 1	85	- 3	87	- 1	- 8	- 2.0
3.	celery	85	81	- 5	80	- 6	83	- 2	82	- 4	- 16	- 4.1
4.	radish	55	59	7	63	15	67	22	60	9	53	13.2
5.	lettuce	84	87	4	89	6	84	0	87	4	13	3.3
6.	onion	75	94	- 1	77	3	80	7	71	- 5	3	0.7
7.	parsnip	80	85	6	86	8	84	5	85	6	25	6.3
8.	English peas	46	65	41	60	30	60	30	55	20	122	30.4
9.	wheat,'Wakeland'	41	52	27	51	24	50	22	47	15	88	22.0
10.	wheat,'CoCorit'	51	49	- 4	52	2	50	- 2	47	- 8	- 12	- 2.9
11.	wheat,'Cajeme'	53	49	- 8	47	-11	49	- 8	46	-13	- 40	- 9.9
12.	wheat,'Crane'	57	52	- 9	52	- 9	51	-11	49	-14	- 42	-10.5
13.	wheat,'Inia 66R'	54	50	- 7	57	6	54	0	51	- 6	- 7	- 1.9
14.	wheat,'Jori'	55	52	- 5	53	- 4	51	- 7	51	- 7	- 24	- 5.9
15.	wheat,'Super-X'	54	56	4	53	- 2	51	- 6	50	- 7	- 11	- 2.8
16.	pine, slash	87	84	- 3	85	- 2	78	-10	86	- 1	- 17	- 4.3
17.	pine, loblolly	82	81	- 1	81	- 1	80	- 1	82	0	- 5	- 1.2
18.	pine, lodgepole	77	77	0	77	0	79	3	78	1	4	1.0
19.	pine, ponderosa	74	76	3	76	3	76	3	77	4	12	3.0
20.	fir, noble	81	83	2	81	0	79	- 2	85	5	5	1.2
21.	fir, white	80	78	- 3	71	-11	79	- 1	86	4	- 8	- 1.9
22.	barley,'Belle'	60	-	-	57	- 5	57	- 5	56	- 7	- 17	- 5.6
23.	barley,'Arivat'	49	-	-	49	0	46	- 6	52	6	0	0

Table 23 Cont'd

		1	2	%	3	%	4	%	5	%	Σ%	$\bar{x}$%
24.	barley,'Hembar'	58	-	-	53	- 9	54	- 7	58	0	- 16	- 5.2
25.	broccoli	80	-	-	90	13	91	14	89	11	38	12.5
26.	brussels sprouts	88	-	-	90	2	88	0	86	- 2	0	0
27.	cabbage	82	-	-	88	7	87	6	90	10	23	7.7
28.	cauliflower	88	-	-	93	6	95	8	90	2	16	5.3
29.	chard	93	-	-	92	- 1	94	1	91	- 2	2	- 0.7
30.	collards	83	-	-	87	5	92	11	88	6	22	7.2
31.	kale	84	-	-	86	2	87	4	87	4	10	3.2
32.	kohlrabi	82	-	-	89	9	89	9	87	5	23	7.7
33.	mustard	91	-	-	91	0	93	2	96	5	8	2.6
34.	rutabega	84	-	-	90	7	88	5	92	10	21	7.1
35.	corn,'Silverqueen'	63	-	-	61	- 3	63	0	64	2	- 2	- 0.5
36.	corn, 'Tobelle'	54	-	-	58	7	63	17	60	11	35	11.7
37.	corn,'Hybrid XL380'	53	-	-	49	- 8	55	4	56	6	2	0.6
38.	corn,'Coker 71'	70	-	-	52	-26	52	-26	56	-20	- 71	-23.8
39.	grass,'Pensacola'	88	-	-	83	- 6	80	- 9	81	- 8	- 23	- 7.6
40.	grass,'Arg. Bahia'	80	-	-	82	9	80	0	77	- 4	5	1.7
41.	grass,'Bermuda'	85	-	-	86	1	86	1	93	9	12	3.9
42.	grass, carpet	79	-	-	80	1	80	1	80	1	4	1.3
43.	soybean,'Hardee'	75	-	-	73	- 3	71	- 5	73	- 3	- 11	- 3.6
44.	artichoke	57	-	-	50	-12	57	0	46	-19	- 31	-10.3
45.	bean, lima	50	-	-	49	- 2	47	- 6	48	- 4	- 12	- 4.0
46.	bean, garden	52	50	- 4	55	6	53	2	56	8	12	3.0
47.	bean, pinto	48	-	-	47	- 2	50	4	52	8	10	3.3
48.	bean,'Tenn. Flat'	51	-	-	51	0	53	4	53	4	8	2.7
49.	bell pepper	57	56	- 2	62	9	60	5	64	12	24	6.0
50.	butterpea	45	-	-	53	18	52	16	52	16	50	16.7
51.	cantelope, 'Hales'	56	71	27	70	25	75	34	74	32	118	29.5
52.	cantelope, 'Honeydew'	51	76	49	72	41	77	51	76	49	190	47.5
53.	chufas	56	-	-	57	2	55	- 2	58	4	4	1.2
54.	clover	70	-	-	75	7	59	-16	72	29	36	12.0
55.	cotton	47	47	0	47	0	52	11	52	11	22	5.5
56.	cucumber	51	69	35	65	27	72	41	75	47	150	37.5
57.	cowpeas	93	-	-	92	- 1	92	- 1	92	- 1	- 3	- 1.0
58.	eggplant	51	-	-	57	12	62	22	62	22	55	18.3

Table 23 Cont'd

		1	2	%	3	%	4	%	5	%	Σ%	$\bar{x}$%
59.	millet,'Starr Pearl'	76	78	3	72	- 5	68	-11	76	0	- 13	- 3.3
60.	millet,'Browntop'	73	-	-	76	4	74	1	78	7	12	4.1
61.	oats	71	74	4	69	- 3	74	4	66	- 7	- 1	- 0.4
62.	okra	50	-	-	51	2	49	- 2	52	4	4	1.3
63.	peanuts	38	40	5	39	3	39	3	41	8	18	4.6
64.	peas, blackeye	54	57	6	55	2	53	- 2	53	- 2	4	0.9
65.	pumpkin	44	-	-	46	5	50	14	48	9	27	9.1
66.	rice,'Lebonett'	72	75	4	73	1	74	3	70	- 3	6	1.4
67.	rice,'Brazos'	73	73	0	73	0	73	0	72	- 1	- 1	- 0.3
68.	rice,'Bluebett'	72	77	7	71	- 1	70	- 3	73	1	4	1.0
69.	rice,'Labelle'	71	73	3	70	- 1	72	1	70	- 1	1	0.4
70.	rice,'Star Bonnet'	73	71	- 3	73	0	77	5	71	- 3	0	0
71.	rhubarb	66	-	-	68	3	75	14	66	0	17	5.6
72.	rye	71	70	- 1	71	0	71	0	70	- 1	- 3	- 0.7
73.	sorghum	66	69	5	67	2	69	5	67	2	12	3.0
74.	squash, Early Summer	45	61	36	57	27	66	47	68	51	160	40.0
75.	squash,'Prolific'	53	73	38	62	17	66	25	68	28	108	26.9
76.	squash,'Zucchini'	50	-	-	62	24	68	36	63	26	86	28.7
77.	squash, Acorn	56	-	-	66	18	71	27	70	25	70	23.2
78.	sudangrass	68	60	-12	67	- 1	71	4	65	- 4	- 13	- 3.3
79.	tomato	52	59	13	56	8	69	33	63	21	75	18.8
80.	watermelon	61	72	18	69	13	76	25	75	23	79	19.7
81.	Douglas-fir	82	-	-	84	2	89	9	82	0	11	3.7
82.	sunflower	44	-	-	45	2	48	9	46	5	16	5.3

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in Section I.

Table 24. Duncan's Multiple Range Test for Percent Leaf differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
1.	asparagus	A	A	A	A	A
2.	carrots	B	B	A	B	B
3.	celery	B	A	B	B	B
4.	radish	A	A	A	A	A
5.	lettuce	A	A	A	A	A
6.	onion	A	A	A	A	A
7.	parsnip	A	A	A	A	A
8.	English peas	B	A	B	B,A	B
9.	wheat,' akeland'	A	A	A	A	A
10.	wheat,'CoCorit'	A	B,A	A	B,A	B
11.	wheat,'Cajeme'	A	B,A	B	B,A	B
12.	wheat,'Crane'	A	B,A	B,A	B	B
13.	wheat,'Inia 66R'	B,A	B	A	B,A	B,A
14.	wheat,'Jori'	A	A	A	A	A
15.	wheat,'SuperX'	A	A	A	A	A
16.	pine, slash	A	A	B,A	B	B,A
17.	pine, loblolly	A	A	A	B	A
18.	pine, lodgepole	A	A	A	B	A
19.	pine, ponderosa	B,A	A	B,C	C	B,C
20.	fir, noble	A	B,A	B,A	C	B
21.	fir, white	A	A	A	A	A
22.	barley,'Belle'	A	-	A	A	A
23.	barley,'Arivat'	A	-	A	A	A
24.	barley,'Hembar'	A	-	B	B,A	B,A
25.	broccoli	A	-	B	B	B
26.	brussel sprouts	A	-	B	C	C
27.	cabbage	A	-	B	B	B
28.	cauliflower	A	-	B	B	B
29.	chard	A	-	B	B	B
30.	collards	A	-	B	B,A	B
31.	kale	A	-	B	B	B
32.	kohlrabi	A	-	B	C,B	C
33.	mustard	A	-	A	B	B
34.	rutabega	A	-	B	B	B
35.	corn,'Silverqueen'	A	-	A	A	A
36.	corn, 'Tobelle'	A	-	A	A	A
37.	corn,'Hybrid XL380'	A	-	A	A	A
38.	corn,'Coker 71'	A	-	A	A	A
39.	grass,'Pensacola'	A	-	B,A	B	B,A
40.	grass,'Arg. Bahia'	A	-	A	A	A
41.	grass,'Bermuda'	A	-	A	A	A
42.	grass, carpet	A	-	A	A	-
43.	soybean,'Hardee'	A	-	A	A	A
44.	artichoke	A	-	A	A	A

Table 24 Con't.

	Species	Light Level 1	2	3	4	5
45.	bean, lima	A	-	A	A	A
46.	bean, garden	A	A	A	A	A
47.	bean, pinto	C,B	-	C	B	A
48.	bean,'Tenn. Flat'	A	-	A	A	A
49.	bell pepper	B	B	B,A	B,A	A
50.	butterpea	B	-	A	A	A
51.	cantelope,'Hales'	B	A	A	A	A
52.	cantelope, 'Honeydew'	C	B,A	B	A	A
53.	chufas	A	-	A	A	A
54.	clover	B	-	B,A	B,A	A
55.	cotton	B	B	B	A	B,A
56.	cucumber	C	B,A	B	A	A
57.	cowpeas	A	-	A	A	A
58.	eggplant	A	-	A	A	A
59.	millet,'Starr Pearl'	A	A	A	A	A
60.	millet,	A	-	A	A	A
61.	oats	A	A	A	A	A
62.	okra	A	-	A	A	A
63.	peanuts	B	A	B,A	B,A	A
64.	peas, blackeye	B	A	B,A	B	B
65.	pumpkin	A	-	A	A	A
66.	rice,'Lebonette'	A	A	A	A	A
67.	rice,'Brazos'	A	A	A	A	A
68.	rice,'Bluebett'	A	A	A	A	A
69.	rice,'Labelle'	A	A	A	A	A
70.	rice,'Star Bonnet'	A	A	A	A	A
71.	rhubarb	A	-	A	A	A
72.	rye	A	A	A	A	A
73.	sorghum	A	A	A	A	A
74.	squash, early summer	D	B,C	C	B,A	A
75.	squash,'Prolific'	C	A	B	A	A
76.	squash,'Zuccini'	B	-	A	A	A
77.	squash, acorn	C	-	B	A	A
78.	sudangrass	B,A	C	B	A	B
79.	tomato	B	B	B	A	B
80.	watermelon	B	A	A	A	A
81.	Douglas-fir	B	-	B	A	B
82.	sunflower	A	-	A	A	A

1/ Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 25. Comparison of the 5 UV-B radiation treatments for biomass partitioning into % stems as to means, mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

		UV-B Treatments[1], Mean Weights and % Differences[2]										
	Species	1	2	%	3	%	4	%	5	%	Σ%	x̄%
45.	bean, lima	35	-	-	33	- 6	37	6	35	0	0	0
46.	bean, garden	27	27	0	27	0	30	11	27	0	11	2.8
47.	bean, pinto	29	-	-	29	0	30	3	29	0	3	1.0
48.	bean, Tenn.flat	28	-	-	28	-	28	0	29	4	4	1.3
49.	bell pepper	20	25	25	22	10	24	20	19	- 5	50	12.5
50.	butter pea	39	-	-	32	-18	32	-18	33	-15	- 51	-17.0
51.	cantelope 'Hales'	33	22	-33	20	-39	16	-52	16	-52	-176	-44.0
52.	cantelope,'Honeydew'	35	15	-57	20	-43	15	-57	15	-57	-214	-53.5
54.	clover	20	-	-	17	-15	29	45	14	-30	0	0
55.	cotton	41	41	0	39	- 5	37	-10	37	-10	- 25	- 6.3
56.	cucumber	33	22	-33	22	-33	19	-42	16	-52	-160	-40.0
58.	eggplant	36	-	-	29	-19	24	-33	25	-31	- 83	-27.8
62.	okra	37	-	-	39	5	43	16	40	8	30	9.9
63.	peanuts	30	44	47	40	33	42	40	38	27	147	36.7
64.	peas	29	29	0	30	3	34	17	32	10	31	7.8
65.	pumpkin	47	-	-	44	- 6	41	-13	42	-11	- 30	- 9.9
71.	rhubarb	25	-	-	25	0	18	-28	24	- 4	- 32	-10.7
74.	squash Early Summer	47	31	-34	33	-30	27	-43	25	-48	-153	-38.3
75.	squash 'Prolific'	37	19	-49	29	-22	26	-30	21	-43	-143	-35.8
76.	squash 'Zucchini'	40	-	-	27	-33	22	-45	22	-45	-123	-40.8
77.	squash Acorn	31	-	-	22	-29	20	-35	19	-39	-103	-34.4
79.	tomato	36	36	0	35	- 3	24	-33	27	-25	- 61	-15.3
80.	watermelon	34	23	-32	25	-26	18	-47	20	-41	-147	-36.8
82.	sunflower	43	-	-	38	-12	36	-16	38	-12	- 40	-13.2

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in section I.

Table 26. Duncan's Multiple Range Test for % Stem differences among UV-B irradiation enhancement levels at the Phytotron[1/]

		Light Level				
	Species	1	2	3	4	5
45.	bean, lima	B,A	-	B	A	B,A
46.	bean, garden	A	A	A	A	A
47.	bean, pinto	A	-	A	A	A
48.	bean,'Tenn. Flat'	A	-	A	A	A
49.	bell pepper	B,C	A	B,C	B,A	C
50.	butterpea	A	-	B	B	B
51.	cantelope,'Hales'	A	B	B	B	B
52.	cantelope, 'Honeydew'	A	C,B	B	C	C
53.	chufas	A	-	B	C	D
54.	clover	A	-	B,A	B,A	B
55.	cotton	A	A	B,A	B	B,A
56.	cucumber	A	C,B	B	C,B	C
57.	cowpeas	A	-	B	C	D
58.	eggplant	A	-	B,A	B	B,A
59.	millet,'Starr Pearl'	A	E	B	C	D
60.	millet,'Browntop'	A	-	B	C	D
61.	oats	A	E	B	C	D
62.	okra	B	-	B,A	A	A
63.	peanuts	B	A	B,A	B,A	B
64.	peas, blackeye	C	B,C	B,C	A	B,A
65.	pumpkin	A	-	B,A	B,A	B
66.	rice,'Lebonette'	A	E	B	C	D
67.	rice,'Brazos'	A	E	B	C	D
68.	rice,'Bluebett'	A	E	B	C	D
69.	rice,'Labelle'	A	E	B	C	D
70.	rice,'Star Bonnet'	A	E	B	C	D
71.	rhubarb	A	-	A	A	A
72.	rye	A	E	B	C	D
73.	sorghum	A	E	B	C	D
74.	squash, early summer	A	B	C,B	C,B	C
75.	squash,'Prolific'	A	B,C	B,A	B	C
76.	squash,'Zuccini'	A	-	B	C,B	C
77.	squash, acorn	A	-	B	B	B
78.	sudangrass	A	E	B	C	D
79.	tomato	B,A,C	A	B,A	C	B,C
80.	watermelon	A	B	B	B	B
81.	Douglas-fir	A	-	B	C	D
82.	sunflower	A	-	B	B	B

[1/] Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 27. Comparison of the 5 UV-B radiation treatments for biomass partitioning into % roots as to means, mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

UV-B Treatments[1], Mean Weights and % Differences[2]

	Species	1	2	%	3	%	4	%	5	%	Σ%	x̄%
1.	asparagus	24	27	13	24	0	26	8	28	17	38	9.4
2.	carrots	12	14	17	13	8	15	25	13	8	58	14.6
3.	celery	15	19	27	20	33	17	13	18	20	93	23.3
4.	radish	45	41	- 9	37	-18	33	-27	40	-11	- 64	-16.1
5.	lettuce	16	13	-19	11	-31	16	0	13	-19	- 69	-17.2
6.	onion	25	26	4	23	- 8	20	-20	29	16	- 8	- 2.0
7.	parsnip	20	15	-25	14	-30	16	-20	15	-25	-100	-25.0
8.	English peas	54	35	-35	40	-26	40	-26	45	-17	-104	-25.9
9.	wheat,'Wakeland'	59	48	-19	49	-17	50	-15	53	-10	- 61	-15.3
10.	wheat,'CoCorit'	49	51	4	48	- 2	50	2	53	8	12	3.1
11.	wheat,'Cajeme'	47	51	9	53	13	51	9	54	15	45	11.2
12.	wheat,'Crane'	43	48	12	48	12	49	14	51	19	56	14.0
13.	wheat,'Inia 66R'	46	50	9	43	- 7	46	0	49	7	9	2.2
14.	wheat,'Jori'	45	48	7	47	4	49	9	49	9	29	7.2
15.	wheat,'Super-X'	46	44	- 4	47	2	49	7	50	9	13	3.3
16.	pine, slash	13	16	23	15	15	22	69	14	8	115	28.8
17.	pine, loblolly	18	19	6	19	6	20	11	18	0	22	5.6
18.	pine, lodgepole	23	23	0	23	0	21	- 9	22	- 4	- 13	- 3.3
19.	pine, ponderosa	26	24	- 8	24	- 8	24	- 8	23	-12	- 35	- 8.7
20.	fir, noble	19	17	-11	19	0	21	11	15	-21	- 21	- 5.3
21.	fir, white	20	22	10	29	45	21	5	14	-30	30	7.5
22.	barley,'Belle'	40	-	-	43	8	43	8	44	10	25	8.3
23.	barley,'Arivat'	51	-	-	51	0	54	6	48	- 6	0	0

Table 27. Cont'd

		1	2	%	3	%	4	%	5	%	Σ%	$\bar{x}$%
59.	millet,'Starr Pearl'	24	22	- 8	28	17	32	33	24	0	42	10.4
60.	millet,'Browntop'	27	-	-	24	-11	26	- 4	22	-19	- 33	-11.1
61.	oats	29	26	-10	31	7	26	-10	34	17	3	0.9
62.	okra	13	-	-	10	-23	7	-46	8	-38	-108	-35.9
63.	peanuts	24	16	-33	21	-13	19	-21	22	- 8	- 75	-18.8
64.	peas, blackeye	18	15	-17	15	-17	13	-28	15	-17	- 78	-19.4
65.	pumpkin	9	-	-	10	11	9	0	10	11	22	7.4
66.	rice,'Lebonett'	28	25	-11	27	- 4	26	- 7	30	7	- 14	- 3.6
67.	rice,'Brazos'	27	27	0	27	0	27	-	28	4	4	0.9
68.	rice,'Bluebett'	28	23	-18	29	4	30	7	27	- 4	- 11	- 2.7
69.	rice,'Labelle'	29	27	- 7	30	3	28	- 3	30	3	- 3	- 0.9
70.	rice,'Star Bonnet'	27	29	7	27	0	23	-15	29	7	0	0
71.	rhubarb	9	-	-	7	-22	7	-22	9	0	- 44	-14.8
72.	rye	29	30	3	29	0	29	0	39	3	7	1.7
73.	sorghum	34	31	- 9	33	- 3	31	- 9	33	- 3	- 24	- 5.9
74.	squash, Early Summer	9	8	-11	9	0	7	-22	7	-22	- 56	-13.9
75.	squash,'Prolific'	10	7	-30	9	-10	8	-20	10	0	- 60	-15.0
76.	squash,'Zucchini'	10	-	-	11	10	10	0	15	50	60	20.0
77.	squash, Acorn	13	-	-	12	- 8	9	-31	11	-15	- 54	-17.9
78.	sudangrass	32	40	25	33	3	29	- 9	35	9	28	7.0
79.	tomato	11	5	-55	9	-18	7	-36	10	- 9	-118	-29.5
80.	watermelon	5	5	0	6	20	6	20	5	0	40	10.0
81.	Douglas-fir	18	-	-	16	-11	11	-39	18	0	- 50	-16.7
82.	sunflower	13	-	-	16	23	16	23	15	15	62	20.5

[1] Means of plant replicates explained in methods section.

[2] UV-B enhancement levels 1 to 5 defined in Section I.

Table 28. Duncan's Multiple Range Test for Percent Root differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
1.	asparagus	A	A	A	A	A
2.	carrots	B,A	B,A	B	A	B,A
3.	celery	A	B	A	A	A
4.	radish	A	A	A	A	A
5.	lettuce	A	A	A	A	A
6.	onion	A	A	A	A	A
7.	parsnip	A	A	A	A	A
8.	English peas	A	B	A	B,A	A
9.	wheat,'Wakeland'	A	A	A	A	A
10.	wheat,'CoCorit'	B	B,A	B	B,A	A
11.	wheat,'Cajeme'	B	B,A	A	B,A	A
12.	wheat,'Crane'	B	B,A	B,A	A	A
13.	wheat,'Inia 66R'	B,A	A	B	B,A	B,A
14.	wheat,'Jori'	A	A	A	A	A
15.	wheat,'SuperX'	A	A	A	A	A
16.	pine, slash	B	B	B,A	A	B,A
17.	pine, loblolly	B	B	B	A	B
18.	pine, lodgepole	B	B	B	A	B
19.	pine, ponderosa	B,C	C	B,A	A	B,A
20.	fir, noble	C	C,B	C,B	A	B
21.	fir, white	A	A	A	A	A
22.	barley,'Belle'	A	-	A	A	A
23.	barley,'Arivat'	A	-	A	A	A
24.	barley,'Hembar'	B	-	A	B,A	B,A
25.	broccoli	B	-	A	A	A
26.	brussel sprouts	C	-	B	A	A
27.	cabbage	B	-	A	A	A
28.	cauliflower	B	-	A	A	A
29.	chard	B	-	A	A	A
30.	collards	B	-	A	B,A	A
31.	kale	B	-	A	A	A
32.	kohlrabi	C	-	B	B,A	A
33.	mustard	B	-	B	A	A
34.	rutabega	A	-	A	A	A
35.	corn,'Silverqueen'	A	-	A	A	A
36.	corn, 'Tobelle'	A	-	A	A	A
37.	corn,'Hybrid XL380'	A	-	A	A	A
38.	corn,'Coker 71'	A	-	A	A	A
39.	grass,'Pensacola'	B	-	B,A	A	B,A
40.	grass,'Arg. Bahia'	A	-	A	A	A
41.	grass,'Bermuda'	A	-	A	A	A
42.	grass, carpet	A	-	A	A	-
43.	soybean,'Hardee'	A	-	A	A	A
44.	artichoke	A	-	A	A	A

Table 28 Con't.

	Species	Light Level 1	2	3	4	5
45.	bean, lima	A	-	A	A	A
46.	bean, garden	B,A	A	B	B	B
47.	bean, pinto	A	-	A	B	B
48.	bean,'Tenn. Flat'	A	-	A	A	A
49.	bell pepper	A	A	A	A	A
50.	butterpea	A	-	A	A	A
51.	cantelope,'Hales'	A	B	B,A	B,A	B,A
52.	cantelope, 'Honeydew'	A	B	B	B	B
53.	chufas	A	-	A	A	A
54.	clover	A	-	A	A	A
55.	cotton	B,A	B,A	A	B	B
56.	cucumber	A	C	B	C	C
57.	cowpeas	A	-	A	A	A
58.	eggplant	B	-	B,A	A	B,A
59.	millet,'Starr Pearl'	A	A	A	A	A
60.	millet,'Browntop'	A	-	A	A	A
61.	oats	A	A	A	A	A
62.	okra	A	-	B	B	B
63.	peanuts	A	B	B,A	B,A	A
64.	peas, blackeye	A	B,A	B,A	B	B
65.	pumpkin	A	-	A	A	A
66.	rice,'Lebonette'	A	A	A	A	A
67.	rice,'Brazos'	A	A	A	A	A
68.	rice,'Kuebett'	A	A	A	A	A
69.	rice,'Labelle'	A	A	A	A	A
70.	rice,'Star Bonnet'	A	A	A	A	A
71.	rhubarb	A	-	A	A	A
72.	rye	A	A	A	A	A
73.	sorghum	A	A	A	A	A
74.	squash,'early summer'	B	B,A	A	B,A	B,A
75.	squash,'Prolific'	B	B,A	B	B	A
76.	squash,'Zuccini'	C	-	B	B	A
77.	squash, acorn	B,A	-	A	B	A
78.	sudangrass	C,B	A	B	C	B
79.	tomato	B,A	B	B,A	A	A
80.	watermelon	B	B,A	B,A	A	B,A
81.	Douglas-fir	A	-	A	B	A
82.	sunflower	B	-	A	A	B,A

1/ Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 29. Comparison of the 5 UV-B radiation treatments for leaf area (cm^2) as to means, means % difference from control for each and average mean percent difference of all treatments vs. the mylar control.

UV-B Treatments[1], and % Differences[2]

	Species	1	2	%	3	%	4	%	5	%	Σ %	$\bar{x}$ %
1.	asparagus	9	9	0	11	22	8	-11	11	22	33	8.3
2.	carrots	117	99	-15	127	9	98	-16	106	-9	-31	-7.8
3.	celery	101	124	23	100	-1	83	-18	85	-16	-12	-3.0
4.	radish	77	91	18	78	-1	67	-13	81	5	11	2.8
5.	lettuce	124	102	-18	97	-22	79	-36	86	-31	107	26.8
6.	onion	16	17	6	17	6	15	-6	13	-19	-13	-3.3
7.	parsnip	117	116	-1	126	8	114	-3	133	14	18	4.5
8.	English peas	94	93	-1	83	-12	68	-28	75	-20	-61	-15.3
9.	wheat, 'Wakeland'	107	107	0	113	6	88	-18	79	-26	-38	-9.5
10.	wheat, 'CoCorit'	98	88	-10	91	-7	78	-20	72	-27	-64	-16.0
11.	wheat, 'Cajame'	96	95	-1	112	17	98	2	72	-25	-7	-1.8
12.	wheat, 'Crane'	108	81	-25	94	-13	84	-22	71	-34	-94	-23.5
13.	wheat, 'Inia 66R'	118	114	-3	120	2	112	-5	96	-19	-25	-6.3
14.	wheat, 'Jori'	113	106	-6	141	25	111	-2	106	-6	11	-2.8
15.	wheat, 'Super-X'	95	105	11	109	15	96	1	73	-23	4	1.0
16.	pine, slash	56	48	-14	43	-23	38	-32	44	-21	-90	-22.5
17.	pine, loblolly	64	72	13	60	-6	53	-17	58	-9	-19	-4.8
18.	pine, lodgepole	51	53	4	50	-2	36	-29	47	-8	-35	-8.8
19.	pine, ponderosa	61	67	10	48	-21	44	-28	52	-15	-54	-13.5
20.	fir, noble	53	56	6	47	-11	34	-36	42	-21	-62	-15.5
21.	fir, white	14	30	114	25	79	23	64	21	50	307	76.8
22.	barley, 'Belle'	156	--	--	125	-20	169	8	122	-22	-34	-11.3
23.	barley, 'Arivat'	124	--	--	113	-9	126	2	112	-10	-17	-5.7

Table 29. Con't.

		1	2	%	3	%	4	%	5	%	Σ %	$\bar{x}$ %
24.	barley, 'Hembar'	161	--	--	96	-40	141	-12	112	-30	-82	-27.3
25.	broccoli	148	--	---	69	-53	50	-66	54	-64	-183	-61.0
26.	brussel sprouts	131	--	--	60	-54	29	-78	44	-66	-198	-66.0
27.	cabbage	189	--	--	75	-60	66	-65	63	-67	-192	-64.0
28.	cauliflower	92	--	--	45	-51	35	-62	35	-62	-175	-58.3
29.	chard	95	--	--	38	-60	29	-69	25	-74	-203	-67.7
30.	collards	120	--	--	64	-47	53	-56	45	-63	-166	-55.3
31.	kale	133	--	--	83	-38	65	-51	60	-55	-144	-48.0
32.	kohlrabi	136	--	--	72	-47	59	-57	44	-68	-172	-57.3
33.	mustard	128	--	--	131	2	33	-74	35	-73	-145	-48.3
34.	rutabega	174	--	--	83	-52	55	-68	45	-74	-194	-64.7
35.	corn, 'Silverqueen'	306	--	--	245	-20	233	-24	216	-29	-73	-24.3
36.	corn, 'Tobelle'	401	--	--	254	-37	262	-35	250	-38	-110	-36.7
37.	corn,'Hybrid XL380'	382	--	--	305	-20	223	-42	301	-21	-83	-27.7
38.	corn, 'Coker 71'	366	--	--	285	-22	177	-52	267	-27	-101	-33.7
39.	grass, 'Pensacola'	30	--	--	29	-3	11	-63	18	-40	-106	-35.3
40.	grass, 'Arg. Bahia'	34	--	--	24	-29	13	-62	20	-41	-132	-44.0
41.	grass, 'Bermuda'	20	--	--	11	-45	29	45	11	-45	-45	-15.0
42.	grass, carpet	23	--	--	9	-61	13	-43	13	-43	-147	-49.0
43.	soybean, 'Hardee'	210	--	--	121	-42	66	-69	69	-67	-178	-59.3
44.	artichoke	80	--	--	96	20	101	26	85	6	52	17.3
45.	bean, lima	367	--	--	227	-38	172	-53	174	-53	-144	-48.0
46.	bean, garden	337	221	-34	281	-17	194	-42	189	-44	-137	-34.3
47.	bean, pinto	374	--	--	297	-21	275	-26	326	-13	-60	-20.0
48.	bean, 'Tenn. Flat'	381	--	--	323	-15	293	-23	285	-25	-63	-21.0
49.	bell pepper	161	246	53	168	4	184	14	181	12	83	20.8
50.	butterpea	356	--	--	171	-52	133	-63	130	-63	-178	-59.3
51.	cantelope, 'Hales'	269	110	-59	137	-49	90	-67	113	-58	-233	-58.3
52.	cantelope, 'Honeydew'	270	83	-69	147	-46	104	-61	91	-66	-242	-60.5
53.	chufas	190	--	--	214	13	232	22	206	8	43	14.3
54.	clover	49	--	--	26	-47	8	-84	15	-69	-200	-66.7
55.	cotton	248	287	16	272	9	275	11	270	9	45	11.3
56.	cucumber	428	315	-26	331	-23	225	-47	236	-45	141	35.3
57.	cowpeas	465	--	--	256	-45	144	-69	139	-70	184	61.3
58.	eggplant	80	--	--	123	54	121	51	89	11	116	38.7

Table 29. Con't.

		1	2	%	3	%	4	%	5	%	Σ %	$\bar{x}$ %
59.	millet, 'Starr Pearl'	313	429	37	293	-6	311	-1	376	20	50	12.5
60.	millet, 'Browntop'	209	--	--	214	2	189	-10	197	-6	-14	-4.7
61.	oats	204	140	-31	214	5	234	15	225	10	-1	-0.3
62.	okra	224	--	--	189	-16	134	-40	132	-41	-97	-32.3
63.	peanuts	245	276	13	258	5	285	16	293	20	54	13.5
64.	peas, blackeye	415	197	-53	244	-41	141	-66	125	-70	230	57.5
65.	pumpkin	519	--	--	493	-5	495	-5	510	-2	-12	-4.0
66.	rice, 'Lebonett '	100	107	7	129	29	98	-2	95	-5	29	7.3
67.	rice, 'Brazos'	117	126	8	137	17	105	-10	117	0	15	3.8
68.	rice, 'Bluebett'	77	62	-19	73	-5	55	-29	59	-23	-76	-19.0
69.	rice, 'Labelle'	83	100	20	79	-5	92	11	71	-14	12	3.0
70.	rice, 'Star Bonnet'	81	86	6	81	0	75	-7	77	-5	-6	-1.5
71.	rhubarb	201	--	--	98	-51	43	-79	46	-77	-207	-69.0
72.	rye	261	236	-10	233	-11	293	12	227	-13	-22	-5.5
73.	sorghum	398	164	-59	323	-19	340	-15	287	-28	-121	-30.3
74.	squash, Early Summer	485	342	-29	360	-26	345	-29	322	-34	-118	-29.5
75.	squash, 'Prolific'	318	219	-31	300	-6	294	-8	283	-11	-56	-14.0
76.	squash, 'Zuccini'	346	--	--	344	-1	302	-13	322	-7	-21	-7.0
77.	squash, Acorn	245	--	--	263	7	263	7	194	-21	-7	-2.3
78.	sudangrass	241	524	117	340	41	335	39	378	57	254	63.5
79.	tomato	186	18	-90	39	-79	28	-85	19	-90	-344	-86.0
80.	watermelon	202	81	-60	104	-49	63	-69	63	-69	-247	-61.8
81.	Douglas-fir	28	--	--	26	-7	25	-10	27	-4	-21	-7.0
82.	sunflower	218	--	--	229	5	231	6	266	22	33	11.0

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in Section I.

Table 30. Duncan's Multiple Range Test for Leaf Area differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
1.	asparagus	A	A	A	A	A
2.	carrots	B,A	B	A	B	B
3.	celery	B,A	A	B,A	B	B
4.	radish	B,A	A	B,A	B	B,A
5.	lettuce	A	B,A	B,A	B	B
6.	onion	A	A	A	A	A
7.	parsnip	A	A	A	A	A
8.	English peas	A	A	B,A	B	B,A
9.	wheat,'Wakeland'	B,A	B,A	A	B,A	B
10.	wheat,'CoCorit'	A	B,A	B,A	B,A	B
11.	wheat,'Cajeme'	A	A	A	A	B
12.	wheat,'Crane'	A	B	B,A	B	B
13.	wheat, 'Inia 66R'	A	A	A	A	A
14.	wheat,'Jori'	B,A	B	A	B	B
15.	wheat,'SuperX'	B,A	A	A	B,A	B
16.	pine, slash	A	B,A	B,A	B	B,A
17.	pine, loblolly	B,A	A	B,C	C	B,C
18.	pine, lodgepole	A	A	A	B	A
19.	pine, ponderosa	B,A	A	C	C	B,C
20.	fir, noble	B,A	A	B,C	D	C
21.	fir, white	C	A	B,A	B,A	B,C
22.	barley,'Belle'	B,A	-	B	A	B
23.	barley,'Arivat'	A	-	A	A	A
24.	barley,'Hembar'	A	-	C	B,A	B,C
25.	broccoli	A	-	B	B	B
26.	brussel sprouts	A	-	B	C	C
27.	cabbage	A	-	B	B	B
28.	cauliflower	A	-	B	B	B
29.	chard	A	-	B	B	B
30.	collards	A	-	B	B	B
31.	kale	A	-	B	B	B
32.	kohlrabi	A	-	B	C,B	C
33.	mustard	A	-	A	B	B
34.	rutabega	A	-	B	C,B	C
35.	corn,'Silverqueen'	A	-	A	A	A
36.	corn,'Tobelle'	A	-	B	B	B
37.	corn,'Hybrid XL380'	A	-	B	C	B
38.	corn,'Coker 71'	A	-	B	C	B
39.	grass,'Pensacola'	A	-	A	A	A
40.	grass,'Arg. Bahia'	A	-	A	A	A
41.	grass,'Bermuda'	B,A	-	B	A	B
42.	grass, carpet	A	-	B	B,A	-
43.	soybean,'Hardee'	A	-	B	C	C
44.	artichoke	A	-	A	A	A

Table 30 Con't.

		Light Level				
	Species	1	2	3	4	5
45.	bean, lima	A	-	B	C	C
46.	bean, garden	A	B,C	B,A	C	C
47.	bean, pinto	A	-	B,A	B	B,A
48.	bean,'Tenn. Flat'	A	-	B,A	B	B
49.	bell pepper	B	A	B	B	B
50.	butterpea	A	-	B	B	B
51.	cantelope,'Hales'	A	B	B	B	B
52.	cantelope, 'Honeydew'	A	C	B	C,B	C,B
53.	chufas	A	-	A	A	A
54.	clover	A	-	B	B	B
55.	cotton	A	A	A	A	A
56.	cucumber	A	B	B	C	C
57.	cowpeas	A	-	B	C	C
58.	eggplant	B	-	A	A	B,A
59.	millet,'Starr Pearl'	A	A	A	A	A
60.	millet,'Browntop'	A	-	A	A	A
61.	oats	A	B	A	A	A
62.	okra	A	-	A	B	B
63.	peanuts	A	A	A	A	A
64.	peas, blackeye	A	C,B	B	C,D	D
65.	pumpkin	A	-	A	A	A
66.	rice,'Lebonette'	B,A	B,A	A	B	B
67.	rice,'Brazos'	B,A	B,A	A	B	B,A
68.	rice,'Bluebett'	A	A	A	A	A
69.	rice,'Labelle'	B,A	A	B,A	B,A	B
70.	rice,'Star Bonnet'	A	A	A	A	A
71.	rhubarb	A	-	B	C	C
72.	rye	B,A	B	B	A	B
73.	sorghum	A	C	B,A	B,A	B
74.	squash, early summer	A	B	B	B	B
75.	squash,'Prolific'	A	A	A	A	A
76.	squash,'Zuccini'	A	-	A	A	A
77.	squash, acorn	A	-	A	A	A
78.	sudangrass	C	A	B	B	B
79.	tomato	A	B	B	B	B
80.	watermelon	A	C,B	B	C	C
81.	Douglas-fir	A	-	A	A	A
82.	sunflower	A	-	A	A	A

1/ Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 31. Comparison of the 5 UV-B radiation treatments for leaf density (g/dm^2) as to means, mean % difference from control for each and average mean percent difference of all treatments vs. the mylar control

UV-B Treatments[1], Mean Weights and % Differences[2]

	Species	1	2	%	3	%	4	%	5	%	Σ%	x̄%
1.	asparagus	0.77	0.66	-14	0.64	-17	0.80	-90	0.67	-13	-134	-33.4
2.	carrots	0.46	0.58	26	0.56	22	0.57	24	0.54	17	89	22.3
3.	celery	0.38	0.52	37	0.45	18	0.42	11	0.46	21	87	21.7
4.	radish	0.33	0.35	6	0.65	97	0.35	6	0.36	9	118	29.5
5.	lettuce	0.17	0.15	-12	0.18	6	0.15	-12	0.08	-59	- 76	-19.1
6.	onion	0.61	0.59	- 3	0.63	3	0.55	-10	0.79	30	20	4.9
7.	parsnip	0.37	0.39	5	0.33	-11	0.39	5	0.36	- 3	- 3	- 0.7
8.	English peas	0.38	1.81	376	0.57	50	1.01	166	0.51	34	626	156.6
9.	wheat,'Wakeland'	0.44	0.47	7	0.46	5	0.53	20	0.56	27	59	14.8
10.	wheat,'CoCorit'	0.49	0.51	4	0.56	14	0.63	29	0.59	20	67	16.8
11.	wheat,'Cajeme'	0.45	0.44	- 2	0.43	- 4	-.44	- 2	0.47	4	- 4	- 1.1
12.	wheat,'Crane'	0.48	0.53	10	0.53	10	0.49	2	0.51	6	29	7.3
13.	wheat,'Inia 66R'	0.44	0.49	11	0.50	14	0.44	0	0.56	27	52	13.1
14.	wheat,'Jori'	0.57	0.88	54	0.53	- 7	0.60	5	0.69	21	74	18.4
15.	wheat,'Super-X'	0.45	0.44	- 2	0.50	11	0.51	13	0.55	22	44	11.1
16.	pine, slash	1.50	1.60	7	1.60	7	1.47	- 2	1.49	- 1	11	2.7
17.	pine, loblolly	1.93	1.64	-15	1.75	- 9	1.66	-14	1.79	- 7	- 46	-11.4
18.	pine, lodgepole	1.46	1.46	0	1.51	3	1.49	2	1.45	- 1	5	1.2
19.	pine, ponderosa	1.92	1.85	- 4	2.08	8	1.85	- 4	1.84	- 4	- 3	- 0.8
20.	fir, noble	1.62	1.44	-11	1.74	7	1.58	- 2	1.62	0	- 6	- 1.5
21.	fir, white	1.90	1.88	- 1	2.73	44	1.93	2	1.63	-14	31	7.8
22.	barley,'Belle'	0.45	-	-	0.42	- 7	0.35	-22	0.45	0	- 29	- 9.6
23.	barley,'Arivat'	0.50	-	-	0.40	-20	0.39	-22	0.44	12	- 54	- 18.0

Table 31 Con't:

		1	2	%	3	%	4	%	5	%	Σ%	$\bar{x}$%
24.	barley,'Hembar'	0.51	-	-	0.49	- 4	0.40	-22	0.51	0	-25	- 8.5
25.	broccoli	0.37	-	-	0.34	- 8	-.35	- 5	0.32	-14	-27	- 9.0
26.	brussels sprouts	0.30	-	-	0.36	20	0.35	17	0.33	10	47	15.6
27.	cabbage	0.33	-	-	0.37	12	0.34	3	0.31	- 6	9	3.0
28.	cauliflower	0.39	-	-	0.41	5	0.41	5	0.37	- 5	5	1.7
29.	chard	0.29	-	-	0.30	3	0.33	14	0.32	10	28	9.2
30.	collards	0.41	-	-	0.33	-20	0,83	102	0.34	-17	66	22.0
31.	kale	0.37	-	-	0.31	-16	0.35	- 5	0.30	-19	-41	-13.5
32.	kohlrabi	0.34	-	-	0.32	- 6	0.30	-12	0.31	- 9	-26	- 8.8
33.	mustard	0.22	-	-	0.25	14	0.50	127	0.28	27	168	56.1
34.	rutabega	0.25	-	-	0.28	12	0.34	20	0.32	28	76	25.3
35.	corn,'Silverqueen'	0.32	-	-	0.37	16	0.31	0 3	0.32	0	13	4.2
36.	corn, 'Tobelle'	0.30	-	-	0.34	13	0.32	7	0.32	7	27	8.9
37.	corn, Hybrid XL	0.31	-	-	0.35	13	0.34	10	0.31	0	23	7.5
38.	corn,'Coker 71'	0.55	-	-	0.31	-44	0.29	-47	0.29	-47	-138	-46.1
39.	grass,'Pensacola'	0.62	-	-	0.59	- 5	0.63	2	0.66	6	3	1.1
40.	grass,'Arg. Bahia'	0.43	-	-	0.47	9	0.88	105	0.48	12	126	41.9
41.	grass,'Bermuda'	0.57	-	-	0.54	- 5	0.61	7	0.95	67	68	22.8
42.	grass, carpet	0.45	-	-	0.51	13	0.56	24	0.56	24	62	20.7
43.	soybean,'Hardee'	0.43	-	-	0.54	26	0.92	114	0.92	114	253	84.5
44.	artichoke	0.48	-	-	0.44	-13	0.48	0	0.42	-13	-25	- 8.3
45.	bean, lima	0.27	-	-	0.42	56	0.48	78	0.41	52	185	61.7
46.	bean, garden	0.27	0.33	22	0.30	11	0.30	11	0.30	11	56	13.9
47.	bean, pinto	0.28	-	-	0.30	7	0.31	11	0.28	0	18	6.0
48.	bean,'Tenn. Flat'	0.25	-	-	0.27	8	0.30	20	0.27	8	36	12.0
49.	bell pepper	0.29	0.28	-3	0.29	0	0.28	0 3	0.28	- 3	- 10	- 2.6
50.	butterpea	0.23	-	-	0.43	87	0.54	135	0.63	174	396	131.9
51.	cantelope, 'Hales'	0.28	0.26	-7	0.29	4	0.28	0	0.25	-11	- 14	- 3.6
52.	cantelope, 'Honeydew'	0.34	0.32	-6	0.26	-24	0.36	6	0.30	-12	- 35	- 8.8
53.	chufas	0.51	-	-	0.63	24	0.58	14	0.58	14	51	17.0
54.	clover	0.28	-	-	0.35	25	0.34	21	0.44	57	104	34.5
55.	cotton	0.33	0.33	0	0.32	- 3	0.34	3	0.31	- 6	- 6	- 1.5
56.	cucumber	0.24	0.25	4	0.25	4	0.31	29	0.27	13	50	12.5
57.	cowpeas											
58.	eggplant	0.23	-	-	0.23	0	0.23	0	0.22	- 4	- 4	- 1.4

Table 31 Cont'd

		1	2	%	3	%	4	%	5	%	Σ%	$\bar{x}$%
59.	millet,'Starr Pearl'	0.45	0.47	4	0.46	2	0,34	-24	0.40	-11	-29	- 7.2
60.	millet,'Browntop'	0.32	-	-	0.37	16	0.34	6	0.37	16	38	12.5
61.	oats	0.45	0.38	-16	0.49	9	0.51	13	0.49	9	16	3.9
62.	okra	0.30	-	-	0.29	- 3	0.33	10	0.30	0	7	2.2
63.	peanuts	0.39	0.42	8	0.42	8	0.36	- 8	0.37	- 5	3	0.6
64.	peas, blackeye	0.30	0.29	- 3	0.29	- 3	0.35	17	0.38	27	37	9.2
65.	pumpkin	0.29	-	-	0.30	3	0.28	- 3	0.26	-10	-10	- 3.4
66.	rice,'Lebonett'	0.68	0.53	-22	0.54	-21	0.56	-18	0.57	-16	-76	-19.1
67.	rice,'Brazos'	0.51	0.42	-18	0.52	2	0.54	6	0.47	- 8	-18	- 4.4
68.	rice,'Bluebett'	0.62	0.52	-16	0.59	- 5	0.61	- 2	0.61	- 2	-24	- 6.0
69.	rice,'Labelle'	0.62	0.50	-19	0.64	3	0.51	-18	0.71	15	-19	- 4.8
70.	rice,'Star Bonnet'	0.60	0.48	-20	0.58	- 3	0.52	-13	0 54	-10	-47	-11.7
71.	rhubarb	0.31	-	-	0.48	55	1.01	226	0.41	32	313	104.3
72.	rye	0.52	0.54	4	0.54	4	0.45	-13	0.57	10	4	1.0
73.	sorghum	0.55	0.39	-29	0.59	7	0.54	- 2	0.44	-20	-44	-10.9
74.	squash, Early Summer	0.34	0.28	-18	0.44	29	0.26	-24	0.23	-32	-44	-11.0
75.	squash,'Prolific'	0.28	0.26	- 7	0.24	-14	0.24	-14	0.24	-14	-50	-12.5
76.	squash,'Zucchini'	0.31	-	-	0.29	- 6	0.27	-13	0.23	-26	-45	-15.1
77.	squash, Acorn	0.24	-	-	0.22	- 8	0.32	-33	0.22	- 8	17	5.6
78.	sudangrass	0.57	0.48	-16	0.64	12	0.43	-25	0.52	- 9	-37	- 9.2
79.	tomato	0.27	0.27	0	0.22	-19	0.24	-11	0.24	-11	-41	-10.2
80.	watermelon	0.35	0.40	14	0.49	40	0.51	46	0.42	20	120	30.0
81.	Douglas-fir	1.30	-	-	1.39	7	1.55	19	1.36	5	31	10.3
82.	sunflower	0.34	-	-	0.33	- 3	0.32	- 6	0.31	- 9	-18	- 5.9

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in Section I.

Table 32. Duncan's Multiple Range Test for Leaf Density differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
1.	asparagus	A	B,A	B	B,A	B
2.	carrots	B,A	A	B	A	A
3.	celery	A	A	A	A	A
4.	radish	B,A	B	B,A	A	B,A
5.	lettuce	A	A	A	A	A
6.	onion	B	B	B	B,A	A
7.	parsnip	A	A	A	A	A
8.	English peas	B	B,A	B	A	B,A
9.	wheat,'Wakeland'	B,A	B,A	B	A	A
10.	wheat,'Coorit'	B	B,A	B,A	A	A
11.	wheat,'Cajeme'	B	B	B	B	A
12.	wheat,'Crane'	B	A	B	B,A	A
13.	wheat,' Inia 66R'	B	B,A	B	B,A	A
14.	wheat,'Jori'	A	A	A	A	A
15.	wheat,'SuperX'	B,A	B	B	B,A	A
16.	pine, slash	A	A	A	A	A
17.	pine, loblolly	B,A	B	A	A	A
18.	pine, lodgepole	B	B	B	A	B
19.	pine, ponderosa	B,C	C	B,A	A	B,A
20.	fir, noble	C	C	C,B	A	B
21.	fir, white	A	B	B	B	B
22.	barley,'Belle'	B	-	B,A	B	A
23.	barley,'Arivat'	A	-	A	A	A
24.	barley,'Hembar'	C	-	A	B,C	B,A
25.	broccoli	C	-	B	A	B,A
26.	brussel sprouts	C	-	B	A	B
27.	cabbage	B	-	A	A	A
28.	cauliflower	B	-	A	A	A
29.	chard	C	-	B	B	A
30.	collards	B	-	B,A	A	A
31.	kale	B	-	B,A	A	A
32.	kohlrabi	C	-	B	B	A
33.	mustard	B	-	B	A	A
34.	rutabega	B	-	B	A	A
35.	corn,'Silverqueen'	A	-	A	A	A
36.	corn, 'Tobelle'	B	-	A	A	A
37.	corn,'Hybrid XL380'	B	-	B	A	B
38.	corn,'Coker 71'	B	-	B	A	B
39.	grass,'Pensacola'	B	-	B	A	B
40.	grass,'Arg. Bahia'	B	-	B,A	A	B,A
41.	grass,'Bermuda'	A	-	A	A	A
42.	grass, carpet	B	-	A	B,A	-
43.	soybean,'Hardee'	B	-	B,A	B,A	A
44.	artichoke	A	-	A	A	A

Table 32 Con't.

	Species	Light Level 1	2	3	4	5
45.	bean, lima	C	-	B	A	B
46.	bean, garden	A	A	A	A	A
47.	bean, pinto	A	-	A	A	A
48.	bean,'Tenn. Flat'	B	-	B,A	A	B,A
49.	bell pepper	A	A	A	A	A
50.	butterpea	B	-	B,A	A	A
51.	cantelope,'Hales'	A	A	A	A	A
52.	cantelope, 'Honeydew'	B,A	B,A	B	A	B,A
53.	chufas	B	-	A	B,A	B,A
54.	clover	A	-	A	A	A
55.	cotton	A	A	A	A	A
56.	cucumber	B	B	B	A	B,A
57.	cowpeas	B	-	B	A	A
58.	eggplant	A	-	A	A	A
59.	millet,'Starr Pearl'	A	A	A	A	A
60.	millet,'Browntop'	A	-	A	A	A
61.	oats	B,A	B	A	A	A
62.	okra	A	-	A	A	A
63.	peanuts	A	A	A	A	A
64.	peas, blackeye	B	B	B	A	A
65.	pumpkin	A	-	A	A	A
66.	rice,'Lebonette'	A	B	B	B	B
67.	rice,'Brazos'	A	A	A	A	A
68.	rice,'Bluebett'	A	A	A	A	A
69.	rice,'Labelle'	B	C	B,A	C	A
70.	rice,'Star Bonnet'	A	A	A	A	A
71.	rhubarb	B	-	B	A	B
72.	rye	A	A	A	A	A
73.	sorghum	A	B	A	A	B
74.	squash, early summer	A	A	A	A	A
75.	squash,'Prolific'	A	B,A	B	B	B
76.	squash,'Zuccini'	A	-	A	B,A	B
77.	squash, acorn	A	-	A	A	A
78.	sudangrass	B,A	B,A	A	B	B,A
79.	tomato	A	A	A	A	A
80.	watermelon	A	A	A	A	A
81.	Douglas-fir	A	-	A	A	A
82.	sunflower	A	-	A	A	A

1/ Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 33 . Comparison of the 5 UV-B radiation treatments for root:shoot ratio as to means, mean % difference from control for each and average mean percent difference of all treatment vs. mylar control.

UV-B Treatments[1] and % Differences[2]

	Species	1	2	%	3	%	4	%	5	%	Σ %	$\bar{x}$ %
1.	asparagus	.342	.456	33	.323	-6	.370	8	.405	18	54	13.6
2.	carrots	.137	.167	22	.153	12	.171	25	.147	7	66	16.4
3.	celery	.179	.237	32	.298	67	.206	15	.214	20	134	33.4
4.	radish	.893	.765	-14	.646	-28	.533	-40	.702	-31	-104	-25.9
5.	lettuce	.192	.157	-18	.126	-34	.194	1	.164	-15	-66	-16.5
6.	onion	.360	.369	3	.306	-15	.369	3	.466	29	19	4.9
7.	parsnip	.334	.183	-45	.172	-49	.192	-43	.172	-49	-185	-46.2
8.	English peas	1.368	.666	-51	.721	-47	.723	-47	.847	-38	-184	-46.0
9.	wheat, 'Wakeland'	.732	.960	31	.983	34	1.032	41	1.170	60	166	41.6
10.	wheat, 'CoCorit'	.948	1.034	9	.769	-19	.872	-8	.980	3	-145	-3.6
11.	wheat, 'Cajeme'	.825	.940	14	.922	12	.988	20	.967	17	63	15.7
12.	wheat, 'Crane'	.870	.809	-7	.915	5	1.021	17	.046	-95	-79	-19.8
13.	wheat, 'Inia 66R'	.948	1.034	9	.769	-19	.872	-8	.980	3	-15	-3.6
14.	wheat, 'Jori'	.825	.940	14	.922	12	.988	20	.967	17	63	15.7
15.	wheat, 'Super-X'	.870	.809	-7	.915	5	1.021	17	1.046	20	36	8.9
16.	pine, slash	.159	.199	25	.172	8	.499	214	.171	8	255	63.7
17.	pine, loblolly	.226	.236	4	.242	7	.271	20	.217	-4	27	6.9
18.	pine, lodgepole	.295	.304	3	.295	0	.271	-8	.281	-5	-10	-2.5
19.	pine, ponderosa	.351	.310	-12	.321	-9	.327	-7	.297	-15	-43	-10.6
20.	fir, noble	.232	.212	-9	.242	4	.266	15	.181	-22	-12	-2.9
21.	fir, white	.258	.284	10	.547	112	.263	2	.172	-33	91	22.7
22.	barley, 'Belle'	.678	--	--	.781	15	.791	17	.799	18	50	16.6
23.	barley, 'Arivat'	1.059	--	--	1.085	3	1.183	12	.754	-11	3	1.0

Table 33 Con't.

	Species	1	2	%	3	%	4	%	5	%	Σ %	$\bar{x}$ %
24.	barley, 'Hembar'	.747	--	--	.911	22	.896	20	.754	1	43	14.3
25.	broccoli	.250	--	--	.113	-55	.101	-60	.130	-48	-162	-54.1
26.	brussel sprouts	.139	--	--	.107	-23	.143	3	.225	62	42	13.9
27.	cabbage	.221	--	--	.136	-39	.198	-10	.108	-51	-100	-33.3
28.	cauliflower	.142	--	--	.074	-48	.057	-60	.108	-24	-132	-43.9
29.	chard	.082	--	--	.089	9	.069	-16	.114	39	32	10.6
30.	collards	.254	--	--	.163	-36	.089	-65	.145	-43	-144	-47.9
31.	kale	.188	--	--	.167	-11	.147	-22	.151	-20	-53	-17.6
32.	kohlrabi	.224	--	--	.128	-43	.129	-42	.157	-30	-115	-38.4
33.	mustard	.104	--	--	.103	-2	.079	-24	.046	-56	-82	-27.2
34.	rutabega	.194	--	--	.112	-42	.171	-12	.086	-56	-110	-36.6
35.	corn, 'Silberqueen'	.935	--	--	.946	1	.949	2	.947	1	4	1.3
36.	corn, 'Tobelle'	.977	--	--	.961	-2	.944	-3	.952	-3	-8	-2.5
37.	corn,'Hybrid XL380'	.980	--	--	1.01	3	.974	-1	.968	-1	1.2	.4
38.	corn, 'Coker 71'	.903	--	--	.991	10	.994	10	.971	8	27	9.1
39.	grass, 'Pennsacola'	.139	--	--	.223	60	.336	142	.278	100	302	100.7
40.	grass, 'Arg. Bahia'	.227	--	--	--	--	.222	-2	.419	85	82	41.2
41.	grass, 'Bermuda'	.142	--	--	.167	18	.204	44	.271	91	152	50.7
42.	grass, carpet	.253	--	--	.119	-53	.263	4	.119	-53	49	24.5
43.	soybean, 'Hardee'	.337	--	--	.384	14	.448	33	.503	49	96	32.0
44.	artichoke	.147	--	--	.108	-27	.143	-3	.147	0	-29	-9.8
45.	bean, lima	.184	--	--	.220	20	.186	1	.214	16	37	12.3
46.	bean, garden	.273	.311	14	.217	-21	.218	-20	.223	-18	-45	-11.3
47.	bean, pinto	.312	--	--	.316	1	.255	-18	.228	-27	-44	-14.6
48.	bean, 'Tenn. Flat'	.269	--	--	.260	-3	.243	-10	.233	-13	-26	-8.8
49.	bell pepper	.297	.218	-27	.194	-35	.189	-36	.200	-33	-130	-32.6
50.	butterpea	.214	--	--	.176	-18	.193	-10	.180	-16	-44	-14.5
51.	cantelope, 'Hales'	.133	.093	-30	.124	-7	.096	-28	.118	-11	-76	-19.0
52.	cantelope, 'Honeydew'	.160	.082	-49	.091	-43	.090	-44	.093	-42	-178	-44.4
53.	chufas	.902	--	--	.934	4	.877	-3	.825	-9	-8	-3
54.	clover	.124	--	--	.153	23	.135	9	.117	-6	27	8.9
55.	cotton	.134	.136	2	.166	24	.125	-7	.121	-10	9	2.2
56.	cucumber	.189	.099	-48	.143	-24	.093	-51	.087	-54	-177	-44.2
57.	cowpeas	--	--	--	--	--	--	--	--	--	--	--
58.	eggplant	.148	--	--	.157	6	.169	14	.161	9	29	9.7

Table 33 Con't.

	Species	1	2	%	3	%	4	%	5	%	Σ %	$\bar{x}$ %
59.	millet, 'Starr Pearl'	.325	.278	-15	.389	20	.563	73	.329	1	80	19.9
60.	millet, 'Browntop'	.436	--	--	.332	-24	.434	-1	.291	-33	58	-19.2
61.	oats	.410	.367	-11	.465	13	.350	-15	.724	77	65	16.2
62.	okra	.154	--	--	.113	-27	.079	-49	.090	-42	-117	-39.0
63.	peanuts	.348	.192	-45	.267	-23	.242	-31	.287	-18	-116	-29.0
64.	peas, blackeye	.216	.173	-20	.180	-17	.153	-29	.187	-13	179	-19.8
65.	pumpkin	.096	--	--	.117	22	.098	1	.119	24	48	16.0
66.	rice, 'Lebonett'	.398	.332	-17	.379	-5	.346	-13	.451	13	-21	-5.3
67.	rice, 'Brazos'	.366	.369	1	.380	4	.367	0	.395	8	13	3.2
68.	rice, 'Bluebett'	.408	.296	-28	.426	4	.587	44	.376	-8	13	3.2
69.	rice, 'Labelle'	.418	.373	-11	.430	3	.389	-7	.433	4	-11	-2.8
70.	rice, 'Star Bonnet'	.393	.407	4	.389	-1	.314	-20	.414	5	-12	-3.1
71.	rhubarb	.099	--	--	.073	-26	.075	-24	.164	66	15	5.1
72.	rye	.417	.440	6	.403	-3	.416	0	.443	6	8	2.0
73.	sorghum	.520	.471	-9	.505	-3	.467	-10	.508	-2	-25	-6.2
74.	squash, early summer	.094	.082	-13	.105	12	.076	-19	.080	-15	-35	-8.8
75.	squash, 'Prolific'	.112	.078	-30	.099	-12	.088	-21	.118	5	-58	-14.5
76.	squash, 'Zuccini'	.108	--	--	.124	15	.116	7	.180	67	89	29.6
77.	squash, acorn	.153	--	--	.139	-9	.098	-36	.126	-18	-63	-20.9
78.	sudangrass	.468	.674	44	.485	4	.419	-11	.564	21	58	14.4
79.	tomato	.129	.056	-57	.107	-17	.076	-41	.124	-4	-119	-29.7
80.	watermelon	.053	.052	-2	.065	23	.062	17	.054	2	40	9.9
81.	Douglas-fir	.216	--	--	.202	-7	.127	-41	.240	11	37	-12.2
82.	sunflower	.151	--	--	.195	29	.200	33	.182	21	82	27.4

[1]Means of plant replicates explained in methods section.

[2]UV-B enhancement levels 1 to 5 defined in Section I.

Table 34 Duncan's Multiple Range Test for Root:Shoot Ratio differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1/]

		Light Level				
	Species	1	2	3	4	5
1.	asparagus	A	A	A	A	A
2.	carrots	B,A	B,A	B	A	B,A
3.	celery	A	B	A	A	A
4.	radish	A	A	A	A	A
5.	lettuce	A	A	A	A	A
6.	onion	A	A	A	A	A
7.	parsnip	A	A	A	A	A
8.	English peas	A	B	B,A	B,A	A
9.	wheat,'Wakeland'	A	A	A	A	A
10.	wheat,'CoCorit'	B	B,A	B	B,A	A
11.	wheat,'Cajeme'	B	B,A	A	B,A	A
12.	wheat,'Crane'	B	B,A	B,A	A	A
13.	wheat,'Inia 66R'	B,A	A	B	B,A	B,A
14.	wheat,'Jori'	A	A	A	A	A
15.	wheat,'SuperX'	A	A	A	A	A
16.	pine, slash	B	B	B,A	A	B,A
17.	pine, loblolly	B	B	B	A	B
18.	pine, lodgepole	B	B	B	A	B
19.	pine, ponderosa	B,C	C	B,A	A	B,A
20.	fir, noble	C	C,B	C,B	A	B
21.	fir, white	A	A	A	A	A
22.	barley,'Belle'	A	-	A	A	A
23.	barley,'Arivat'	A	-	A	A	A
24.	barley,'Hembar'	B	-	A	B,A	B,A
25.	broccoli	B	-	A	A	A
26.	brussel sprouts	C	-	B	A	A
27.	cabbage	B	-	A	A	A
28.	cauliflower	B	-	A	A	A
29.	chard	B	-	A	A	A
30.	collards	B	-	A	B,A	A
31.	kale	B	-	A	A	A
32.	kohlrabi	C	-	B	B,A	A
33.	mustard	B	-	B	A	A
34.	rutabega	B	-	A	A	A
35.	corn,'Silverqueen'	A	-	A	A	A
36.	corn, 'Tobelle'	A	-	A	A	A
37.	corn,'Hybrid XL380'	A	-	A	A	A
38.	corn,'Coker 71'	B	-	A	A	B,A
39.	grass,'Pensacola'	B	-	B,A	A	B,A
40.	grass,'Arg. Bahia'	A	-	A	A	A
41.	grass,'Bermuda'	A	-	A	A	A
42.	grass, carpet	A	-	A	A	-
43.	soybean,'Hardee'	A	-	A	A	A
44.	artichoke	A	-	A	A	A

Table 34 Con't.

		Light Level				
	Species	1	2	3	4	5
45.	bean, lima	A	-	A	A	A
46.	bean, garden	A	A	A	A	A
47.	bean, pinto	A	-	A	B	B
48.	bean,'Tenn. Flat'	A	-	A	A	A
49.	bell pepper	A	A	A	A	A
50.	butterpea	A	-	A	A	A
51.	cantelope,'Hales'	A	A	A	A	A
52.	cantelope, 'Honeydew'	A	B	B	B	B
53.	chufas	A	-	A	A	A
54.	clover	A	-	A	A	A
55.	cotton	B	B	A	B	B
56.	cucumber	A	C	B	C	C
57.	cowpeas	A	-	A	A	A
58.	eggplant	B	-	B,A	A	B,A
59.	millet,'Starr Pearl'	B	B	B,A	A	B
60.	millet, 'Browntop'	A	-	A	A	A
61.	oats	A	A	A	A	A
62.	okra	A	-	B	B	B
63.	peanuts	A	B	B,A	B,A	B,A
64.	peas, blackeye	A	B	B	C	B
65.	pumpkin	A	-	A	A	A
66.	rice,'Lebonette'	B,A	B	B,A	B	A
67.	rice,'Brazos'	A	A	A	A	A
68.	rice,'Bluebett'	A	A	A	A	A
69.	rice,'Labelle'	A	A	A	A	A
70.	rice,'Star Bonnet'	A	A	A	A	A
71.	rhubarb	A	-	A	A	A
72.	rye	A	A	A	A	A
73.	sorghum	A	A	A	A	A
74.	squash, early summer	B	B,A	A	B,A	B,A
75.	squash,'Prolific'	B	B,A	B	B	A
76.	squash,'Zuccini'	B	-	B	B	A
77.	squash, acorn	B,A	-	A	B	A
78.	sudangrass	C,B	A	C,B	C	B
79.	tomato	B,A	B	B,A	B,A	A
80.	watermelon	B	B,A	B,A	A	B,A
81.	Douglas-fir	B,A	-	B,A	B	A
82.	sunflower	B	-	A	A	B,A

1/ Light levels not followed by the same letter are significantly different (.05 level). Only horizontal comparisons are valid. See species list for scientific names and varietal designations. UV-B enhancement irradiances are defined in section I.

Table 35. Susceptibility ratings for 82 agricultural crops grown under 4 or 5 different UV-B enhancement regimes in the Duke University Phytotron. Favored (+) = biomass increases of 5% or more, resistant (0) = biomass ± 5% of the mylar control, moderately susceptible (1) = 5-25% reduction in biomass, susceptible (2) = 25-50% reduction in biomass, highly susceptible (3) = greater than 50% reduction in biomass below mylar control.

I. Chenopodiaceae	Rating
1 chard	3
II. Compositae	
1. artichoke	+
2. lettuce	1
3. sunflower	+
III. Cruciferae	
1. broccoli	3
2. brussel sprouts	3
3. cabbage	3
4. cauliflower	3
5. collards	3
6. kale	3
7. kohlrabi	3
8. mustard	2
9. radish	+
10. rutabega	3
IV. Cucurbitaceae	
1. cantelope, 'Hales' best jumbo'	2
2. cantelope, 'Honeydew'	2
3. cucumber	3
4. squash, acorn	2
5. squash, early summer	3
6. squash, 'Prolific Straight'	2
7. squash, 'Zuccini'	2
8. pumpkin	1
9. watermelon	3

V. Gramineae	Rating
1. barley, 'Arivat'	1
2. barley, 'Belle'	1
3. barley, 'Hembar'	2
4. chufas	+
5. corn, 'Silverqueen'	2
6. corn, 'Sweet Tobelle'	2
7. corn, 'Hybrid XL380'	2
8. corn, 'Coker 71'	3
9. grass, 'Pensacola'	2
10. grass, 'Arg. Bahia'	2
11. grass, 'Bermuda'	1
12. grass, carpet	2
13. millet, 'Starr Pearl'	1
14. millet, 'Browntop'	1
15. oats	+
16. rice, 'Lebonnet'	1
17. rice, 'Brazos'	0
18. rice, 'Bluebett'	1
19. rice, 'Labelle'	0
20. rice, 'Star Bonnet'	1
21. rye	1
22. sorghum	1
23. sundangrass	+
24. wheat, 'Cajeme'	+
25. wheat, 'CoCorit'	0
26. wheat, 'Crane'	1
27. wheat, 'Inia 66R'	0
28. wheat, 'Jori'	+
29. wheat, 'Super X'	+
30. wheat, 'Wakeland'	+
VI. Leguminosae	
1. bean, garden	1

Table 35 Con't.

	Rating
VI. Leguminosae	
2. bean, lima	1
3. bean, pinto	1
4. bean,'Tenn. Flat'	1
5. butterpea	1
6. cowpea	1
7. clover	3
8. peanuts	+
9. peas, blackeye	3
10. peas, English	+
11. soybean	2
VII. Liliaceae	
1. asparagus	0
2. onion	0
VIII. Malvaceae	
1. cotton	0
2. okra	2
IX. Pinaceae	
1. pine, loblolly	1
2. pine, lodgepole	1
3. pine, ponderosa	1
4. pine, slash	1
5. Douglas-fir	0
6. fir, noble	1
7. fir, white	+
X. Polygonaceae	
1. rhubarb	3
XI. Solanaceae	
1. bell pepper	0
2. eggplant	+
3. tomato	3
XII. Umbelliferae	
1. carrots	+
2. celery	+
3. parsnip	0

Table 36 . List of species by sensitivity rating, family, overall increase (+), decrease (-), or no change (0) in leaf density.

(+) Favored Species

D		
+	1.	artichoke - Compositae
+	2.	sunflower - Compositae
+	3.	radish - Cruciferae
+	4.	chufas - Gramineae
+	5.	oats - Gramineae
-	6.	sudangrass - Gramineae
0	7.	wheat, 'Cajeme' - Gramineae
+	8.	wheat, 'Jori' - Gramineae
+	9.	wheat, 'Super X' - Gramineae
+	10.	ehrsy,' Wakeland' - Gramineae
+	11.	peanuts - Leguminosae
+	12.	English peas - Leguminosae
+	13.	fir, white - Pinaceae
0	14.	eggplant - Solanaceae
+	15.	carrots - Umbelliferae
+	16.	celery - Umbelliferae

(0) Resistant Species

D		
0	1.	rice, 'Brazos' - Gramineae
-	2.	rice, 'Labelle' - Gramineae
+	3.	wheat, 'CoCorit' - Gramineae
+	4.	wheat, 'Inia 66R' - Gramineae
-	5.	asparagus - Liliaceae
0	6.	onion - Liliaceae
0	7.	cotton - Malvaceae
+	8.	Douglas-fir - Pinaceae
0	9.	bell pepper - Solanaceae
0	10.	parsnip - Unbelliferae

(1) Moderately Susceptible Species

D		
+	1.	lettuce - Compositae
-	2.	pumpkin - Cruciferae
-	3.	barley, 'Arivat' - Gramineae
-	4.	barley, 'Belle' - Gramineae
+	5.	grass, 'Bermuda' - Gramineae
-	6.	millet, 'Star Pearl' - Gramineae
+	7.	millet, 'Browntop' - Gramineae
-	8.	rice, 'Lebonnet' - Gramineae
-	9.	rice, 'Bluebett' - Gramineae
-	10.	rice, 'Star Bonnet' - Gramineae
+	11.	rye, - Gramineae
-	12.	sorghum - Gramineae
+	13.	wheat, 'Crane' - Gramineae
+	14.	bean, garden - Leguminosae
+	15.	bean, lima - Leguminosae
+	16.	bean, pinto - Leguminosae

(1) Moderately Sensitive Species

D		
+	17.	bean, 'Tenn. Flat' - Leguminosae
+	18.	butterpea - Leguminosae
+	19.	cowpea - Leguminosae
-	20.	pine, loblolly - Pinaceae
0	21.	pine, lodgepole - Pinaceae
0	22.	pine, ponderose - Pinaceae
0	23.	pine, slash - Pinaceae
0	24.	fir, noble - Pinaceae

(2) Sensitive Species

D		
+	1.	mustard - Cruciferae
-	2.	cantelope,' Hales best jumbo' - Cucurbitaceae
-	3.	Cantelope,' Honeydew' - Cucurbitaceae
-	4.	squash, acorn - Cucurbitaceae
-	5.	squash,' Prolific Straight' - Cucurbitaceae
-	6.	squash, 'Zuccini' - Cucurbitaceae
-	7.	barley,' Hemb r' - Gramineae
+	8.	corn,' Silverqueen' - Gramineae
+	9.	corn,' Sweet Tobelle' - Gramineae
+	10.	corn,' Hybrid XL380' - Gramineae
0	11.	grass,' Pensacola' - Gramineae
+	12.	grass, 'Arg. Bahia' - Gramineae
+	13.	grass, carpet - Gramineae
+	14.	soybean - Leguminosae
0	15.	okra - Malvaceae

(3) Highly Sensitive Species

D		
+	1.	chard - Chenopodiaceae
-	2.	broccoli - Cruciferae
+	3.	brussel sprouts - Cruciferae
+	4.	cabbage - Cruciferae
+	5.	cauliflower - Cruciferae
-	6.	collards - Cruciferae
-	7.	kale - Cruciferae
-	8.	kohlrabi - Cruciferae
+	9.	rutabega - Cruciferae
+	10.	cucumber - Cucurbitaceae
-	11.	squash, early summer - Cucurbitaceae
+	12.	watermelon - Cucurbitaceae
-	13.	corn, 'Coker 71' - Gramineae
+	14.	clover - Leguminosae
+	15.	peas, blackeye - Leguminosae
+	16.	rhubarb - Polygonaceae
-	17.	tomato - Solanaceae

EFFECTS OF ULTRAVIOLET-B RADIATION ENHANCEMENTS ON SOYBEAN AND WATERMELON VARIETIES

Abstract

Nineteen different soybean (Glycine max L. Merr.) and 3 different watermelon (Citrullus vulgaris L.) varieties were grown in controlled environmental chambers at the Duke University Phytotron under 5 different UV-B enhancement regimes. Height was measured weekly. After 4 weeks the plants were harvested and analysed for 1) leaf fresh and 2) dry weight, 3) stem fresh and 4) dry weight, 5) root fresh and 6) dry weight, 7) total fresh and 8) dry weight biomass, 9) leaf area, 10) % leaves, 11) % stems, 12) % roots, 13) root:shoot ratio, 14) chlorosis, and 15) leaf density.

Significant differences among varieties for sensitivity to UV-B radiation was found. Biomass, as determined by fresh and dry weights, and height were reduced. The % biomass partitioned into leaves increased, that into stem decreased and for the majority of the varieties the % in roots decreased. Root:shoot ratios varied, depending primarily on the relative changes in root biomass. Leaf density was consistently increased, being more pronounced in watermelons. Significant differences in the amount of chlorotic leaf surface were also observed.

Introduction

'Hardee' soybean in the screening study of section 2 was a sensitive species showing pronounced interveinal chlorosis, leaf bronzing, leaf thickening, stunting, loss of apical dominance and occasionally a deeper green color developed in the primary leaves at intermediate UV-B enhancement levels. Dr. Kneull Hinson of the University of Florida who is a soybean geneticist indicated Hardee soybean was one of the parent lines he had been propagating for 12 years which developed curled and wrinkled leaves, stunting and a bushy form when grown under field conditions in Florida. Unless special attention was given the plants, they did not survive and reproduce (Appendix I-34). The cause of this condition was unknown, other lines also showed the symptoms and the inheritance patterns were elusive. The symptoms under field conditions were similar to those observed on 'Hardee' soybeans grown at the Duke University Phytotron. Because of the similarities and the agricultural implications, a larger scale experiment was undertaken with an amendment to the original proposal. Dr. Hinson supplied seed of 19 different varieties for testing. It was also observed that Dr. James Crawl of the University of Florida had among his genetic lines of watermelon in his progeny trials lines that had a "disease" with symptoms similar to those described for UV-B treated watermelon plants. He supplied two numbered progeny from Charleston Gray watermelon crosses that were prone to produce these symptoms under field conditions at the ARC; Leesburg, Florida. These two plus a commercial source of Charleston Gray watermelon were included with the 19 soybean varieties test trials in the Duke Phytotron.

Materials and Methods

The controlled environment chambers modified for UV-B enhancement at the Duke University Phytotron were the same as those described in the screening test of 82 species in Section II (Appendix I-5). As in the first tests of the 82 species, 6 pots per variety were planted in each of 2 chambers per UV-B enhancement regime. $UV\text{-}B_{seu}$ were set for 0, 0.5, 1.0, 1.5 and 2.0 (Table 1). All varieties were thinned for uniformity to two plants per pot after one week. The temperature was set for 26°/22°C day/night and the photoperiod, watering and fertilizer schedules were as before. FS-40 sun lamps with filters for the UV-B enhancement levels were established in the same manner as previously described and protocal for filter changes were the same.

Height was measured twice a week beginning with the second week and the plants were grown in the chambers for 4 weeks. At harvest, data taken on a per pot basis included: 1) total fresh and 2) dry weight, 3) leaf fresh and 4) dry weight, 5) stem fresh and 6) dry weight, 7) root fresh and 8) dry weight, 9) % leaves, 10) % stems, and 11) % roots, 12) leaf area, 13) root: shoot ratio, 14) leaf density, 15) a chlorosis rating of 0-9 and 16) final height. Treatment means and statistical analyses for these parameters to isolate differences among the 5-radiation levels were conducted. In addition, the varieties were ranked by Duncan's Multiple range test for 14 parameters to indicate varietal differences to any given parameter.

A photographic record was made of sample plants of each variety at each $UV\text{-}B_{seu}$ (Appendix I-23 to 27), as well as comparison photographs of different varieties from each of the $UV\text{-}B_{seu}$'s (Appendix I-28-30). Individual and comparison photographs were also taken of the three watermelon varieties (Appendix I-32, 33).

Results

Visual symptoms of the soybeans grown under enhanced UV-B radiation were similar with variations in intensity depending upon the $UV\text{-}B_{seu}$ (Tables 2-36). Stunting and interveinal chlorosis were the first symptoms to appear, followed by convex leaf cupping (Appendix I-31). Later in development buds in the axils of the primary leaves began to grow out and this response was very UV-B-dose responsive (Appendix I-23). Soybeans grown at 2.0 $UV\text{-}B_{seu}$ showed decreased apical dominance the earliest and the lateral shoots had the greatest extension at the end of 4 weeks.

Within the soybean varieties, the percent reduction in biomass as compared to the control ranged from 27 (Hutton) to 60% (Jupiter) and sensitivity ratings were made similar to those given the 82 agricultural species in section 2.

Overall biomass reduction by UV-B treatment was very obvious just from casual inspection of the chambers (Appendix I-23). Within the soybean varieties the percent reduction in biomass as compared to the control ranged from 27 (Hutton) to 60% (Jupiter) and sensitivity ratings were similar to those given the 82 agricultural species in section 2. Varieties showing less than a 30% reduction were classified as moderately sensitive 30-50% as sensitive and greater than 50% reduction in biomass were highly sensitive. Hutton and Cobb varieties were the least sensitive (Tables 7,8). Combining all UV-B enhancement regimes, the Altona variety had the greatest biomass and Santa Maria the least (Table 9).

Leaf densities were increased from 74 (Hutton) to 223% (Bossier) above the mylar control (Tables 10, 11). However, the relative amount of increase did not correspond to reductions in biomass. That is, varieties with low reductions in biomass did not necessarily have thicker leaves.

Soybean varieties with the least reduction in biomass also tended to have

the least reduction in leaf area (Tables 12, 13), leaf dry weight (Tables 14, 15) stem dry weight (Tables 16, 17) and root dry weight (Tables 18, 19). Mean reductions for these parameters ranged from 44 (Hutton) to 78% (Acadian) for leaf area, 10 (Cobb) to 49% (Acadian) for leaf dry weight and 49 (Hutton) to 73% (Hardee) for stem dry weight and 24 (Hutton) to 65% (Jupiter) for root dry weights. On a dry weight basis, stems were most affected, then roots and finally, dry weight of leaves.

Biomass was partitioned into leaves at the expense of stems and roots (Table 20). The percent increase in leaves over the respective Mylar control ranged from 14 (Biloxi) to 38% (Bossier) (Tables 21, 22) and for stems from 17 (Biloxi) to 42% (Hardee) (Tables 23, 24). The percent root values ranged from 14% less than the control (Santa Maria) to 37% more than the control (Acadian) (Tables 25, 26). Thus, root response was highly variable, sometimes increasing or decreasing depending upon the variety. This was reflected in the root: shoot ratio which ranged from a decrease of 19% (Jupiter) below the respective Mylar control to 48% (Acadian) above (Tables 27, 28). As a general rule, the varieties with the least reduction in biomass showed an increase in % roots and an increase in root:shoot ratio.

Each soybean was given a leaf chlorosis rating from 0 to 9 based on the amount of leaf surface showing chlorosis (Tables 29, 30). All varieties became chlorotic to some degree with the mean ratings ranging from 4.5 (Hutton) to 8.5 (Acadian). None of the controls demonstrated any chlorosis. Species with the "highly sensitive" rating also showed more chlorosis and vice versa.

Height was increasingly reduced the longer the soybeans were grown in the chambers. At the end of 2 weeks percent reductions ranged from 10 (Seminole) to 35% (Mineira), (Tables 31, 32) 30 (Biloxi) to 55% (Altona) (Tables 33, 34) at the end of 3 weeks and 42 (Biloxi) to 63% (Altona) (Tables 35,36) at harvest

at the end of 4 weeks. However, height reductions did not necessarily follow biomass reductions.

The watermelon varieties were slow growing in the Phytotron chambers and although UV-B treated plants were reduced in every parameter, the relative sensitivity should be more accurately defined in future studies of a longer duration. Some cotyledons became brown and curled and leaf expansion was completely inhibited (Appendix I-32, 33). The small amount of growth made measurements difficult and a sensitivity rating system with this data would be inappropriate. Data and statistical analysis for the various parameters are included on tables with the soybean varieties.

Discussion

In looking for threshold effects using the parameters measured, it appeared that the 0.5 UV-B_{seu} was greater than threshold under the controlled environment chamber conditions even for species showing the least reductions in biomass, i.e., Hutton, Cobb, Hood, Biloxi. The low of a 17% reduction in biomass can hardly be considered threshold. The abscence of normal plants at any UV-B_{seu} regime was probably due to increase sensitivity to the UV-B_{seu} levels in the low photosynthetically active radiation (PAR) levels in the chambers, ranging from 170to240 . Without sufficient photoprotection which occurs at the higher wavelengths and at higher intensities, accumlative UV-B damage severely limited growth of the soybean varieties.

Plant responses to UV-B radiation were not linear. Decreases appeared to fall into two groups with the percent reductions below the Mylar control being similar for 0.5 and 1.0 UV-B_{seu} and then greater, but similar in magnitude at 1.5 and 2.0 UV-B_{seu}. This suggests a stepwise sensitivity to UV-B radiation and probably occurs as more anabolic functions become affected, either as a

result of increases in dose or reciprocity reactions related to duration of the type without adequate photorepair.

Although the PAR levels in the growth chambers were low in relation to full sunlight, the present study has provided important information for soybean physiologist, breeders and growers who may be interested in introducing new varieties. That there was a difference in sensitivity to UV-B radiation was quite evident.

Leaf, stem and root data indicated large genetic differences in biomass production just among the Mylar control plants (Appendix I-27 to 30) (Tables 2 to 6). Soybeans which were large under Mylar or low light were not necessarily those with the lower percent reductions in biomass or the higher sensitivity ratings. Significant differences among the varieties in sensitivity to UV-B were found. Also, significant varietal differences were found for every parameter measured at every UV-B radiation level. With leaf density within any given UV-B irradiance level, the leaf density of all varieties had less of a difference than among the radiation regimes. A marked difference in leaf density occurred between the Mylar controls and the 0.5 UV-B_{seu} level. Increases in response to UV-B radiation was also evident.

A loss of apical dominance of buds in the axils of primary leaves was observed to be dependent upon the UV-B enhancement level, although this parameter was not measured quantitatively. For many of the varieties one could predict the UV-B_{seu} under which the plant had grown by the length of the shoots from axillary buds of the primary leaves (i.e. see Altona, Davis, Hood, Hutton, Jupiter and other varieties in Appendix I-23-26 for varietal comparisons among UV-B radiation levels). Under the field situation, a bushier plant with more above ground biomass and a reduced root system could result from these responses. If this was the case, yield of beans would probably decrease.

Overall biomass was reduced and this was accompanied by a shift in biomass

partitioning. For every variety, the % biomass in leaves was increased and the % in stems decreased. The latter is the usual stunting response. However, in approximately two-thirds of the varieties, the % biomass found in roots was decreased.

This could have serious consequences for a crop which is usually grown withoug irrigation from two standpoints. First, non-irrigated plants may have reduced yields. Secondly, increased irrigation may occur. In the mid-south and south, soybeans are irrigated if they are grown where facilities are available for irrigating cotton or rice. Also, some soybeans are irrigated in drier regions such as Nebraska. At this time, the decision to irrigate is not based on whether irrigation will increase yields but whether it will increase profits. A reduced root system due to increases in UV-B levels might necessitate irrigation and aggravate already short water supplies in some areas of the United States.

The shift to a short statured plant under enhanced UV-B radiation levels might allow maor northerly indeterminate type soybean characters to be bred into varieties for the south to decrease lodging. However, this would probably have to come via a genetic breeding program because soybean adaptability is very zone specific.

Thus, in light of the significant differences found among soybean varieties in sensitivity to UV-B radiation, it should become yet another factor to be evaluated in a soybean breeding program.

Table 1. Light quality in "C" chambers at the Duke University Phytotron.

UV-B seu[1]	mil CA Filter[2]	Photosynthetically Active Radiation[3] Cool White Lights Only	Photosynthetically Active Radiation[3] Cool White + FS - 40
0.036	M	200	205
0.007	M	240	245
0.540	10+10	235	240
0.500	10+10	240	245
1.120	10	225	230
1.070	10	230	235
1.460	3+5	180	185
1.570	3+5	230	235
2.050	5	235	240
2.050	5	210	215

[1] $UV\text{-}B_{seu}$ defined in Section I.

[2] M = mylar type S, 5 and 10 are mil thicknesses of cellulose acetate (CA).

[3] Photosynthetically active radiation measured in microeinsteins m^{-2} sec^{-1}.

Table 2 . Ranking of soybean varieties, high to low, by Duncans Multiple Range Test for 13 different parameters under Mylar Control for UV-B enhancement radiation treatments.[1]

No. Soybean Var.	Var No.	Leaf Area (cm^2)		Var No.	Leaf Dry Wt. (g)		Var No.	Root Dry Wt. (g)		Var No.	Stem Dry Wt. (g)	
1=Acadian	3	A	385	18	A	.833	18	A	.405	2	A	.655
2=Americana	6	A	377	4	AB	.771	2	AB	.374	6	B	.555
3=Altona	4	A	372	2	ABC	.738	6	AB	.364	4	B	.532
4=Biloxi	18	A	364	15	BCD	.669	4	AB	.350	3	BC	.495
5=Bossier	13	B	300	6	BCD	.668	13	AB	.347	12	BC	.493
6=Centennial	15	B	297	13	B→E	.651	12	AB	.343	18	BCD	.482
7=Cobb	1	BC	285	12	B→E	.626	15	ABC	.328	13	BCD	.480
8=Davis	9	BCD	262	10	C→F	.586	10	BCD	.272	15	CDE	.423
9=Forrest	2	BCD	262	11	D→G	.539	16	CDE	.253	9	DE	.412
10=Hood	12	BCD	256	9	D→G	.528	11	DEF	.225	1	EF	.406
11=Hutton	7	BCD	244	1	D→G	.528	9	D→G	.220	10	EF	.401
12=Jupiter	10	BCD	243	19	D→H	.512	7	D→G	.204	11	EF	.386
13=Mineira	14	CD	231	3	D→H	.508	8	D→G	.197	7	EFG	.361
14=Otootan	17	CD	224	16	E→H	.498	3	D→H	.191	17	E→H	.355
15=Pickett	8	CD	222	17	FGH	.458	19	E→H	.178	16	E→H	.348
16=Roanoke	16	D	218	14	FGH	.442	1	E→H	.168	5	FGH	.333
17=Santa Maria	5	D	218	7	FGH	.432	14	E→H	.161	14	GHI	.308
18=Seminole	19	D	217	8	GH	.400	5	FGH	.158	19	HI	.284
19=Hardee	11	D	198	5	H	.360	17	FGH	.155	8	HI	.281
Watermelon												
1=CGFL. 77-1	3	A	19	1	A	1.118	3	A	.248	1	A	.348
2=CGFL. 77-2	2	A	19	2	A	1.085	2	A	.218	2	AB	.301
3=Charl. Gray	1	A	18	3	A	1.074	1	A	.176	3	B	.209

[1] UV-B enhancement defined in section 1.

Table 2. Continued

Var No.	Density (g/dm^2)		Var No.	% Leaf		Var No.	% Root		Var No.	% Stem		Var No.	R/S Ratio	
11	A	.28	19	A	53	18	A	24	3	A	42	18	A	.315
10	A	.24	14	B	49	13	AB	23	5	AB	40	13	A	.305
12	A	.24	18	B	48	12	ABC	23	2	BC	37	12	AB	.297
19	A	.24	1	BC	47	6	ABC	22	1	BC	37	15	AB	.293
16	A	.23	17	BC	47	15	ABC	22	17	BC	37	6	AB	.292
18	A	.23	15	BC	47	8	ABC	22	7	BCD	36	8	AB	.287
15	A	.22	4	BCD	47	16	ABC	21	9	B→E	36	16	A→D	.274
13	A	.22	10	B→E	47	10	A→D	21	6	C→F	35	10	A→D	.274
17	A	.21	16	B→F	46	2	A→D	21	14	C→F	35	2	A→D	.271
4	A	.21	11	B→F	46	4	A→E	20	12	C→G	34	4	A→E	.258
6	A	.20	8	B→G	46	7	A→E	20	11	C→G	34	7	A→E	.257
9	A	.20	9	B→G	46	11	A→F	20	4	D→G	33	11	A→E	.248
3	A	.19	13	B→G	44	9	C→F	18	13	D→G	33	9	A→F	.228
2	A	.19	7	C→G	43	5	C→F	18	16	D→H	32	5	A→F	.226
14	A	.19	12	C→G	43	19	C→G	18	10	E→H	32	19	A→F	.224
1	A	.18	3	D→G	42	14	D→G	17	8	FGH	32	14	B→F	.206
8	A	.18	6	EFG	42	3	E→H	16	15	GHI	31	3	C→F	.190
7	A	.18	5	FG	42	17	E→H	16	19	HI	29	17	C→F	.188
5	A	.17	2	G	42	1	FGH	15	18	I	28	1	DEF	.183
1	A	.65	2	A	68	3	A	19	1	A	20	3	A	.253
2	A	.59	1	A	68	2	AB	14	2	AB	18	2	A	.160
3	A	.58	3	A	67	1	B	12	3	B	14	1	A	.137

Table 2. Continued

Var No.	Dry Wt. Biomass(g)		Var No.	Height 2 (mm)		Var No.	Height 3 (mm)		Var No.	Height 4 (mm)		Var No.	Chlorosis Rating 0-9	
2	A	1.767	3	A	183	3	A	374	3	A	495	1	A	0
18	AB	1.719	2	A	178	2	B	301	13	B	415	2	A	0
4	ABC	1.653	4	B	156	13	C	270	2	BC	406	3	A	0
6	ABC	1.588	13	B	151	4	C	270	4	BCD	380	4	A	0
13	BCD	1.478	6	B	151	1	CD	262	9	BCD	379	5	A	0
12	BCD	1.462	1	C	134	6	CD	258	1	CDE	376	6	A	0
15	CDE	1.420	12	C	134	7	CD	257	6	CDE	373	7	A	0
10	DEF	1.258	11	CD	128	12	CDE	248	7	DEF	357	8	A	0
3	EFG	1.194	10	CD	127	9	DE	242	12	DEF	353	9	A	0
9	E→H	1.160	9	CD	126	5	EF	229	14	EF	341	10	A	0
11	FGH	1.150	7	D	121	10	FG	211	5	FG	330	11	A	0
1	F→I	1.103	16	E	107	11	G	204	17	FG	327	12	A	0
16	F→I	1.099	17	E	105	17	G	204	11	GH	301	13	A	0
7	F→I	0.997	5	EF	99	14	GH	189	10	GH	299	14	A	0
19	G→J	0.973	8	EF	96	16	GH	187	15	GH	293	15	A	0
17	G→J	0.968	18	EF	95	8	GH	186	16	H	287	16	A	0
14	G→J	0.911	15	FG	90	15	GH	185	8	H	282	17	A	0
8	HIJ	0.878	14	FG	87	18	H	172	18	H	276	18	A	0
5	IJ	0.850	19	G	79	19	I	141	19	I	237	19	A	0
1	A	1.654	1	A	26	1	A	26	1	A	32	1	A	7.8
2	A	1.604	2	B	21	2	B	20	2	B	24	3	A	6.4
3	A	1.531	3	B	19	3	B	19	3	B	24	2	A	6.3

Table 3. Ranking of soybean varieties, high to low, by Duncans Multiple Range Test for 13 different parameters under UV-B enhancement radiation treatment 2.[1]

No. Soybean Var.	Var No.	Leaf Area (cm^2)		Var No.	Leaf Dry Wt. (g)		Var No.	Root Dry Wt. (g)		Var No.	Stem Dry Wt. (g)	
1=Acadian	2	A	262	2	A	.621	2	A	.312	2	A	.383
2=Americana	15	B	197	18	AB	.593	4	B	.237	4	B	.328
3=Altona	6	B	194	4	ABC	.579	6	BC	.226	6	BC	.316
4=Biloxi	18	BC	185	15	ABC	.578	15	BC	.213	15	DE	.251
5=Bossier	4	BC	185	11	A→D	.525	16	BCD	.202	16	DE	.236
6=Centennial	7	BC	178	13	A→D	.518	10	B→E	.197	11	DE	.234
7=Cobb	13	BC	174	6	A→D	.503	18	B→E	.189	10	DE	.229
8=Davis	10	BC	174	10	A→E	.490	9	B→F	.180	13	DE	.228
9=Forrest	16	BCD	157	9	A→F	.475	13	B→F	.169	7	DE	.228
10=Hood	11	CD	150	16	A→F	.475	7	C→G	.161	9	EF	.215
11=Hutton	9	CD	149	7	B→G	.431	11	C→G	.160	18	EF	.210
12=Jupiter	12	DE	124	12	C→G	.401	3	D→H	.136	12	EFG	.202
13=Mineira	17	EF	108	19	D→G	.351	12	E→H	.131	17	FGH	.163
14=Otootan	19	EF	107	14	EFG	.322	8	FGH	.128	3	GHI	.150
15=Pickett	3	EF	97	17	EFG	.321	14	GHI	.101	14	HIJ	.138
16=Roanoke	14	EF	95	8	FG	.309	1	GHI	.098	8	HIJ	.128
17=Santa Maria	8	EF	93	3	G	.289	5	HI	.090	5	HIJ	.118
18=Seminole	5	EF	86	5	G	.286	19	HI	.068	19	IJ	.097
19=Hardee	1	F	80	1	G	.258	17	I	.061	1	J	.092
Watermelon												
1=CGFL.77-1	1	A	22	1	A	1.078	3	A	.197	1	A	.274
2=CGFL.77-2	3	A	20	2	A	0.984	1	A	.128	2	A	.213
3=Charl. Gary	2	A	19	3	A	0.926	2	A	.124	3	A	.208

[1] UV-B enhancement defined in section 1.

Table 3. Continued

Var No.	Density (g/dm^2)		Var No.	% Leaf		Var No.	% Root		Var No.	% Stem		Var No.	R/S Ratio	
5	A	.60	19	A	67	3	A	23	17	A	30	3	A	.353
14	A	.37	18	B	60	2	A	23	6	A	30	2	AB	.307
11	A	.36	5	B	60	1	AB	22	2	AB	29	8	ABC	.286
19	A	.35	17	B	59	8	AB	22	4	ABC	29	1	ABC	.283
12	A	.34	14	BC	58	6	AB	22	7	A→D	28	6	ABC	.278
4	A	.34	1	BC	58	16	AB	21	12	B→E	27	16	ABC	.276
8	A	.34	11	BC	57	4	AB	20	3	C→F	26	4	BC	.259
18	A	.34	13	BC	57	9	AB	20	16	C→G	26	9	BC	.255
16	A	.33	15	BCD	56	15	AB	20	11	D→G	26	10	BC	.252
9	A	.33	12	B→E	55	7	ABC	20	10	D→G	26	15	BC	.252
1	A	.33	8	B→E	55	10	ABC	20	13	D→G	25	7	BCD	.249
17	A	.33	9	B→E	55	18	ABC	19	9	D→G	25	18	BCD	.232
15	A	.31	10	B→E	55	13	BC	18	14	EFG	24	13	BCD	.225
3	A	.31	7	C→F	53	14	BC	18	15	E→H	24	14	BCD	.220
13	A	.30	16	C→G	53	12	BC	18	5	FGH	23	12	BCD	.218
10	A	.28	4	D→G	51	5	BCD	17	8	GHI	23	5	BCD	.213
6	A	.26	3	EFG	51	11	BCD	17	18	HIJ	21	11	CDE	.208
7	A	.24	6	FG	48	19	DEF	13	1	IJ	21	19	DEF	.157
2	A	.24	2	G	48	17	EFG	11	19	JK	20	17	EF	.122
1	A	.56	2	A	75	3	A	15	1	A	19	3	A	.195
2	A	.54	1	A	72	2	B	9	3	A	17	2	B	.102
3	A	.52	3	A	68	1	B	9	2	A	16	1	B	.097

Table 3. Continued

Var No.	Dry Wt. Biomass(g)		Var No.	Height 2 (mm)		Var No.	Height 3 (mm)		Var No.	Height 4 (mm)		Var No.	Chlorosis Rating 0-9	
2	AB	1.316	4	A	156	2	A	224	2	A	256	1	A	8.0
4	BC	1.144	2	A	153	4	AB	216	6	A	249	3	AB	7.1
6	CD	1.044	3	B	141	3	B	206	4	AB	247	4	BC	6.1
15	CD	1.042	6	B	140	6	B	205	12	BC	228	9	CD	5.0
18	CDE	0.993	1	C	121	12	C	182	3	CD	221	5	CD	5.0
11	CDE	0.919	12	C	121	7	D	166	7	CDE	214	14	CD	4.8
10	CDE	0.916	10	CD	115	9	D	166	10	CDE	210	18	CD	4.7
13	CDE	0.916	11	CD	112	10	D	165	9	C→F	207	17	CD	4.5
16	CDE	0.913	9	CD	111	11	D	163	11	DEF	204	6	CDE	4.4
9	DE	0.870	13	DE	108	1	DE	158	13	EFG	193	19	CDE	4.4
7	DE	0.819	17	DEF	107	17	DE	158	16	EFG	193	8	DE	4.0
12	EF	0.733	7	EFG	99	13	DEF	152	15	FGH	185	15	DE	3.7
3	FG	0.575	18	E→H	98	15	EFG	148	17	GHI	181	12	DE	3.4
8	FG	0.564	15	FGH	97	16	FGH	142	1	HI	171	7	DE	3.4
14	FG	0.560	16	FGH	97	18	GHI	137	18	HIJ	168	16	DE	3.3
17	FG	0.544	5	GHI	89	5	HI	131	14	HIJ	165	10	DE	3.2
19	FG	0.516	14	HI	88	8	HI	130	8	IJ	162	11	DE	3.1
5	FG	0.493	8	I	85	14	I	128	5	J	148	13	DE	3.1
1	G	0.448	19	J	72	19	J	102	19	K	119	2	E	2.5
1	A	1.480	1	A	25	1	A	27	1	A	34	1	A	5.1
3	A	1.331	2	B	21	2	B	21	3	AB	27	3	A	4.6
2	A	1.321	3	B	21	3	B	20	2	B	25	2	A	4.4

Table 4. Ranking of soybean varieties, high to low, by Duncans Multiple Range Test for 13 different parameters under UV-B enhancement radiation treatment 3.[1]

No. Soybean Var.	Var No.	Leaf Area (cm^2)		Var No.	Leaf Dry Wt. (g)		Var No.	Root Dry Wt. (g)		Var No.	Stem Dry Wt. (g)	
1=Acadian	2	A	194	2	AB	.657	2	A	.248	2	A	.298
2=Americana	6	B	154	4	BC	.562	10	B	.193	4	AB	.287
3=Altona	13	BC	147	18	CD	.553	11	BC	.185	6	B	.256
4=Biloxi	18	BC	144	6	CDE	.515	18	BC	.183	7	C	.208
5=Bossier	4	BCD	136	11	CDE	.505	6	BC	.180	11	C	.203
6=Centennial	15	BCD	132	13	C→F	.476	4	BC	.178	5	CDE	.183
7=Cobb	11	BCD	131	15	C→G	.463	13	BCD	.163	10	CDE	.175
8=Davis	7	CD	127	7	C→H	.451	7	B→F	.143	3	CDE	.173
9=Forrest	10	DE	117	10	D→H	.443	8	C→F	.140	13	CDE	.173
10=Hood	9	DEF	113	9	E→I	.411	16	C→F	.139	9	DEF	.161
11=Hutton	16	EFG	98	16	F→J	.383	15	DEF	.123	18	D→G	.154
12=Jupiter	8	EFG	89	8	F→J	.378	1	D→G	.116	8	E→H	.145
13=Mineira	5	GHI	80	5	F→J	.363	5	D→G	.116	16	FGH	.132
14=Otootan	12	GHI	78	3	G→J	.353	3	E→H	.109	15	GH	.123
15=Pickett	3	GHI	76	12	H→K	.341	9	FGH	.103	12	GH	.121
16=Roanoke	17	HI	70	9	IJK	.319	12	FGH	.103	17	HI	.113
17=Santa Maria	14	HI	69	1	JK	.292	19	GHI	.072	1	HI	.111
18=Seminole	1	I	62	14	K	.239	14	HI	.063	14	IJ	.083
19=Hardee	19	I	60	17	K	.237	17	I	.053	19	J	.076
Watermelon												
1=CGFL.77-1	1	A	17	2	A	1.032	1	A	.155	1	A	.253
2=CGFL.77-2	2	A	16	1	AB	0.901	2	A	.147	2	B	.188
3=Charl. Gray	3	B	10	3	B	0.750	3	B	.113	3	C	.116

[1]UV-B enhancement defined in section 1.

Table 4. Continued

Var No.	Density (g/dm^2)		Var No.	% Leaf		Var No.	% Root		Var No.	% Stem		Var No.	R/S Ratio	
19	A	.55	19	A	69	1	A	22	4	A	28	10	A	.298
3	A	.48	15	ABC	66	10	AB	22	17	A	28	1	A	.288
12	A	.48	14	BCD	63	16	ABC	21	5	AB	28	16	AB	.270
1	A	.48	18	B→E	62	8	ABC	21	3	AB	27	8	AB	.268
5	A	.47	9	C→F	61	18	A→D	20	6	AB	27	11	ABC	.256
16	A	.43	12	D→G	60	2	A→D	20	7	ABC	26	18	ABC	.256
4	A	.43	13	D→H	59	11	A→E	20	2	BCD	25	2	ABC	.255
8	A	.43	17	D→H	59	13	A→E	20	9	CDE	23	13	ABC	.248
11	A	.41	16	D→H	59	6	A→F	19	11	DE	23	6	A→D	.237
14	A	.41	11	D→H	57	12	B→G	18	10	DE	22	12	BCD	.223
18	A	.41	8	E→H	57	7	C→G	18	8	DE	22	7	BCD	.217
10	A	.40	1	FGH	57	5	C→G	17	12	E	22	5	B→E	.212
9	A	.38	7	FGH	56	4	C→G	17	14	E	21	4	B→E	.211
17	A	.37	10	FGH	56	3	D→J	17	13	E	21	3	B→E	.209
15	A	.37	3	GH	56	15	D→G	17	1	E	21	15	B→E	.207
7	A	.36	5	GH	55	14	E→H	16	16	EF	20	14	CDE	.194
13	A	.35	2	GH	55	9	FGH	15	18	FG	17	9	DEF	.184
6	A	.34	4	H	54	19	GHI	15	15	G	17	19	DEF	.177
2	A	.34	6	H	54	17	HIJ	13	19	GH	16	17	EF	.154
3	A	.79	3	A	77	1	A	13	1	A	21	1	A	.151
2	AB	.68	2	A	75	3	A	12	2	B	14	3	A	.134
1	B	.58	1	B	67	2	A	11	3	B	12	2	A	.128

Table 4. Continued

Var No.	Dry Wt. Biomass(g)		Var No.	Height 2 (mm)		Var No.	Height 3 (mm)		Var No.	Height 4 (mm)		Var No.	Chlorosis Rating 0-9	
2	A	1.203	4	A	141	4	A	196	4	A	227	1	A	8.9
4	B	1.027	2	AB	134	6	B	177	6	AB	219	3	A	8.9
6	BC	0.951	3	AB	134	2	B	177	2	B	208	4	AB	7.2
11	BC	0.893	6	B	128	3	B	173	3	C	187	19	BC	6.3
18	BC	0.890	1	C	116	12	C	148	7	C	186	18	BC	6.2
10	CD	0.810	12	D	105	7	CD	142	11	CD	174	14	BC	6.0
13	CD	0.811	9	D	105	9	CD	140	12	D	171	2	BCD	5.8
7	CD	0.803	13	DE	101	11	CD	139	10	D	169	5	C→F	4.9
15	DE	0.709	11	DEF	99	1	D	137	9	DE	165	12	C→F	4.9
9	DEF	0.674	10	DEF	96	17	DE	133	13	DE	163	17	C→F	4.8
8	DEF	0.663	5	D→G	95	13	DE	132	17	EF	154	8	C→F	4.4
5	DEF	0.661	7	D→G	94	10	DE	131	1	F	146	9	C→F	4.4
16	DEF	0.654	17	E→H	90	5	EF	125	18	F	145	16	DEF	4.0
3	EF	0.634	18	FGH	90	18	EF	124	8	F	144	6	DEF	3.9
12	EFG	0.564	8	GHI	85	8	FG	119	5	F	144	7	EF	3.4
1	FGH	0.518	16	HI	83	16	FG	117	16	F	142	13	EF	3.4
19	GH	0.467	15	IJ	76	15	GH	110	15	G	129	10	EF	3.2
17	H	0.402	14	IJ	75	14	H	100	14	G	120	11	EF	3.2
14	H	0.386	19	J	71	19	I	86	19	H	91	15	F	3.1
2	A	1,511	1	A	24	1	A	24	1	A	28	1	A	5.4
1	A	1.335	2	B	18	3	B	19	2	B	21	3	A	5.2
3	B	1.277	3	B	18	2	B	16	3	B	20	2	A	5.1

Table 5. Ranking of soybean varieties, high to low, by Duncans Multiple Range Test for 13 different parameters under UV-B enhancement radiation treatment 4.[1]

No. Soybean Var.	Var No.	Leaf Area (cm^2)		Var No.	Leaf Dry Wt. (g)		Var No.	Root Dry Wt. (g)		Var No.	Stem Dry Wt. (g)	
1=Acadian	2	A	87	2	A	.427	2	A	.201	2	A	.233
2=Americana	18	B	68	4	AB	.415	11	ABC	.173	4	B	.198
3=Altona	4	BC	66	11	AB	.404	18	ABC	.170	6	BC	.183
4=Biloxi	11	BC	65	18	AB	.398	6	ABC	.168	11	CDE	.159
5=Bossier	6	CD	58	10	ABC	.355	4	ABC	.166	10	D→G	.139
6=Centennial	10	DE	56	6	BC	.343	13	BCD	.163	7	E→H	.127
7=Cobb	15	DE	54	15	CD	.318	16	B→E	.159	12	E→H	.126
8=Davis	7	DE	53	13	CD	.312	10	B→E	.158	1	E→I	.122
9=Forrest	13	DE	51	12	CDE	.308	15	C→F	.145	18	E→I	.121
10=Hood	12	DE	51	16	C→F	.295	12	D→G	.128	9	F→I	.117
11=Hutton	16	EF	47	7	C→F	.289	7	EFG	.125	3	GHI	.110
12=Jupiter	8	FG	41	3	D→G	.261	9	FG	.120	13	GHI	.110
13=Mineira	1	GH	36	9	D→G	.261	8	FG	.117	15	G→J	.103
14=Otootan	9	GH	35	8	D→H	.244	1	GH	.099	16	G→J	.103
15=Pickett	3	GH	35	5	E→H	.228	3	GHI	.093	8	H→K	.093
16=Roanoke	5	GH	34	1	FGH	.218	5	HIJ	.082	5	IJK	.085
17=Santa Maria	14	HI	31	19	GH	.188	19	IJ	.063	17	JKL	.068
18=Seminole	17	HI	30	14	GH	.182	14	IJ	.063	14	KL	.063
19=Hardee	19	I	23	17	H	.176	17	J	.055	19	L	.038
Watermelon												
1=CGFL.77-1	1	A	10	2	A	.746	2	A	.194	3	A	.165
2=CGFL.77-2	2	A	10	1	A	.679	1	A	.179	1	A	.164
3=Charl. Gray	3	A	8	3	A	.657	3	A	.163	2	A	.150

[1] UV-B enhancement defined in section 1.

Table 5. Continued

Var No.	Density (g/dm^2)		Var No.	% Leaf		Var No.	% Root		Var No.	% Stem		Var No.	R/S Ratio	
19	A	.81	19	AB	66	16	A	28	1	A	27	16	A	.407
3	A	.76	17	BC	61	13	AB	28	6	A	27	13	AB	.392
9	A	.75	14	C	60	8	ABC	26	2	AB	26	8	ABC	.351
5	A	.67	5	CD	58	15	A→D	25	4	ABC	26	15	ABC	.347
10	A	.66	18	CD	58	18	A→D	24	3	A→D	24	18	A→D	.330
1	A	.64	3	CDE	56	6	A→E	24	7	A→D	24	6	BCD	.322
12	A	.63	15	CDE	56	10	A→F	24	9	A→E	23	10	BCD	.319
11	A	.63	11	CDE	56	9	B→F	24	12	B→F	22	9	B→E	.314
16	A	.63	12	CDE	55	2	C→F	23	17	C→G	21	1	B→E	.313
4	A	.63	10	C→F	55	11	C→G	23	11	C→G	21	2	B→E	.308
13	A	.62	8	DEF	54	7	C→G	23	10	C→G	21	11	C→F	.303
17	A	.60	13	DEF	54	12	C→H	23	5	C→G	21	7	C→F	.302
8	A	.60	7	DEF	53	1	C→I	22	8	D→H	20	12	C→F	.295
18	A	.60	4	DEF	53	19	C→J	21	14	D→H	20	19	C→G	.277
15	A	.59	9	DEF	53	4	C→J	21	15	E→I	19	4	C→G	.270
6	A	.59	16	DEF	53	5	D→J	21	16	E→I	19	5	C→G	.265
14	A	.58	1	EF	50	14	E→J	20	13	E→I	18	14	D→G	.249
7	A	.55	2	EF	50	3	F→J	19	18	F→I	17	3	D→G	.248
2	A	.50	6	F	49	17	HIJ	18	19	J	13	17	FG	.221
3	A	.90	2	A	67	2	A	18	3	A	17	2	A	.231
2	AB	.79	3	A	66	1	A	18	1	A	16	1	A	.220
1	B	.70	1	A	66	3	A	17	2	A	14	3	A	.206

Table 5. Continued

Var No.	Dry Wt. Biomass(g)		Var No.	Height 2 (mm)		Var No.	Height 3 (mm)		Var No.	Height 4 (mm)		Var No.	Chlorosis Rating 0-9	
2	A	.860	4	A	129	4	A	171	4	A	211	14	A	9.0
4	AB	.779	2	AB	122	2	B	158	2	B	184	17	A	8.8
11	BC	.736	6	BC	113	6	C	143	6	C	153	3	A	8.7
6	BCD	.695	3	C	111	3	C	141	3	CD	149	19	A	8.6
18	BCD	.689	1	C	108	12	CD	137	12	CD	149	4	AB	8.5
10	CDE	.652	12	C	104	11	CDE	132	11	CD	146	18	ABC	8.3
13	DEF	.584	11	D	93	1	DE	127	10	DE	141	1	ABC	8.3
15	EFG	.566	9	D	92	17	EF	121	17	EF	135	9	BCD	7.7
12	EFG	.562	13	DE	90	10	EF	120	1	EF	135	16	CD	7.5
16	EFG	.557	10	DE	89	9	FG	114	18	FG	130	6	DE	7.4
7	E→H	.541	7	DEF	82	13	FGH	113	7	FG	127	7	DEF	7.2
9	F→I	.498	17	EF	81	7	F→I	111	13	FGH	126	5	DEF	7.1
3	GHI	.463	18	EF	81	18	F→I	110	9	GHI	122	8	D→G	6.8
8	GHI	.453	5	FG	77	5	G→J	102	16	HIJ	117	2	E→H	6.6
1	HI	.439	16	FG	77	8	G→J	102	8	IJK	113	13	F→I	6.4
5	IJ	.395	14	FG	75	16	HIJ	101	5	JK	111	15	F→I	6.3
14	J	.308	8	FG	72	14	IJ	99	14	JK	110	10	GHI	6.2
17	J	.298	15	G	69	15	J	94	15	K	104	12	HI	6.0
19	J	.289	19	H	56	19	K	74	19	L	84	11	I	5.8
2	A	1.090	1	A	23	1	A	22	1	A	23	2	A	9.0
1	A	1.022	2	B	18	3	B	19	2	B	19	3	A	9.0
3	A	0.985	3	B	17	2	B	18	3	B	18	1	A	8.9

Table 6. Ranking of soybean varieties, high to low, by Duncans Multiple Range Test for 13 different parameters under UV-B enhancement radiation treatment 5.[1]

No. Soybean Var.	Var No.	Leaf Area (cm^2)		Var No.	Leaf Dry Wt. (g)		Var No.	Root Dry Wt. (g)		Var No.	Stem Dry Wt. (g)	
1=Acadian	6	A	138	18	A	.548	18	A	.244	2	AB	.254
2=Americana	2	AB	119	2	AB	.481	13	BC	.186	6	BC	.239
3=Altona	15	B	114	11	AB	.479	16	BC	.183	4	BCD	.217
4=Biloxi	18	BC	111	15	AB	.476	2	CD	.173	11	CDE	.190
5=Bossier	11	BCD	101	4	ABC	.468	15	CD	.169	18	CDE	.190
6=Centennial	4	B→E	98	6	ABC	.453	6	CD	.168	10	C→F	.182
7=Cobb	10	C→F	91	10	BCD	.422	10	CD	.164	9	D→G	.178
8=Davis	13	C→F	90	13	B→E	.400	11	CDE	.153	15	D→G	.174
9=Forrest	7	D→G	83	16	B→E	.387	7	CDE	.152	7	D→G	.171
10=Hood	12	D→G	78	7	B→F	.371	8	DEF	.140	13	D→G	.171
11=Hutton	5	E→H	76	9	C→G	.351	9	DEF	.140	12	D→H	.157
12=Jupiter	16	FGH	75	12	D→G	.333	4	D→G	.134	16	E→I	.143
13=Mineira	1	FGH	74	8	D→G	.310	12	EFG	.121	3	E→I	.142
14=Otootan	9	F→I	70	1	D→G	.303	19	FGH	.102	5	E→I	.130
15=Pickett	8	G→J	66	5	EFG	.298	3	GH	.098	17	E→I	.130
16=Roanoke	3	G→J	60	3	EFG	.295	1	H	.079	8	F→I	.125
17=Santa Maria	17	HIJ	54	19	EFG	.288	5	H	.078	1	GHI	.122
18=Seminole	14	IJ	49	17	FG	.263	14	H	.063	14	HI	.100
19=Hardee	19	J	47	14	G	.246	17	H	.063	19	I	.084
Watermelon												
1=CGFL.77-1	3	A	57	3	A	.766	2	A	.197	3	A	.249
2=CGFL.77-2	2	A	51	2	AB	.649	3	A	.131	1	AB	.190
3=Charl. Gray	1	A	44	1	B	.416	1	A	.102	2	B	.166

[1]UV-B enhancement defined in section 1.

Table 6. Continued

Var No.	Density (g/dm^2)		Var No.	% Leaf		Var No.	% Root		Var No.	% Stem		Var No.	R/S Ratio	
19	A	.66	19	A	61	16	A	26	17	A	28	16	A	.348
16	A	.56	14	AB	60	18	AB	25	2	AB	28	18	AB	.330
18	A	.55	1	ABC	59	13	ABC	24	6	AB	28	13	ABC	.327
14	A	.54	5	A→D	59	8	ABC	24	3	ABC	27	8	ABC	.325
17	A	.54	17	A→D	59	7	A→D	22	9	ABC	27	7	A→D	.286
3	A	.52	11	A→E	58	10	BCD	21	4	ABC	26	10	BCD	.275
9	A	.52	15	A→E	58	19	BCD	21	12	A→D	26	19	BCD	.273
4	A	.51	4	A→F	57	9	BCD	21	5	A→D	26	9	B→E	.268
12	A	.50	18	B→G	56	15	CD	20	1	A→E	25	15	C→F	.258
8	A	.50	3	C→G	55	6	DE	19	14	B→E	24	12	D→H	.242
11	A	.49	12	C→G	55	12	DE	19	7	B→E	24	6	D→H	.240
10	A	.49	10	D→G	55	2	DE	19	10	C→F	24	2	D→H	.237
13	A	.48	16	D→G	54	11	DE	19	11	C→F	23	11	D→H	.231
5	A	.46	8	EFG	54	3	DE	18	13	D→H	23	3	D→I	.223
7	A	.45	7	FG	54	4	EF	16	8	E→I	22	4	E→J	.197
15	A	.44	13	FG	53	1	EFG	16	15	E→I	21	1	F→J	.192
1	A	.43	2	FG	53	14	EFG	15	16	G→J	20	14	G→J	.184
2	A	.42	6	FG	53	5	EFG	15	18	HIJ	19	5	HIJ	.180
6	A	.36	9	G	52	17	FG	13	19	J	18	17	J	.150
2	A	.21	3	A	64	2	A	19	1	A	28	2	A	.280
3	A	.21	2	A	63	1	A	15	3	AB	23	1	A	.177
1	A	.16	1	A	58	3	A	13	2	B	18	3	A	.152

Table 6. Continued

Var No.	Dry Wt. Biomass(g)		Var No.	Height 2 (mm)		Var No.	Height 3 (mm)		Var No.	Height 4 (mm)		Var No.	Chlorosis Rating 0-9	
18	A	.982	3	A	121	4	A	170	6	A	202	14	A	9.0
2	AB	.908	2	AB	119	6	A	164	4	AB	199	3	A	8.9
6	ABC	.860	6	AB	117	2	A	160	2	ABC	190	1	AB	8.8
11	A→D	.822	1	AB	115	3	A	160	3	A→D	176	4	ABC	8.5
4	A→D	.819	4	B	113	12	B	149	12	BCD	172	9	A→D	8.3
15	A→D	.819	12	C	103	1	BC	141	9	B→E	171	19	A→E	8.3
10	B→E	.770	9	C	102	9	BC	139	8	CDE	168	18	A→F	7.9
13	B→E	.757	10	CD	98	11	CD	135	10	CDE	168	16	A→G	7.8
16	C→F	.712	13	CD	96	10	CD	134	11	CDE	168	17	A→H	7.7
7	C→G	.693	11	D	94	17	CD	132	1	DEF	159	7	B→J	7.4
9	E→H	.669	17	D	91	7	DE	124	17	DEF	152	12	B→J	7.4
12	E→I	.611	7	E	83	13	DE	124	7	DEF	152	8	C→K	7.3
8	F→J	.575	5	EF	82	5	EF	116	13	D→G	148	6	D→K	6.9
3	G→J	.535	16	EFG	79	15	FG	110	15	EFG	141	10	D→K	6.9
5	HIJ	.505	8	FG	75	8	FG	109	5	FG	134	2	E→K	6.9
1	HIJ	.503	18	FG	75	16	FG	108	16	FG	133	13	F→K	6.7
19	IJ	.474	14	G	74	18	FG	105	18	FG	132	5	G→K	6.4
17	IJ	.456	15	G	73	14	G	102	14	G	121	11	JK	6.1
14	J	.409	19	H	61	19	H	77	19	H	87	15	K	5.9
3	A	1.146	1	A	26	1	A	50	1	A	62	1	A	0
2	AB	1.012	2	A	26	3	A	39	3	A	59	2	A	0
1	B	0.708	3	A	24	2	A	39	2	A	56	3	A	0

Table 7. Mean dry weight biomass in grams per pot by UV-B enhancement regime[1] and corresponding percent reductions below the mylar control (UV-B enhancement regime #1).

Variety	UV-B Enhancement Regime										
Soybean	1	2	2-%	3	3-%	4	4-%	5	5-%	Sum%	Mean%
1. Acadian	1.10	0.44	60	0.52	53	0.44	60	0.50	55	228	57.0
2. Americana	1.77	1.31	26	1.20	32	0.86	51	0.91	49	158	39.5
3. Altona	1.19	0.58	51	0.63	47	0.46	61	0.54	55	214	53.5
4. Biloxi	1.65	1.14	31	1.02	38	0.78	53	0.82	49	171	42.8
5. Bossier	0.85	0.49	42	0.66	22	0.40	53	0.51	40	157	39.3
6. Centennial	1.59	1.04	35	0.95	40	0.70	56	0.86	46	177	44.3
7. Cobb	1.0	0.82	18	0.80	20	0.54	46	0.59	31	115	28.8
8. Davis	0.88	0.56	37	0.66	25	0.45	49	0.58	34	145	36.3
9. Forrest	1.16	0.87	25	0.67	42	0.50	57	0.67	42	166	41.5
10. Hood	1.26	0.92	27	0.81	36	0.66	48	0.77	39	150	37.5
11. Hutton	1.15	0.92	20	0.89	23	0.73	37	0.82	29	109	27.3
12. Jupiter	1.46	0.73	50	0.56	61	0.56	59	0.61	69	239	59.8
13. Mineira	1.47	0.92	38	0.81	45	0.58	61	0.76	48	192	48.0
14. Ottotan	0.91	0.56	38	0.29	57	0.31	66	0.41	55	216	54.0
15. Pickett	1.42	1.04	27	0.71	50	0.57	60	0.82	42	179	44.8
16. Roanoke	1.10	0.91	17	0.65	41	0.56	49	0.71	35	142	35.5
17. Santa Maria	0.97	0.54	44	0.40	59	0.30	69	0.46	53	225	56.3
18. Seminole	1.72	0.99	42	0.89	48	0.69	60	0.98	58	208	52.0
19. Hardee	0.97	0.52	46	0.47	52	0.29	70	0.47	52	220	55.0
Watermelon											
1. CGF177-1	0.70	0.15	79	0.13	81	0.10	85	0.17	76	321	80.3
2. CGF177-2	1.01	0.13	87	0.14	86	0.11	89	0.16	84	346	86.5
3. Charl. Gray	1.15	0.13	88	0.10	91	0.10	91	0.15	87	357	89.3

[1] UV-B enhancement levels 1 to 5 defined in section I.

Table 8. Duncan's Multiple Range Test for Total Dry Weight differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	A	B	B	B	B
2. Americana	A	B	B	C	C
3. Altona	A	C,B	B	C	C,B
4. Biloxi	A	B	C,B	D	C,D
5. Bossier	A	C	B	C	C
6. Centennial	A	B	B	C	C,B
7. Cobb	A	B	B	D	C
8. Davis	A	B	B	C	B
9. Forrest	A	B	C	D	C
10. Hood	A	B	C,B	C	C,B
11. Hutton	A	B	B	C	C,B
12. Jupiter	A	B	B	B	B
13. Mineira	A	B	C,B	D	C
14. Otootan	A	B	C	C	C
15. Pickett	A	B	D,C	D	C
16. Roanoke	A	B	C	C	C
17. Santa Maria	A	B	C,D	D	C,B
18. Seminole	A	B	B	C	B
19. Hardee	A	B	B	C	B
Watermelon					
1. CG F1.77-1	D	B,A	B,C	C	A
2. CG F1.77-2	B	B,A	B,A	B	A
3. Charl. Gray	B	B,A	B	B	A

[1]Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid.

Table 9. Overall means for measured and computed parameters of soybean (Glycine max) and watermelon (Citrullus vulgaris L.) varieties: LA = leaf area, LFW = leaf fresh weight, LDW = leaf dry weight, SFW = stem fresh weight, SDW = stem dry weight, RFW = root fresh weight, RDW = root dry weight, LSp. Th. = leaf specific thickness.[1]

Watermelon or Soybean Variety	LA[2]	LFW	LDW	SFW	SDW	RFW	RDW	Bio-mass[3]	Root: Shoot Ratio[4]	Leaf Density 10^{-1}
Acadian	107	2.1	0.31	1.5	0.17	2.0	0.11	0.59	0.52	4.01
Altona	209	3.9	0.58	2.7	0.36	4.5	0.26	1.21	0.45	3.37
Biloxi	183	4.0	0.56	2.7	0.31	3.7	0.21	1.08	0.37	4.14
Bossier	99	2.0	0.31	1.3	0.17	1.5	0.10	0.58	0.34	4.73
Centennial	184	3.3	0.50	2.2	0.31	3.3	0.22	1.03	0.44	3.52
Cobb	137	2.7	0.39	1.9	0.22	2.4	0.16	0.77	0.41	3.56
Davis	102	2.3	0.33	1.4	0.15	2.2	0.14	0.63	0.44	4.09
Forrest	126	2.6	0.41	1.7	0.22	2.2	0.15	0.77	0.38	4.36
Hood	136	3.1	0.46	2.0	0.23	2.8	0.20	0.88	0.42	4.13
Hutton	129	3.3	0.49	2.0	0.23	2.4	0.18	0.90	0.37	4.34
Jupiter	131	2.6	0.40	1.8	0.22	2.3	0.17	0.79	0.39	4.34
Mineira	152	3.2	0.47	1.8	0.23	3.1	0.21	0.91	0.44	3.95
Ottotan	95	1.9	0.29	1.2	0.14	1.3	0.09	0.51	0.31	4.20
Pickett	159	3.3	0.49	1.7	0.21	2.6	0.20	0.90	0.45	3.76
Roanoke	119	2.9	0.41	1.7	0.19	3.1	0.19	0.79	0.45	4.36
Santa Maria	97	2.0	0.29	1.5	0.17	1.2	0.08	0.53	0.29	4.02
Seminole	174	4.2	0.59	2.1	0.23	3.4	0.24	1.05	0.40	4.23
Hardee	91	2.3	0.33	1.1	0.12	1.6	0.10	0.54	0.29	5.22
CG F1 77-1	22	1.0	0.09	0.6	0.02	0.3	0.02	0.13	0.20	5.30
CG F1 77-2	23	1.1	0.09	0.5	0.02	0.3	0.02	0.13	0.23	5.60
Charl.Gray	23	0.9	0.08	0.5	0.02	0.3	0.02	0.12	0.25	6.00

[1] Fresh and dry weights in grams.

[2] Leaf area (LA) in cm^2.

[3] Biomass = sum of leaf, stem and root dry weights.

[4] Root: shoot ratio = Root dry weight divided by shoot dry weight.

[5] Leaf specific thickness = Leaf area (cm^2) divided by leaf dry weight.

Table 10. Mean leaf specific thickness (leaf dry weight in grams ÷ leaf area in cm^2) by UV-B enhancement regime[1] and corresponding percent increases above the mylar control (UV-B enhancement regime #1). Values X 10^{-3}.

		Light Regime									
	Variety	1	2	%	3	%	4	%	5	%	Sum %	$\bar{X}$ %
	Soybeans											
1.	Acadian	1.8	3.3	83	4.7	161	6.4	256	4.3	139	639	159.8
2.	Americana	1.9	2.4	26	3.4	79	5.0	163	4.2	121	389	97.4
3.	Altona	1.9	3.1	63	4.8	153	7.6	300	5.2	174	689	172.4
4.	Biloxi	2.1	3.4	62	4.3	105	6.3	200	5.1	143	510	127.4
5.	Bossier	1.7	6.0	53	4.7	176	6.7	294	4.6	171	894	223.5
6.	Centennial	2.0	2.6	30	3.4	70	5.9	195	3.6	80	375	93.8
7.	Cobb	1.8	2.4	33	3.6	100	5.4	200	4.5	150	483	121.0
8.	Davis	1.8	3.4	89	4.3	139	6.0	233	5.0	178	639	159.7
9.	Forrest	2.0	3.3	65	3.9	95	7.5	275	5.2	160	595	148.8
10.	Hood	2.4	2.8	17	4.0	67	6.6	175	4.9	104	363	90.6
11.	Hutton	2.7	3.5	30	4.1	52	6.3	133	4.9	81	296	74.0
12.	Jupiter	2.4	3.4	42	4.7	96	6.3	162	5.0	108	408	102.0
13.	Mineira	2.2	3.0	36	3.5	59	6.2	182	4.8	118	395	98.9
14.	Otootan	1.9	3.7	95	4.1	116	5.8	205	5.4	184	600	150.0
15.	Pickett	2.2	3.1	41	3.7	68	5.9	168	4.4	100	377	94.3
16.	Roanoke	2.3	3.3	43	4.3	87	6.3	174	5.6	143	448	112.0
17.	Santa Maria	2.1	3.3	57	3.7	76	6.0	186	5.4	157	476	119.0
18.	Seminole	2.3	3.4	48	4.1	78	6.0	161	5.5	139	426	106.5
19.	Hardee	2.4	3.5	46	5.5	129	8.1	238	6.6	175	588	147.0
	Watermelons											
1.	CG F1.77-1	16.4	55.9	241	57.8	252	69.7	325	64.8	295	1113	278.4
2.	CG F1.77-2	21.1	54.4	158	67.7	221	78.8	273	59.3	181	833	208.3
3.	Charl. Gray	20.9	52.4	151	78.9	278	90.0	331	58.2	178	937	234.3

[1]UV-B enhancement levels 1 to 5 are defined in section I.

Table 11. Duncan's Multiple Range Test for Leaf Density differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	D	C	B	A	B
2. Americana	E	D	C	A	B
3. Altona	D	C	B	A	B
4. Biloxi	E	D	C	A	B
5. Bossier	B	A	B,A	A	B,A
6. Centennial	D	C	B	A	B
7. Cobb	E	D	C	A	B
8. Davis	E	D	C	A	B
9. Forrest	D	C	C	A	B
10. Hood	D	D	C	A	B
11. Hutton	D	C	C,B	A	B
12. Jupiter	C	C	B	A	B
13. Mineira	D	D	C	A	B
14. Otootan	C	B	B	A	A
15. Pickett	D	C	C	A	B
16. Roanoke	D	C	B	A	A
17. Santa Maria	C	B	B	A	A
18. Seminole	C	B	B	A	A
19. Hardee	E	D	C	A	B
Watermelon					
1. CG F1.77-1	C	B	B,A	A	B,A
2. CG F1.77-2	D	C	B	A	C,B
3. Charl. Gray	C	B	A	A	B

[1]Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid.

Table 12. Mean leaf area (cm^2) by UV-B enhancement regime[1] and corresponding percent reductions below the mylar control (UV-B enhancement regime #1).

		Light Regime									
	Variety	1	2	%	3	%	4	%	5	%	Sum %	$\bar{X}$ %
	Soybeans											
1.	Acadian	285	80	72	62	78	36	87	74	74	312	77.9
2.	Americana	385	262	32	194	50	87	77	119	69	228	57.0
3.	Altona	262	97	63	76	71	35	87	60	77	298	74.4
4.	Biloxi	372	185	50	136	63	66	82	98	74	270	67.4
5.	Bossier	218	86	61	80	63	34	84	76	65	273	68.3
6.	Centennial	377	194	49	155	59	58	85	138	63	255	63.9
7.	Cobb	244	178	27	127	48	53	78	83	66	219	54.8
8.	Davis	222	93	58	89	60	41	82	66	70	270	67.5
9.	Forrest	262	149	43	113	57	35	87	70	73	260	65.0
10.	Hood	243	174	28	117	52	56	77	91	63	220	54.9
11.	Hutton	198	150	24	131	34	65	67	101	49	174	43.6
12.	Jupiter	256	124	52	78	70	51	80	78	70	271	67.7
13.	Mineira	300	174	42	147	51	51	83	90	70	246	61.5
14.	Otootan	231	95	59	69	70	31	87	49	79	294	73.6
15.	Pickett	297	197	34	132	56	54	82	114	62	233	58.2
16.	Roanoke	218	157	28	98	55	47	78	75	66	227	56.8
17.	Santa Maria	224	108	52	70	69	30	87	54	76	283	70.8
18.	Seminole	364	185	49	144	60	68	81	111	70	260	65.1
19.	Hardee	217	107	51	60	72	23	89	47	78	291	72.7
	Watermelons											
1.	CG F1.77-1	44	22	50	17	61	10	77	18	59	248	61.9
2.	CG F1.77-2	51	19	63	16	69	10	80	19	63	275	68.6
3.	Charl. Gray	57	20	65	10	82	8	86	19	67	300	75.0

[1] UV-B enhancement levels 1 to 5 are defined in section I.

Table 13. Duncan's Multiple Range Test for Leaf Area differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	A	B	B	C	B
2. Americana	A	B	C	E	D
3. Altona	A	B	C,B	D	C,D
4. Biloxi	A	B	C,B	D	C,D
5. Bossier	A	B	B	C	B
6. Centennial	A	B	B	C	C,B
7. Cobb	A	B	C	E	D
8. Davis	A	B	B	D	C
9. Forrest	A	B	C	E	D
10. Hood	A	B	C	D	C
11. Hutton	A	B	B	D	C
12. Jupiter	A	B	C	C	C
13. Mineira	A	B	C	E	D
14. Otootan	A	B	C	D	D,C
15. Pickett	A	B	C	D	C
16. Roanoke	A	B	C	D	D,C
17. Santa Maria	A	B	C	D	D,C
18. Seminole	A	B	C	D	C
19. Hardee	A	B	C	D	C
Watermelon					
1. CG F1.77-1	A	B	B	B	B
2. CG F1.77-2	A	B	B	B	B
3. Charl. Gray	A	B	C	C	C,B

[1] Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid.

Table 15. Duncan's Multiple Range Test for Leaf Dry Weight differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	A	C,B	B	C	B
2. Americana	A	B	B,A	C	C
3. Altona	A	C,B	B	C	C,B
4. Biloxi	A	B	B	C	C,B
5. Bossier	B,A	B,C	A	C	B,A,C
6. Centennial	A	B	B	C	B
7. Cobb	A	A	A	C	B
8. Davis	A	B	A	C	B
9. Forrest	A	A	B	C	B
10. Hood	A	B	B	C	C,B
11. Hutton	A	A	A	B	A
12. Jupiter	A	B	C,B	C	C,B
13. Mineira	A	B	B	D	C
14. Otootan	A	B	C	D	C
15. Pickett	A	B	C	D	C
16. Roanoke	A	A	B	C	B
17. Santa Maria	A	B	C	D	C,B
18. Seminole	A	B	B	C	B
19. Hardee	A	B	C,B	D	C
Watermelon					
1. CG F1.77-1	C	A	B,A	B	A
2. CG F1.77-2	C	B,A	A	B,C	A
3. Charl. Gray	B	B,A	B	B	A

[1]Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid.

Table 16. Mean stem dry weight (in grams at 60°C) by UV-B enhancement regime[1] and corresponding percent reductions [(-) or increases (+) in watermelons] below the mylar control (UV-B enhancement regime #1).

		Light Regime									
	Variety	1	2	%	3	%	4	%	5	%	Sum %	$\bar{X}$ %
	Soybeans											
1.	Acadian	.41	.09	78	.11	73	.12	71	.12	51	273	62.3
2.	Americana	.66	.38	42	.30	55	.23	65	.25	62	224	56.1
3.	Altona	.50	.15	70	.17	66	.11	78	.14	72	286	71.5
4.	Biloxi	.53	.33	38	.29	45	.20	62	.22	58	204	50.9
5.	Bossier	.33	.12	64	.18	45	.09	73	.13	61	242	60.6
6.	Centennial	.56	.32	43	.26	54	.18	68	.24	57	221	55.4
7.	Cobb	.36	.23	36	.21	42	.13	64	.17	53	195	48.8
8.	Davis	.28	.13	54	.15	46	.09	68	.13	54	221	55.4
9.	Forrest	.41	.22	46	.16	61	.12	71	.18	56	234	58.5
10.	Hood	.40	.23	43	.18	55	.14	65	.18	55	218	54.4
11.	Hutton	.38	.23	39	.20	47	.16	58	.19	50	194	48.5
12.	Jupiter	.49	.21	57	.12	76	.13	73	.16	67	273	68.3
13.	Mineira	.48	.23	52	.17	65	.11	77	.17	65	258	64.6
14.	Otootan	.31	.14	55	.08	74	.06	81	.10	68	277	69.4
15.	Pickett	.42	.25	40	.12	71	.10	76	.17	60	248	61.9
16.	Roanoke	.35	.24	31	.13	63	.10	71	.14	60	226	56.4
17.	Santa Maria	.35	.16	54	.11	69	.07	80	.13	63	266	66.5
18.	Seminole	.48	.21	56	.15	69	.12	75	.19	60	260	65.1
19.	Hardee	.28	.10	64	.08	71	.04	86	.08	71	292	73.0
	Watermelons											
1.	CG F1.77-1	.19	.27	+42	.25	+32	.16	-16	.35	+84	+142	+35.5
2.	CG F1.77-2	.17	.21	+24	.19	+12	.15	-12	.30	+76	+100	+25.0
3.	Charl. Gray	.25	.21	-16	.12	-52	.17	-32	.21	-16	116	29.0

[1]UV-B enhancement levels 1 to 5 are defined in section I.

Table 17. Duncan's Multiple Range Test for Stem Dry Weight differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	A	B	B	B	B
2. Americana	A	B	C	C	C
3. Altona	A	C,B	B	C	C,B
4. Biloxi	A	B	B	C	C
5. Bossier	A	D,C	B	D	C
6. Centennial	A	B	C	D	C
7. Cobb	A	B	B	D	C
8. Davis	A	B	B	C	B
9. Forrest	A	B	C,D	D	C,B
10. Hood	A	B	D,C	D	C
11. Hutton	A	B	C,B	D	C,D
12. Jupiter	A	B	C	C	C,B
13. Mineira	A	B	C	D	C
14. Otootan	A	B	D,C	D	C
15. Pickett	A	B	D	D	C
16. Roanoke	A	B	C	C	C
17. Santa Maria	A	B	C	D	C,B
18. Seminole	A	B	C,D	D	C,B
19. Hardee	A	B	B	C	B
Watermelon					
1. CG F1.77-1	D,C	B,A	B,C	D	A
2. CG F1.77-2	B	B	B	B	A
3. Charl. Gray	A	B,A	C	B,C	B,A

[1] Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid.

Table 18. Mean root dry weight (in grams at 60°C) by UV-B enhancement regime[1] and corresponding percent reductions [(-) or increases (+) in watermelons] below the mylar control (UV-B enhancement regime #1).

		Light Regime										
	Variety	1	2	%	3	%	4	%	5	%	Sum %	$\bar{X}$ %
	Soybeans											
1.	Acadian	.17	.10	41	.12	29	.10	41	.08	53	164	41.0
2.	Americana	.37	.31	16	.25	32	.20	46	.17	54	149	37.2
3.	Altona	.19	.14	26	.11	42	.09	53	.10	47	168	42.1
4.	Biloxi	.35	.24	31	.18	49	.17	51	.13	63	194	48.6
5.	Bossier	.16	.09	44	.12	25	.08	50	.08	50	169	42.2
6.	Centennial	.36	.23	36	.18	50	.17	53	.17	53	192	47.9
7.	Cobb	.20	.16	20	.14	30	.13	35	.15	25	110	27.5
8.	Davis	.20	.13	35	.14	30	.12	40	.14	30	135	33.8
9.	Forrest	.22	.18	18	.10	55	.12	45	.14	36	155	38.6
10.	Hood	.27	.20	26	.19	30	.16	41	.16	41	137	34.3
11.	Hutton	.22	.16	27	.19	14	.17	23	.15	32	96	24.0
12.	Jupiter	.34	.13	62	.10	71	.13	62	.12	65	260	65.0
13.	Mineira	.35	.17	51	.16	54	.16	54	.19	46	206	51.4
14.	Otootan	.16	.10	38	.06	63	.06	63	.06	63	225	56.3
15.	Pickett	.33	.21	36	.12	64	.15	55	.17	48	203	50.8
16.	Roanoke	.25	.20	20	.14	44	.16	36	.18	28	128	32.0
17.	Santa Maria	.16	.06	63	.05	69	.06	63	.06	63	258	64.5
18.	Seminole	.41	.19	54	.18	56	.17	59	.24	41	210	52.4
19.	Hardee	.18	.07	61	.07	61	.06	67	.10	44	233	58.3
	Watermelons											
1.	CG F1.77-1	.10	.13	+30	.16	+60	.18	+80	.19	+90	+260	+65.0
2.	CG F1.77-2	.20	.12	-40	.15	-25	.19	-5	.22	+10	-60	-15.0
3.	Charl. Gray	.13	.20	+54	.11	-15	.16	+23	.25	+92	+154	+38.5

[1]UV-B enhancement levels 1 to 5 are defined in section I.

Table 19. Duncan's Multiple Range Test for Root Dry Weight differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	A	C,B	B	C,B	C
2. Americana	A	B	C	D,C	D
3. Altona	A	B	B	B	B
4. Biloxi	A	B	C,B	C,B	C
5. Bossier	A	C,B	B	C,B	C
6. Centennial	A	B	B	B	B
7. Cobb	A	B	C,B	C	C,B
8. Davis	A	B	B	B	B
9. Forrest	A	B,A	C	C	B,C
10. Hood	A	B,A	B,A	B	B
11. Hutton	A	B	B,A	B	B
12. Jupiter	A	B	B	B	B
13. Mineira	A	B	B	B	B
14. Otootan	A	B	C	C	C
15. Pickett	A	B	C	C,B	C,B
16. Roanoke	A	B,A	B	B	B
17. Santa Maria	A	B	B	B	B
18. Seminole	A	C	C	C	B
19. Hardee	A	C	C	C	B
Watermelon					
1. CG F1.77-1	C	B,C	B,A	A	A
2. CG F1.77-2	B,A	B	B,A	B,A	A
3. Charl. Gray	B,C	B,A	C	B,C	A

[1] Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid.

Table 20. Mean biomass per pot for mylar control and 4 UV-B enhancement treatments and biomass partitioning.

Variety	Mean biomass per pot for Mylar control (M) and all UV-B treatments								Biomass Partitioning in Percent					
	Leaves		Stems		Roots		Biomass		Leaves		Stems		Roots	
Soybean	M	UV-B	M	UV-B	M	UV-B	M	UV-B	M	UV-B	M	UV-B	M	UV-B
1. Acadian	0.53	0.27	0.41	.11	0.17	.10	1.11	0.48	48	56	37	23	15	21
2. Americana	0.74	0.55	0.66	.17	0.37	.23	1.77	1.07	42	52	37	27	21	22
3. Altona	0.51	0.30	0.50	.13	0.19	.11	1.20	0.55	43	54	42	26	16	20
4. Biloxi	0.77	0.51	0.53	.13	0.35	.18	1.65	0.95	47	54	32	27	21	19
5. Bossier	0.36	0.30	0.33	.08	0.16	.09	0.85	0.52	42	57	39	25	19	18
6. Centennial	0.67	0.45	0.56	.14	0.36	.19	1.59	0.89	42	51	35	28	23	21
7. Cobb	0.43	0.39	0.36	.09	0.20	.15	0.99	0.72	43	54	36	26	20	20
8. Davis	0.40	0.31	0.28	.07	0.20	.13	0.88	0.57	45	55	32	22	23	23
9. Forrest	0.53	0.38	0.41	.10	0.22	.14	1.16	0.68	46	55	35	25	19	20
10. Hood	0.59	0.43	0.40	.10	0.27	.18	1.26	0.79	47	54	32	23	32	23
11. Hutton	0.54	0.48	0.38	.10	0.22	.17	1.14	0.84	47	57	33	23	19	20
12. Jupiter	0.63	0.35	0.49	.12	0.34	.12	1.46	0.62	43	56	34	25	23	19
13. Mineira	0.65	0.43	0.48	.12	0.35	.17	1.48	0.77	44	57	32	22	24	22
14. Otootan	0.44	0.25	0.31	.08	0.16	.07	0.91	0.41	48	60	34	23	18	17
15. Pickett	0.67	0.46	0.42	.11	0.33	.16	1.42	0.78	47	59	30	20	23	21
16. Roanoke	0.50	0.39	0.35	.09	0.25	.17	1.10	0.72	45	54	32	21	23	24
17. Santa Maria	0.46	0.25	0.35	.09	0.16	.06	0.97	0.43	47	59	36	28	16	14
18. Seminole	0.83	0.52	0.48	.12	0.41	.20	1.72	0.89	47	59	28	19	24	22
19. Hardee	0.51	0.29	0.28	.07	0.18	.08	0.97	0.44	53	66	29	17	19	17
Watermelon														
1. CGF1.77-1	0.42	0.95	0.19	0.25	0.10	.17	0.71	1.37	59	69	27	19	14	12
2. CGF1.77-2	0.65	0.96	0.17	0.21	0.20	.17	1.02	1.35	64	72	17	16	20	13
3. Charl. Gray	0.77	0.85	0.25	0.18	0.13	.18	1.15	1.21	67	70	22	15	11	15

Table 21. Biomass partitioning for % leaves by UV-B enhancement regime[1] and corresponding percent increase above the mylar control (UV-B enhancement regime #1).

		Light Regime											
	Variety	1	2	%	3	%	4	%	5	%	Sum %	$\bar{X}$	%
	Soybeans												
1.	Acadian	47	58	23	57	21	50	6	59	26	76	19.0	
2.	Americana	42	48	14	55	31	50	19	53	26	90	22.6	
3.	Altona	42	51	21	56	33	56	33	55	31	119	29.8	
4.	Biloxi	47	51	9	54	15	53	13	57	21	57	14.4	
5.	Bossier	42	60	43	55	31	58	38	59	40	152	38.1	
6.	Centennial	42	48	14	54	29	49	17	53	26	86	21.4	
7.	Cobb	43	52	21	56	30	53	23	54	26	100	25.0	
8.	Davis	46	55	20	57	24	54	17	54	17	78	19.6	
9.	Forrest	46	55	20	61	33	53	15	52	13	80	20.1	
10.	Hood	47	55	17	56	19	55	17	55	17	70	17.6	
11.	Hutton	46	57	24	57	24	56	22	58	26	96	24.0	
12.	Jupiter	43	55	28	60	40	55	28	55	28	124	31.0	
13.	Mineira	44	57	30	59	34	54	23	53	20	107	26.7	
14.	Otootan	49	58	18	63	29	60	22	60	22	92	23.0	
15.	Pickett	47	56	19	66	40	56	19	58	23	102	25.5	
16.	Roanoke	46	53	15	59	28	53	15	54	17	76	19.0	
17.	Santa Maria	47	59	26	59	26	61	30	59	26	108	27.0	
18.	Seminole	48	60	25	62	29	58	21	56	17	92	22.9	
19.	Hardee	53	67	26	69	30	66	25	61	+15	96	24.0	
	Watermelons												
1.	CG F1.77-1	58	72	24	67	16	66	14	68	17	71	17.7	
2.	CG F1.77-2	63	75	19	75	19	67	6	68	8	52	13.1	
3.	Charl. Gray	64	68	6	77	20	66	3	67	5	34	8.6	

[1]UV-B enhancement levels 1 to 5 are defined in section I.

Table 22. Duncan's Multiple Range Test for Percent Leaf differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	B	A	A	B	A
2. Americana	D	C	A	B,C	B,A
3. Altona	C	B	B,A	A	B,A
4. Biloxi	D	C	B	C,B	A
5. Bossier	C	A	B	B,A	A
6. Centennial	C	B	A	B	A
7. Cobb	B	A	A	A	A
8. Davis	B	A	A	A	A
9. Forrest	C	B	A	B	B
10. Hood	B	A	A	A	A
11. Hutton	B	A	A	A	A
12. Jupiter	C	B	A	B	B
13. Mineira	C	A	A	B	B
14. Otootan	B	A	A	A	A
15. Pickett	C	B	A	B	B
16. Roanoke	C	B	A	B	B
17. Santa Maria	B	A	A	A	A
18. Seminole	D	B,A	A	B,C	C
19. Hardee	C	A	A	A	B
Watermelon					
1. CG F1.77-1	B	A	A	A	A
2. CG F1.77-2	B	A	A	B	B
3. Charl. Gray	B	B	A	B	B

[1] Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid.

Table 23. Biomass partitioning for % stems by UV-B enhancement regime[1] and corresponding percent reductions below the mylar control (UV-B enhancement regime #1).

		Light Regime										
	Variety	1	2	%	3	%	4	%	5	%	Sum %	$\bar{X}$%
	Soybeans											
1.	Acadian	37	21	43	21	43	27	27	25	32	145	36.3
2.	Americana	37	29	22	25	32	26	30	28	24	108	27.0
3.	Altona	42	26	38	27	36	24	43	27	36	153	38.3
4.	Biloxi	33	29	12	28	15	26	21	26	21	69	17.3
5.	Bossier	40	23	43	28	30	21	48	26	35	155	38.8
6.	Centennial	35	30	14	27	23	27	23	28	20	80	20.0
7.	Cobb	36	28	22	26	28	24	33	24	33	116	29.0
8.	Davis	32	23	28	22	31	20	38	22	31	128	32.0
9.	Forrest	36	25	31	23	36	23	36	27	25	128	31.9
10.	Hood	32	26	19	22	31	21	34	24	25	109	27.3
11.	Hutton	34	26	24	23	32	21	38	23	32	126	31.5
12.	Jupiter	34	27	21	22	35	22	35	26	24	115	28.8
13.	Mineira	33	25	24	21	36	18	45	23	30	136	34.1
14.	Otootan	35	24	31	21	40	20	43	24	31	146	36.4
15.	Pickett	31	24	23	17	45	19	39	21	32	139	34.7
16.	Roanoke	32	26	19	20	38	19	41	20	38	134	33.6
17.	Santa Maria	37	30	19	28	24	21	43	28	24	110	27.5
18.	Seminole	28	21	25	17	39	17	39	19	32	136	33.9
19.	Hardee	29	20	31	16	45	13	55	18	38	169	42.3
	Watermelons											
1.	CG F1.77-1	28	19	32	21	25	16	43	20	29	129	32.1
2.	CG F1.77-2	18	16	11	14	22	14	22	18	0	56	13.9
3.	Charl. Gray	23	17	26	12	48	17	26	14	39	139	34.8

[1]UV-B enhancement levels 1 to 5 are defined in section I.

Table 24. Duncan's Multiple Range Test for Percent Stem differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	A	C	C	B	C,B
2. Americana	A	B	C	C,B	B
3. Altona	A	C,B	B	C	C,B
4. Biloxi	A	B	B	C	C,B
5. Bossier	A	C,D	B	D	C,B
6. Centennial	A	B	C,B	C	C,B
7. Cobb	A	B	C,B	C	C
8. Davis	A	B	B	B	B
9. Forrest	A	B	B	B	B
10. Hood	A	B	C	C	C,B
11. Hutton	A	B	C,B	C	C,B
12. Jupiter	A	B	C	C	B
13. Mineira	A	B	C	D	C
14. Otootan	A	B	B	B	B
15. Pickett	A	B	D	D	C
16. Roanoke	A	B	C	C	C
17. Santa Maria	A	B	B	C	B
18. Seminole	A	B	C	C	C
19. Hardee	A	B	C	D	C,B
Watermelon					
1. CG F1.77-1	A	B	B	B	B
2. CG F1.77-2	A	A	A	A	A
3. Charl. Gray	A	B	C	B	C,B

[1]Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid.

Table 25. Biomass partitioning for % root by UV-B enhancement regime[1] and corresponding percent reductions below the mylar control (UV-B enhancement regime #1).

		Light Regime									
	Variety	1	2	%	3	%	4	%	5	%	Sum %	$\bar{X}$ %
	Soybeans										
1.	Acadian	15	22	+47	22	+47	22	+47	16	+7	+148	37.0
2.	Americana	21	23	+10	20	-5	23	+10	19	-10	+5	+1.2
3.	Altona	16	23	+44	17	+6	19	+19	18	+13	+81	+20.3
4.	Biloxi	20	20	0	17	-15	21	+5	16	-20	-30	-7.5
5.	Bossier	18	17	-6	17	-6	21	+17	15	-17	-11	-2.8
6.	Centennial	22	22	0	19	-14	24	+9	19	-14	-18	-4.5
7.	Cobb	20	20	0	18	-10	23	+15	22	+10	+15	3.7
8.	Davis	22	22	0	21	+5	26	-18	24	-9	-23	-5.7
9.	Forrest	18	20	+11	15	-17	24	+33	21	+17	+44	+11.1
10.	Hood	21	20	-5	22	+5	24	+14	21	0	+14	+3.6
11.	Hutton	20	17	-15	20	0	23	+15	19	-5	-5	-1.3
12.	Jupiter	23	18	-22	18	-22	23	0	19	-17	-61	15.3
13.	Mineira	23	18	-22	20	-13	28	+22	24	+4	-9	+2.2
14.	Otootan	17	18	+6	16	-6	20	+18	15	-12	+6	+1.5
15.	Pickett	22	20	-9	17	-23	25	+14	20	-9	-27	-6.8
16.	Roanoke	21	21	0	21	0	28	+33	26	+24	+57	+14.3
17.	Santa Maria	16	11	-31	13	-19	18	+13	13	-19	-56	-14.0
18.	Seminole	24	19	-21	20	-17	24	0	25	+4	-33	-8.3
19.	Hardee	18	13	-28	15	-17	21	+17	21	+17	-11	-2.8
	Watermelons											
1.	CG F1.77-1	15	9	-40	13	-13	18	+20	12	-20	-53	-13.3
2.	CG F1.77-2	19	9	-53	11	-42	18	-5	14	-26	-126	-31.6
3.	Charl. Gray	13	15	+15	12	-8	17	+31	19	+46	+85	+21.2

[1]UV-B enhancement levels 1 to 5 are defined in section I.

Table 26. Duncan's Multiple Range Test for Percent Root differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	B	A	A	A	B
2. Americana	B,A	A	B	A	B
3. Altona	B	A	B	B,A	B,A
4. Biloxi	A	A	B	A	B
5. Bossier	B,A	B,C	B,C	A	C
6. Centennial	A	B,A	B	A	B
7. Cobb	B,A,C	B,C	C	A	B,A
8. Davis	B,A	B,A	B	A	B,A
9. Forrest	B,C	B	C	A	B,A
10. Hood	A	A	A	A	A
11. Hutton	B	B	B	A	B
12. Jupiter	A	B	B	A	B,A
13. Mineira	B	C	C	A	B
14. Otootan	B,A	B,A	B	A	B
15. Pickett	B,A	B,C	C	A	B,C
16. Roanoke	B	B	B	A	A
17. Santa Maria	B,A	C	B,C	A	B,C
18. Seminole	A	B	B	A	A
19. Hardee	B,A	C	B,C	A	A
Watermelon					
1. CG F1.77-1	B,A	C	B,C	A	B,C
2. CG F1.77-2	A	B	B	A	B,A
3. Charl. Gray	B,A	B,A	B	B,A	A

[1] Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid.

Table 27. Mean root:shoot ratios by UV-B enhancement regime[1] and corresponding increases (+) or decreases (-) relative to the mylar control (UV-B enhancement regime #1).

		Light Regime									
	Variety	1	2	%	3	%	4	%	5	%	Sum %	$\bar{X}$ %
	Soybeans										
1.	Acadian	.18	.28	+56	.29	+61	.31	+72	.19	+6	195	+48.0
2.	Americana	.27	.31	+15	.26	-4	.31	+15	.24	-11	+15	+3.7
3.	Altona	.19	.35	+84	.21	+11	.25	+32	.22	+16	+142	+35.5
4.	Biloxi	.26	.26	0	.21	-19	.27	+4	.20	-23	-38	-9.6
5.	Bossier	.23	.21	-9	.21	-9	.27	+17	.18	-22	-22	-5.4
6.	Centennial	.29	.28	-3	.24	-17	.32	+10	.24	-17	-28	-6.9
7.	Cobb	.26	.25	-4	.22	-15	.30	+15	.29	+11	+7	+1.8
8.	Davis	.29	.29	0	.27	-7	.35	+21	.32	+10	+24	+6.0
9.	Forrest	.23	.25	+9	.18	-22	.31	+35	.27	+17	+39	+9.8
10.	Hood	.27	.25	-7	.30	+11	.32	+19	.28	+4	+26	+6.5
11.	Hutton	.25	.21	-16	.26	0	.30	+20	.23	-8	-4	-1.0
12.	Jupiter	.30	.22	-27	.22	-27	.29	-3	.24	-20	77	-19.3
13.	Mineira	.31	.23	-26	.25	-19	.39	+26	.33	+6	-13	-3.2
14.	Otootan	.21	.22	+5	.19	-10	.25	+19	.18	-14	0	0
15.	Pickett	.29	.25	-14	.21	-28	.35	+21	.26	-10	-31	-7.8
16.	Roanoke	.27	.28	+4	.27	0	.41	+52	.35	+30	+85	+21.3
17.	Santa Maria	.19	.12	-16	.15	-21	.22	+16	.15	-21	-42	-10.5
18.	Seminole	.31	.23	-26	.26	-16	.33	+6	.33	+6	-29	-7.3
19.	Hardee	.22	.16	-27	.18	-18	.28	+27	.27	+23	+5	+1.3
	Watermelons											
1.	CG Fl.77-1	.18	.10	-44	.15	-17	.22	+22	.14	-22	-61	-15.3
2.	CG Fl.77-2	.28	.10	-64	.13	-54	.23	-18	.16	-43	-179	-44.6
3.	Charl. Gray	.15	.19	+27	.13	-13	.21	+40	.25	+67	+120	+30.0

[1] UV-B enhancement levels 1 to 5 are defined in section I.

Table 28. Duncan's Multiple Range Test for Root:Shoot Ratio differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	C	B,A,C	B,A	A	B,C
2. Americana	B,A	A	B	A	B
3. Altona	B	A	B	B,A	B,A
4. Biloxi	A	A	B	A	B
5. Bossier	B,A	B,C	B,C	A	C
6. Centennial	A	B,A	B	A	B
7. Cobb	B,A,C	B,C	C	A	B,A
8. Davis	B,A	B,A	B	A	B,A
9. Forrest	B,C	B	C	A	B,A
10. Hood	A	A	A	A	A
11. Hutton	B,A	B	B,A	A	B
12. Jupiter	A	B	B	A	B
13. Mineira	B	C	C	A	B
14. Otootan	B,A	B,A	B	A	B
15. Pickett	B,A	B,C	C	A	B,C
16. Roanoke	B	B	B	A	A
17. Santa Maria	B,A	C	B,C	A	B,C
18. Seminole	A	B	B	A	A
19. Hardee	B,A	C	B,C	A	A
Watermelon					
1. CG F1.77-1	B,A	C	B,C	A	B,C
2. CG F1.77-2	A	B	B	B,A	B,A
3. Charl. Gray	A	A	A	A	A

[1]Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid.

Table 29 . Mean chlorosis rating (0-9) by UV-B enhancement regime[1].

		Light Regime						
	Variety	1	2	3	4	5	Sum %	$\bar{X}$ %
	Soybeans							
1.	Acadian	0	8.0	8.9	8.3	8.6	33.8	8.5
2.	Americana	0	2.5	5.8	6.6	6.9	21.8	5.5
3.	Altona	0	7.1	8.9	8.7	8.9	33.6	8.4
4.	Biloxi	0	6.1	7.2	8.5	8.5	30.3	7.6
5.	Bossier	0	5.0	4.9	7.1	6.4	23.4	5.9
6.	Centennial	0	4.4	3.9	7.4	6.9	22.6	5.7
7.	Cobb	0	3.4	3.4	7.2	7.4	21.4	5.4
8.	Davis	0	4.0	4.4	6.8	7.3	22.5	5.6
9.	Forrest	0	5.0	4.4	7.7	8.3	25.4	6.4
10.	Hood	0	3.2	3.2	6.2	6.9	19.5	4.9
11.	Hutton	0	3.1	3.2	5.8	6.1	18.1	4.5
12.	Jupiter	0	3.4	4.9	6.0	7.4	21.7	5.4
13.	Mineira	0	3.1	3.4	6.4	6.7	19.6	4.9
14.	Otootan	0	4.8	6.0	9.0	9.0	28.8	7.2
15.	Pickett	0	3.7	3.1	6.3	5.9	19.0	4.8
16.	Roanoke	0	3.3	4.0	7.5	7.8	22.6	5.7
17.	Santa Maria	0	4.5	4.7	8.8	7.7	25.7	6.4
18.	Seminole	0	4.7	6.2	8.3	7.9	27.1	6.8
19.	Hardee	0	4.4	6.3	8.6	8.3	27.6	6.9
	Watermelons							
1.	CG F1.77-1	0	5.1	5.4	8.9	7.8	27.2	6.8
2.	CG F1.77-2	0	4.4	5.1	9.0	6.3	24.8	6.2
3.	Charl. Gray	0	4.6	5.2	9.0	6.4	25.2	6.3

[1]UV-B enhancement levels 1 to 5 are defined in section I.

Table 30. Duncan's Multiple Range Test for Chlorosis differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	D	C	A	B,C	B,A
2. Americana	C	B	A	A	A
3. Altona	C	B	A	A	A
4. Biloxi	D	C	B	A	A
5. Bossier	C	B	B	A	B,A
6. Centennial	C	B	B	A	A
7. Cobb	C	B	B	A	A
8. Davis	C	B	B	A	A
9. Forrest	C	B	B	A	A
10. Hood	C	B	B	A	A
11. Hutton	C	B	B	A	A
12. Jupiter	E	D	C	B	A
13. Mineira	C	B	B	A	A
14. Otootan	D	C	B	A	A
15. Pickett	C	B	B	A	A
16. Roanoke	C	B	B	A	A
17. Santa Maria	C	B	B	A	A
18. Seminole	D	C	B	A	A
19. Hardee	D	C	B	A	A
Watermelon					
1. CG F1.77-1	C	B	A	A	A
2. CG F1.77-2	C	B	A	A	B
3. Charl. Gray	C	B	A	A	B

[1]Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid.

Table 31. Mean height (mm) after 2 weeks by UV-B enhancement regime[1] and corresponding percent reductions below the mylar control (UV-B enhancement regime #1).

		Light Regime									
	Variety	1	2	%	3	%	4	%	5	%	Sum %	$\bar{X}$ %
	Soybeans											
1.	Acadian	134	121	10	116	13	108	19	115	14	56	14.0
2.	Americana	178	153	14	134	25	122	31	119	33	103	25.8
3.	Altona	183	141	23	134	27	111	39	121	34	123	30.7
4.	Biloxi	156	156	0	141	10	129	17	113	28	54	13.6
5.	Bossier	99	89	10	95	4	77	22	82	17	54	13.4
6.	Centennial	151	140	7	128	15	113	25	117	23	70	17.5
7.	Cobb	121	99	18	94	22	82	32	83	31	103	25.8
8.	Davis	96	85	11	85	11	72	25	75	22	70	17.4
9.	Forrest	126	111	12	105	17	92	27	102	19	75	18.7
10.	Hood	127	115	9	96	24	89	30	98	23	87	21.7
11.	Hutton	128	112	13	99	23	93	27	94	27	95	22.5
12.	Jupiter	134	121	10	105	22	104	22	103	23	77	19.3
13.	Mineira	151	108	28	101	33	90	40	96	36	138	34.6
14.	Otootan	87	88	+1	75	14	75	14	74	15	41	10.3
15.	Pickett	90	97	+8	76	16	69	23	73	19	50	12.5
16.	Roanoke	107	97	9	83	22	77	28	79	26	86	21.5
17.	Santa Maria	105	107	+2	90	14	81	23	91	13	48	12.0
18.	Seminole	95	98	+3	90	5	81	15	75	21	38	9.5
19.	Hardee	79	72	9	71	10	56	29	61	23	71	17.8
	Watermelons											
1.	CG F1.77-1	31	25	19	24	23	23	26	26	16	84	21.0
2.	CG F1.77-2	26	21	19	18	31	18	31	21	19	100	25.0
3.	Charl. Gray	24	21	13	18	25	17	29	19	21	88	21.9

[1]UV-B enhancement levels 1 to 5 are defined in section I.

Table 32. Duncan's Multiple Range Test for Height 2 differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	A	B	C,B	C	C,B
2. Americana	A	B	C	D	D
3. Altona	A	B	B	C	C
4. Biloxi	A	A	B	C	D
5. Bossier	A	B,A,C	B,A	C	B,C
6. Centennial	A	A	B	C	C,B
7. Cobb	A	B	B	C	C
8. Davis	A	B	B	C	C,B
9. Forrest	A	B	B	C	C,B
10. Hood	A	B	C	C	C
11. Hutton	A	B	C	C	C
12. Jupiter	A	B	C	C	C
13. Mineira	A	B	C,B	D	C,D
14. Otootan	A	A	B	B	B
15. Pickett	A	A	B	B	B
16. Roanoke	A	B	C	C	C
17. Santa Maria	A	A	B	B	B
18. Seminole	A	A	B,A	B,C	C
19. Hardee	A	A	A	B	B
Watermelon					
1. CG F1.77-1	A	A	A	A	A
2. CG F1.77-2	A	B	B	B	B
3. Charl. Gray	A	B	C,B	C	C,B

[1] Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid. Height 2 is two weeks after planting.

Table 33. Mean height (mm) after 3 weeks by UV-B enhancement regime[1] and corresponding percent reductions below the mylar control (UV-B enhancement regime #1).

		Light Regime										
	Variety	1	2	%	3	%	4	%	5	%	Sum %	$\bar{X}$ %
	Soybeans											
1.	Acadian	262	158	40	137	48	127	52	141	46	186	46.5
2.	Americana	301	224	26	177	41	158	48	160	47	161	40.3
3.	Altona	374	206	45	173	54	141	62	160	57	218	54.5
4.	Biloxi	270	216	20	196	27	179	34	170	37	118	29.5
5.	Bossier	229	131	43	125	45	102	55	116	49	193	48.3
6.	Centennial	258	205	21	177	31	143	45	164	36	133	33.2
7.	Cobb	257	166	35	142	45	111	57	124	52	189	47.3
8.	Davis	186	130	30	119	36	102	45	109	41	153	38.2
9.	Forrest	242	166	31	140	42	114	53	139	43	169	42.3
10.	Hood	211	165	22	131	38	120	43	134	36	139	34.8
11.	Hutton	204	163	20	139	32	132	35	135	34	121	30.3
12.	Jupiter	248	182	27	148	40	137	45	149	40	152	38.0
13.	Mineira	270	152	44	132	51	113	58	124	54	207	51.8
14.	Otootan	189	128	32	100	47	99	48	102	46	173	43.3
15.	Pickett	185	148	20	110	41	94	49	110	41	150	37.6
16.	Roanoke	187	142	24	117	37	100	47	108	42	150	37.6
17.	Santa Maria	204	158	23	133	35	121	41	132	35	134	33.5
18.	Seminole	172	137	20	124	28	110	36	105	39	123	30.8
19.	Hardee	142	102	28	86	39	74	48	77	46	161	40.3
	Watermelons											
1.	CG F1.77-1	50	27	46	24	52	22	56	26	48	202	50.5
2.	CG F1.77-2	39	21	46	16	59	18	54	20	49	208	51.9
3.	Charl. Gray	39	20	49	19	51	19	51	19	51	203	50.6

[1]UV-B enhancement levels 1 to 5 are defined in section I.

Table 34. Duncan's Multiple Range Test for Height 3 differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	A	B	C	C	C
2. Americana	A	B	C	C	C
3. Altona	A	B	C	D	C
4. Biloxi	A	B	C	D	D
5. Bossier	A	B	B	C	C,B
6. Centennial	A	B	C	D	C
7. Cobb	A	B	C	E	D
8. Davis	A	B	C,B	D	C,D
9. Forrest	A	B	C	D	C
10. Hood	A	B	C	C	C
11. Hutton	A	B	C	C	C
12. Jupiter	A	B	C	C	C
13. Mineira	A	B	C	D	D,C
14. Otootan	A	B	C	C	C
15. Pickett	A	B	C	C	C
16. Roanoke	A	B	C	D	D,C
17. Santa Maria	A	B	C	C	C
18. Seminole	A	B	C	D	D
19. Hardee	A	B	C,B	C	C
Watermelon					
1. CG F1.77-1	A	B	B	B	B
2. CG F1.77-2	A	B	B	B	B
3. Charl. Gray	A	B	B	B	B

[1]Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid. Height 3 is three weeks after planting.

Table 35. Mean height (mm) after 4 weeks by UV-B enhancement regime[1] and corresponding percent reductions below the mylar control (UV-B enhancement regime #1).

		Light Regime											
	Variety	1	2	%	3	%	4	%	5	%	Sum %	$\bar{X}$	%
	Soybeans												
1.	Acadian	376	171	55	146	61	134	64	159	58	238	59.5	
2.	Americana	406	256	37	208	49	184	55	190	53	194	48.4	
3.	Altona	495	221	55	187	62	149	70	176	64	252	63.0	
4.	Biloxi	380	247	35	227	40	211	44	199	48	167	41.8	
5.	Bossier	330	148	55	144	56	111	66	134	59	237	59.3	
6.	Centennial	373	249	33	219	41	153	59	202	46	179	44.8	
7.	Cobb	357	214	40	186	48	127	64	158	56	208	52.0	
8.	Davis	282	162	43	144	49	113	60	168	40	192	48.0	
9.	Forrest	379	207	45	165	56	122	68	171	55	225	56.1	
10.	Hood	299	210	30	169	43	141	53	168	44	170	42.5	
11.	Hutton	302	204	32	174	42	146	52	168	44	170	42.5	
12.	Jupiter	353	262	26	171	52	149	58	172	51	187	46.8	
13.	Mineira	415	193	53	163	61	126	70	148	64	248	62.0	
14.	Otootan	340	165	51	120	65	110	68	121	64	248	62.1	
15.	Pickett	293	185	37	129	56	104	65	141	52	209	52.3	
16.	Roanoke	287	193	33	142	51	117	59	133	54	196	49.0	
17.	Santa Maria	327	181	45	154	53	135	59	152	54	211	52.8	
18.	Seminole	276	168	39	145	47	130	53	132	52	192	47.9	
19.	Hardee	237	119	50	91	62	84	65	87	63	240	60.0	
	Watermelons												
1.	CG F1.77-1	62	34	45	28	55	23	63	32	48	211	52.8	
2.	CG F1.77-2	56	25	55	21	63	19	66	24	57	241	60.3	
3.	Charl. Gray	59	27	54	20	66	18	69	24	59	249	62.3	

[1]UV-B enhancement levels 1 to 5 are defined in section I.

Table 36. Duncan's Multiple Range Test for Height 4 differences among UV-B irradiation enhancement levels at the Duke University Phytotron.[1]

Soybean Variety	Light Level 1	2	3	4	5
1. Acadian	A	B	C,D	D	C,B
2. Americana	A	B	C	C	C
3. Altona	A	B	C	D	C
4. Biloxi	A	B	C	D	D
5. Bossier	A	B	B	C	B
6. Centennial	A	B	C	D	C
7. Cobb	A	B	C	E	D
8. Davis	A	B	C,B	C	B
9. Forrest	A	B	C	D	C
10. Hood	A	B	C	D	C
11. Hutton	A	B	C	D	C
12. Jupiter	A	B	C	C	C
13. Mineira	A	B	C	D	C
14. Otootan	A	B	C	C	C
15. Pickett	A	B	C	D	C
16. Roanoke	A	B	C	D	D,C
17. Santa Maria	A	B	C	C	C
18. Seminole	A	B	C	C	C
19. Hardee	A	B	C	C	C
Watermelon					
1. CG F1.77-1	A	B	B	B	B
2. CG F1.77-2	A	B	B	B	B
3. Charl. Gray	A	B	C,B	C	C,B

[1] Light levels not followed by the same letter are significantly different (.05 level). UV-B enhancement irradiances are defined in Section I. Only horizontal comparisons are valid. Height 4 is four weeks after planting.

EFFECTS OF ULTRAVIOLET-B RADIATION ENHANCEMENTS UNDER FIELD CONDITIONS ON POTATOES, TOMATOES, CORN, RICE, SOUTHERN PEAS, PEANUTS, SQUASH, MUSTARD AND RADISH

Abstract

Nine crops were grown to maturity in the field under a UV-B gradient irradiator using Westinghouse FS-40 sun lamps equipped with cellulose acetate filters. $UV\text{-}B_{seu}$ levels ranged from 0.10 to 0.84 for corn, potatoes and tomatoes, 0.10 to 1.55 for peanuts, peas and rice and 0.18 to 3.1 for squash, mustard and radish. Fruit quality and quantity, leaf area, total biomass and biomass partitioning, root:shoot ratios and leaf density were all affected by enhanced UV-B radiation. Most of these affects can probably be accounted for by reduction in net carbon exchange, leaf expansion and phloem translocation.

Yield was consistently reduced at the highest UV-B enhancement levels for all crops with lower levels of UV-B approaching or equaling control yields. Treated plants had fewer large fruit (i.e. tomatoes, number of large peanuts and potatoes). In most cases, fewer fruit of a smaller size were harvested. However, in the case of corn, despite reductions in vegetative growth and the number of tillers and silk length in corn, the percent fill and weight of the ears of corn was not statistically reduced. Significant reductions in the number and total weight of Southern peas were also found.

Biomass accumulations were similar except increases were noted for

radishes, and potato biomass was similar to the controls. Biomass partitioning was altered, especially in mature plants where a larger percent of the dry matter was found in the leaves with reductions in stems and roots. This also tended to reduce root:shoot ratios. Reductions in biomass were found even at the time of thinning but these were overall reductions with root reductions becoming more pronounced with age.

Flowering was delayed in UV-B treated plants. Flower counts were higher and earlier in tomatoes. The number of fruit was higher in control squash plants at the early harvest date indicating either flowering was delayed in the treated plants or the treated squash were not setting fruit. Spike weight was reduced and maturity was delayed in rice. This seems to have been due to delayed growth during bolting.

The purpose of the present study was to evaluate the main effects and interactions of 4 flux levels of UV-B radiation on soybeans with simultaneous exposure to 4 flux levels of longer wavelength light. More specifically, the objectives were 1) to determine if UV-B radiation in lower fluxes was affecting net carbon exchange, transpiration, dark respiration and the associated diffusive resistances; 2) to test if these UV-B fluxes were effective over a range of PAR and if photorepair is complete at high irradiances; and 3) to examine the validity of extrapolating from low PAR irradiance experiment in greenhouses or growth chambers to field or natural situations.

Materials and Methods

Plant Materials and Growth Conditions

'Hardee' soybeans (Glycine max), supplied by the Florida State Seed Laboratory, and 'Jori' wheat (Triticum aestivum) were grown from seed in the controlled environment facilities of the Southern Plant Environment Laboratories located at Duke University. Seeds were sown into 250 cm^3 of a 1:1 mixture of course sand and vermiculite (v:v). These were watered with dionized water and placed into a phytotron greenhouse with a 26/20°C day-night temperature regime. Natural daylight was extended to 16 hours by incandescant floodlamps. Soon after germination, the soybeans were thinned to uniformity to 2 per pot and the wheat to 4 per pot. During the first few weeks, the pots were watered to excess twice daily with dionized water. Thereafter, all plants were watered three times daily, with 1/2 strength modified Hoagland's solution in the mornings, followed by dionized water in the afternoons and evenings.

Nine replicate containers were grown under each of 16 UV-B and PAR treat-

V. Introduction

Many species of economically important crop plants exhibit reductions in growth and net carbon exchange following exposure to UV-B[1] irradiances (Brandle et al., 1977; Van et al., 1976; Bartholic et al., 1975; Biggs et al., 1975). However, the mode of action of UV-B radiation on biological systems is not clearly understood. Much of this is a reflection of the wide range of treatment and experimental conditions used by different investigators. Earlier workers used germicidal lamps as a UV irradiance source, which are essentially line source emitters at 253.7 nm (UV-C region). Since ultraviolet radiation below 295 nm is effectively absorbed before reaching the earth's surface, the conclusions of these earlier investigations must be viewed with caution.

Studies using polychromatic UV-B emitters (such as filtered Westinghouse FS 40 sunlamps) have generally employed UV-B irradiances approximately equivalent to 35 to 50% ozone depletions (Van et al., 1976; Sisson and Caldwell, 1976; Ambler et al., 1975). Only a few studies have examined UV-B enhancement and ozone depletions below this level.

Photoreactivation has been shown to be an effective mechanism in the repair of UV-B induced damage in micro-organisms and algae. This repair requires simultaneous or subsequent exposure to radiation of longer wavelengths (315-550 nm). There is evidence suggesting that UV-B associated decreases in net carbon exchange are photoreactible (Van et al., 1976; Sisson and Caldwell, 1976). However, these studies incorporated low PAR irradiances, combined with large UV-B fluxes.

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[1] Abbreviations: UV-B = Ultraviolet light between 280-320 nm; PAR = Photosynthetically Active Radiation (between 400-700 nm).

EFFECTS OF ULTRAVIOLET-B RADIATION ENHANCEMENTS AND PAR FLUX DENSITIES ON SEVERAL GROWTH PARAMETERS AS RELATED TO NCE, DARK RESPIRATION, AND TRANSPIRATION OF SOYBEAN AND SEVERAL GROWTH PARAMETERS OF WHEAT

Abstract

Plants were grown under four UV-B flux levels (simulating ozone depletions ranging from 6 to 25%) with simultaneous exposure to four PAR flux densities in a factorial design. Measurements were made on the effects of each treatment on NCE, dark respiration, transpiration, and growth of soybean (Glycine max (L.) Merr. cv Hardee). The effects of UV-B on soybean growth were compared with wheat (Triticum aestivum cv Jori). UV-B effects were dependent upon PAR flux densities incident during growth. Photorepair of UV-B induced NCE reductions was ineffective at low PAR fluxes, but was important at levels saturating photosynthesis in the field. At low PAR levels, UV-B affected both stomatal and non-stomatal resistances to CO_2 and water vapor. Wheat and soybeans were both affected by low level UV-B enhancements, however, they differed markedly in their growth and biomass allocation patterns. The present study points out the importance of the interactions between UV-B radiation and PAR in understanding the effects of UV-B on plant processes.

Introduction

Vegetable and agronomic crops were grown in the field from March to December 1977 under a gradient UV-B irradiator under field conditions to determine the crops response in regards to both vegetative and reproductive capacities to enhanced UV-B radiation (Appendix I-1). The crops tested were 'Silverqueen' corn, potatoes, 'Walter' tomatoes, Southern peas, 'Florunner' peanuts, yellow-neck squash, 'Star Bonnet' rice, mustard and 'Red Globe' radish. The crops were grown under different UV-B gradients and different UV-B attenuating cellulose acetate filters which are indicated for each crop in Table 1.

Materials and Methods

Field beds with open bottoms to natural soil were constructed with sides of cypress posts and boards. Each bed measured 0.3 meters deep, 1 meter wide and 12.2 meters long. The entire construction site was fumigated with methyl bromide. Redi-Earth soil mix supplied by W.R. Grace and Co. in Jacksonville, Florida was used to fill the beds. It was fortified with fertilizer and each crop was given additional fertilizer as required (Table 2). Irrigation was supplied by placing a loop of Via-flo tubing in each bed (Appendix I-1) so that it was 8 cm from either side of the plants. Tensiometers were used to regulate irrigation.

The field irradiator for UV-B enhancement consisted of 12 irradiator units, each with 6 FS-40 Westinghouse "sun lamps" mounted end to end and in

Table 1. UV-B radiation enhancement levels in the field gradient irradiator in total watts/m^2, (DNA) weighted mw/m^2 and UV-B solar equivalent units (seu).

Corn - Potatoes - Tomatoes

Meter	Weighted	w/m^2	seu
1	9.352	0.596	0.841
2	6.682	0.426	0.601
3	4.835	0.308	0.435
4	3.584	0.228	0.322
5	3.551	0.226	0.319
6	3.424	0.218	0.308
7	2.355	0.145	0.211
8	1.168	0.074	0.105

Peanuts - Peas - Rice

Meter	Weighted	w/m^2	seu
1	17.253	1.099	1.552
2	6.763	0.431	0.608
3	3.775	0.240	0.339
4	3.166	0.202	0.285
5	2.743	0.175	0.247
6	2.320	0.148	0.209
7	1.801	0.115	0.162
8	1.013	0.065	0.091

Squash - Mustard - Radish

Meter	Weighted	w/m^2	seu
1	34.506	2.198	3.104
2	13.526	0.861	1.217
3	7.550	0.481	0.679
4	6.332	0.403	0.570
5	5.486	0.349	0.493
6	4.640	0.296	0.417
7	3.603	0.230	0.324
8	2.027	0.129	0.182

Table 2 . 1977 Crop Culture.

	Crop					
	Peas	Peanuts	Rice	Squash	Mustard	Radish
Date planted	7/1	6/17	6/24	9/9	9/30	10/25
Thinning date	8/1	7/27	8/4	10/3	10/10	11/2
# pls./m.	6	6	10	6	20	50
Date & pesticide	7/14, malthion 7/19, lanate July 22 thiodan 8/16, thiodan	7/14, Malthion 7/22, thiodan 8/11, thiodan 8/16, thiodan	7/15, captan 10/4, benlate	9/23, cygon, 10/4, cygon	10/2, cygon	
Date kind and g/meter of fert.[1] in 1.25 liters per meter	7/15,#1 10.5g. Aug. 16 5.3g.	7/6,#1, 10.5g. 8/17,#2 9/15 5.3g.	7/13,#1, 10.5g. 8/11,#1, 5.3g. 9/15,#1, 5.3g. 10/14,#1, 5.3g.	10/13,#1, 5.3g.	11/14,#3, 10.5g.	11/14,#3,
Harvest date	9/15	10/3	11/1	10/20	12/2	12/9

[1]
#1=20-20-20 fertilizer
#2=gypsum, 15 g/meter
#3=15-0-0 fertilizer

an aluminum reflector (Appendix I-2). The 6 lamps and reflector were constructed as one unit. It was attached to pulleys and chains at either end and the center so height adjustments could be made to establish the desired gradient and to maintain it as the plants grew. The UV-B irradiation gradient was established by raising and lowering the ends of each irradiator unit to give an angle of 12^{o}. The lower end of the irradiator was off-set by 3 meters from one end of the bed to give a non-irradiate control section. Thus, the highest irradiance level was the 4th meter and the lowest at the 11th meter. The gradient was adjusted twice weekly. Automatic timers controlled the FS-40 lamps for an on period for 6 hours in the center of each day.

Each bed was fully planted. The first meter served as a buffer, second as the untreated control and third as a buffer between the control and the lower end of the UV-B gradient receiving the highest UV-B enhancement (Appendix I-1). The 8 meters under the UV-B irradiance gradient received different levels of UV-B enhancement (Table 1, Table 4). Each crop was replicated in 4 separate field beds.

On April 28, 1977 a total and weighted UV-B flux between 295nm and 340nm was measured with the Gamma Scientific spectroradiometer. The UV-B solar equivalent unit ($UV\text{-}B_{seu}$) was determined to be 11.2 W/m^2 for the weighted value and 7.08 W/m^2 for the absolute value. In the field study, when the weighted flux equaled 11.2 mW/m^2 under an FS-40 lamp, the absolute flux between 295nm and 340nm was 0.71 W/m^2. with a 5 mil cellulose acetate filter. These values were used as one $UV\text{-}B_{seu}$ for the UV-B enhancement treatments.

As each crop was planted the Optronics, Model 741, spectroradiometer equipped with a solar blind filter, a cosine receptor and a Hewlett-Packard 9815 A calculator was used to determine UV-B irradiance fluxes for adjusting

Table 3. Solarization of 3 mil and 5 mil cellulose acetate in the field after 3 and 4 days as measured with an Optronics 725 radiometer with a neutral density filter. Each number is the mean of 23 measurements.

3 mil Cellulose Acetate[1]		5 mil Cellulose Acetate[1]			
		Roll 1		Roll 2	
3 days	4 days	3 days	4 days	3 days	4 days
5.66	5.50	2.73	2.67	3.16	3.05

[1]Initial readings for 3 mil and 5 mil cellulose acetate were set for 7.4 and 3.9 respectively.

Table 4. Natural solar UV-B flux (290-320nm), UV-B and enhancement in w/m^2 and solar equivalent units (seu) (290-320nm) on field grown crops at the center of the 1st lamp in the gradient field. UV-B enhancement measured twice each week with optronics 725 radiometer and 725 radiometer calibrated weekly with Gamma Scientific and Optronics 741 spectroradiometer. Natural solar flux measured daily every ½ hour between 9 a.m. and 4 p.m.

Crop Growing Dates	6/17 to 10/3	7/1 to 9/5	9/9 to 10/20	6/24 to 11/1	9/30 to 12/2	10/25 to 12/9
	Peanuts	Peas	Squash	Rice	Mustard	Radish
# Growing Days	108	66	44	130	63	45
Thickness C.A. used	5 mil	5 mil	3 mil	5 mil	3 mil	3 mil
$\bar{X}$ UV-B w/m^2						
Bed 1	1.302	1.243	2.455	1.350	2.513	2.607
" 2	1.533	1.225	2.477	1.330	2.495	2.607
" 3	1.269	1.212	2.472	1.350	2.509	2.492
" 4	1.164	1.226	2.432	1.345	2.521	2.531
$\bar{X}$ Bed w/m^2	1.317	1.234	2.459	1.040	2.510	2.559
$\bar{X}$ UV-B seu						
Bed 1	1.8390	1.7556	3.4675	1.9067	3.5494	3.6822
" 2	2.1652	1.7302	3.4985	1.8785	3.5240	3.6822
" 3	1.7924	1.7119	3.4915	1.9067	3.5437	3.5198
" 4	1.6441	1.7316	3.4350	1.8997	3.5607	3.5749
$\bar{X}$ Bed seu w/m^2	1.8601	1.7323	3.4731	1.8979	3.5444	3.6148
$\bar{X}$ Bed seu Weighted (DNA)	20.6793	19.2584	38.6114	21.0995	39.4042	40.1868
$\bar{X}$ UV-B Solar Flux During Crop Growth						
Weighted (DNA)	12.7355	10.8174	12.2998	11.3861	7.1566	4.546
Total w/m^2	6.5838	5.4318	6.7518	6.1919	4.610	3.525

[1] 1 seu = 11.1173 weighted (DNA) = 0.708 w/m^2 under an FS-40 lamp and 708 w/m^2 under natural sunlight conditions.

the initial distance from the center of the first lamp to the soil surface for the desired gradient. This UV-B enhancement level was set for .8 $UV\text{-}B_{seu}$ using 5 mil cellulose acetate filters for 'Silverqueen' corn, 'Irish' potatoes and 'Walter' tomatoes, 1.5 $UV\text{-}B_{seu}$ for 'Southern' peas and 'Florunner' peanuts, 'Starr Bonnet' rice and 3.1 $UV\text{-}B_{seu}$ using 3 mil cellulose acetate filters for squash, mustard and radish (Table 1). After the initial measurements were made, the UV-B flux was measured with a Optronics 725 broad band UV meter sensitive up to 370 nm before and after each changing of cellulose acetate filters which was done twice a week. The "after" measurement was maintained at the same level by adjusting each irradiator unit to yield UV-B enhancement levels from the center of this first bulb to "plant height" at .8, 1.5 or 3.1 $UV\text{-}B_{seu's}$ depending upon the crop. The "before" changing the filter measurements was used to determine the amount of solarization (Table 3) and from this measurement an average daily UV-B enhancement for the 3 or 4-day period was determined each time filters were changed and lamps were checked. These values were then used to arrive at the mean measured UV-B enhancement level actually obtained from planting the crop to harvest (Table 1). Responsibility for UV-B enhancement measurements was contracted for the first 3 crops. This was occasionally done by lamp adjustment with a sun-burn radiometer. This was determined not to be adequate and a different protocol was established by the project coordinator for this most critical operation.

The natural solar irradiance of UV-B at ground level from 295-340 nm was measured by nm every half hour from 10to 4 daily and a mean daily and weekly flux computed. Measurements were taken with a Gamma Scientific spectroradiometer and computer calculations made on a 2100 Hewlett-Packard computer with a digital voltmeter and crossbar scanner (Appendix I-4).

Seed was purchased locally except the rice seed which was donated by Dr. Victor Green, Agronomy Department, University of Florida, Gainesville, 32611.

At maturity, all the plants in the control and the 8 meters in the UV-B gradient flux were harvested from each bed. Parameters measured at harvest and on seedlings at the time of harvest are discussed with each crop but always included at least leaf area, leaf fresh and dry weight, stem fresh and dry weight and root fresh and dry weight. Leaf area was determined for all plants removed at the time of thinning. At harvest of mature plants, leaf area was determined on the first plant of each meter of the 8 in the UV-B flux field and the control meters for corn, potatoes, tomatoes, peanuts, for the first 2 plants for Southern peas, for the first 3 plants for rice and mustard and for the first 5 radish plants in each. All 4 bed replicates were handled the same for each crop. A Lambda, model LI 3050 A, leaf area meter with a high speed option was used to obtain leaf areas. Fresh weights were measured to 0.1g and dry weights to 0.001g using a digital top-load mettler balance.

To analyze the field data, polynomial regressions as to the amount of $UV\text{-}B_{seu}$ enhancement were fitted sequentially beginning with a first order (linear) model. The control was not used to estimate these equations. The sequential process continued as long as (a) a significant increase in the regression mean square was obtained and/or (b) the lack-of-fit mean square was significant. Significance was determined using the error mean square obtained by removing the total variation due to treatments and blocks. To complete the analysis a comparison of the check with the treatment average was made. All data in this report indicated significantly different at the 5% or less level.

I. 'Irish' potato

'Irish'potato (Solanium tuberosum L.) tuber pieces were planted March 18, 1977& grown for 80 days to harvest on June 6, 1977. The crop was fertilized every three weeks with 20-20-20 fertilizer at the rate of 10.5g/meter in 1.25 liters of water. UV-B enhancement was set for 0.84 $UV\text{-}B_{seu}$ at the center of the first lamp and 5 mil cellulose acetate was used (Table 4).

To determine if UV-B radiation altered the pattern of flowering, the number of open flowers per plant were counted on May 2, 4 and 9 (Appendix I-2). At harvest, data taken for all 6 plants in each meter of the 4 replicate beds included: 1) leaf area (first plant in each meter only), 2) leaf fresh and 3) dry weight 4) stem fresh and 5) dry weight, 6) root fresh and 7) dry weight and 8) total fresh and 9) total dry weight biomass, 10) number and 11) weight of potatoes by 4 grades, 12) mean weight of potatoes by 4 grades, 13) total number and 14) weight of potatoes, and 15) mean weight of potatoes.

II. 'Walter'tomato

'Walter'tomato (Lycospersicum esculentum Mill.) transplants were set March 18, 1977, grown for 98 days &fruits harvested as they matured with final harvest on June 24, 1977 (Appendix I-2). They were fertilized every 3 to 4 weeks with 20-20-20 fertilizer at the rate of 10.5g/meter in 1.25 liters of water. UV-B enhancement was set for 0.84 $UV\text{-}B_{seu}$ at the center of the first lamp and 5 mil cellulose acetate was used (Table 4).

Determination of a possible alteration in the pattern of flowering was followed by counting the number of flowers opening at the second and third flower clusters (hands) on April 25, 27, 29 and May 4.

The tomatoes were harvested June 10 and 17 and these were fruit in the advanced mature maturity class and some unmarketable fruit. Unmarketable tomatoes consisted of 1) defective (catface, crooks and other inherent defects); 2) culls (rots, cracks, sunscald and other impinging defects and 3) immature (sound fruit less than 50g in weight). The second and final harvest on June 24 included all the remaining fruit and these were sorted into size and maturity classes. Fruits in the maturity class of mature green were fully developed, showing no red color. The size groups, equivalent to USDA grading standards, were as follows: 1) 5 x 6 and larger = over 200g; 2) 6 x 6 = 150 - 200g; 3) 6 x 7 = 100 - 150g; and 4) 7 x 7 = 50 - 100g. Tomato fruit data taken from the 3 harvests was number, weight of individual fruit and mean weight for each size or maturity class.

On June 24 all the plants were harvested and the following data taken on each plant: 1) leaf area (first plant in each meter only), 2) leaf fresh and 3) dry weight 4) stem fresh and 5) dry weight, 6) root fresh and 7) dry weight and 8) total fresh and 9) dry weight biomass.

III. 'Silverqueen'corn

'Silverqueen corn'(Zea mays var. saccharate L.) was planted March 17, 1977 but was nipped by frost at the end of the month. Frost at this stage can decrease subsequent yields so the crop was replanted March 28, 1977, grown for 75 days and harvested. The crop was fertilized every 3 to 4 weeks with 20-20-20 fertilizer at the rate of 10.5g/meter in 1.25 liters of water. UV-B enhancement was set for 0.84 UV-B_{seu} at the center of the first 5 mil cellulose acetate filtered lamp and the gradient set (Table 4).

The corn was thinned to 6 plants per meter. The number of silks per ear of corn was counted May 23, 1977 and data taken on the corn ears at

harvest included 1) weight and 2) length of the whole ear, 3) weight, 4) length and 5) diameter of the trimmed ear and 6) percentage of the ear filled with kernels of marketable size. The trimmed ears had the shuck, shank and silks removed.

At harvest, main stalk and sucker stalk data taken included 1) leaf area (first plant/meter only) 2) stalk, and 3) tassel length, 4) stalk fresh and 5) dry weight, 6) leaf fresh and 7) dry weight, 8) root fresh and 9) dry weight 10) total fresh and 11) dry weight and for the main stalks 12) internode number and 13) length. The number of suckers was tallied for each plant as well as the height of the tallest sucker on each plant. Main stalk and sucker data was then combined to obtain a whole plant 1) stem fresh and 2) dry weight, 3) leaf fresh and 4) dry weight and 5) total fresh and 6) dry weight biomass for each plant in all the meters (Appendix I-2).

IV. Southern peas

Southern peas (Vigna unguiculata L.) were planted July 1, 1977, grown for 166 days and harvested September 5, 1977 (Appendix I-2). The crop was sprayed for aphids 4 times using malthion, lanate or thiodan. A 20-20-20 fertilizer was applied twice, first at 10.5 g/meter on July 15, and then 5.3 g/meter on August 16 in 1.25 liters of water per meter (Table 2). UV-B enhancement was set for 1.5 $UV\text{-}B_{seu's}$ at the center of the first lamp and 5 mil cellulose acetate was used (Table 4).

On August 1, 1977, the peas were thinned (7 to 19 seedlings per meter removed) to 6 plants per meter. Data taken on each removed seedling by meter was 1) total leaf area, 2) leaf fresh and 3) dry weight, 4) stem fresh and 5) dry weight and 6) root fresh and 7) dry weight, 8) total

fresh and 9) dry weight biomass, 10) root:shoot ratio 11) leaf density (leaf area divided by leaf dry weight) 12) % leaves 13) % stems 14) % roots.

Beginning 57 days after planting the marketable peas were harvested by meter, counted and fresh weights determined every 3 or 4 days for 5 harvests. The final harvest data taken on each plant included 1) leaf area (first plant/meter only) 2) leaf fresh and 3) dry weight, 4) stem fresh and 5) dry weight, and 6) root fresh and 7) dry weight 8) total fresh and 9) dry weight biomass 10) root:shoot ratio and 11) leaf density, 12) % leaves 13) % stems, and 14) % roots. Total leaf area was taken on the first two plants in each meter.

V. 'Florunner'peanuts

'Florunner'peanuts(Arachis hypogaea L.) were planted June 17, 1977, grown for 108 days and harvested October 3, 1977 (Appendix I-3). The crop was sprayed 4 times with thiodan or malthion, fertilized twice with 20-20-20 fertilizer at the rate of 10.5 g/meter (July 6) and 5.3 g/m (September 15) in 1.25 liters of water. Fifteen grams gypsum per meter was applied August 17, 1977, one week after flowering (Table 2). UV-B enhancement was set for 1.5 UV-B $_{seu's}$ at the center of the first lamp and 5 mil cellulose acetate was used (Table 4).

Five to eight peanut seedlings per meter were removed to obtain an even stand of 6 plants per meter on July 27, 1977. Data taken for each seedling included 1) leaf area 2) leaf fresh and 3) dry weight, 4) stem fresh and 5) dry weight and 6) root fresh and 7) dry weight 8) total fresh and 9) dry weight biomass 10) root:shoot ratio 11) leaf density 12) % leaves, 13) % stems and 14) % roots.

Harvest began October 3. Data taken on each plant was 1) leaf area 2) leaf fresh and 3) dry weight, 4) stem fresh and 5) dry weight, and 6) root fresh and 7) dry weight 8) total fresh and 9) dry weight biomass

10) root:shoot ratio, 11) leaf density, 12) % leaves, 13) % stem, 14) % roots, 15) total number of pop (unfilled) peanuts, 16) weight of the pops 17) total number of filled peanuts, 18) weight of the filled peanuts and 19) plant height.

VI. 'Star Bonnet' rice

'Star Bonnet' rice (Oryza sativa L.) was planted June 24, 1977, grown for 130 days and harvested November 1, 1977 (Appendix 1-3,4). The crop was sprayed July 15 with captan and October 4 with benlate. A 20-20-20 fertilizer was applied July 13, August 11, September 15 and October 14 at the rate of 10.5 g/meter, 5.3 g/meter, and 2.6 g/meter all in 1.25ℓ H_2O on indicated dates, respectively (Table 2). UV-B enhancement was set for 0.8 $UV\text{-}B_{seu}$ at the center of the first lamp and 5 mil cellulose acetate was used (Table 4).

Five to 26 rice seedlings per meter were removed in thinning the crop to 10 plants per meter. Data taken for each seedling included 1) leaf area, 2) leaf fresh and 3) dry weight 4) stem fresh and 5) dry weight and 6) root fresh and 7) dry weight, 8) total fresh and 9) dry weight biomass 10) leaf density, 11) % leaves, 12) % stems and 13) % roots.

Rice height for each plant in all meters was measured every week for 15 weeks after seedling emergence.

At harvest each tiller of the plant was analysed separately for the first 3 control plants, the first 3 plants in meter one and the first plant in every meter thereafter under the UV-B gradient. The number of tillers per plant ranged from 10 to 26. The following parameters were measured and observations made for each tiller: 1) fruiting or vegetative tiller, 2) leaf fresh 3) and dry weight, 4) stem fresh 5) and dry weight, 6) root fresh 7) and dry weight, 8) spike length, 9) spike fresh 10) and dry

weight, 11) stage of spike development, 12) height to spike base, 13) number of leaves/tiller, 14) leaf area minus flag leaf, and 15) flag leaf area 16) length, 17) fresh weight, 18) dry weight, and 19) leaf specific thickness or density, 20) total # of tillers per plant, 21) total dry weight biomass/tiller, 22) root:shoot ratio/tiller, and 23) tiller leaf specific thickness or density.

The stage of spike development was determined by rating the amount of the spike which had turned brown: no brown = 1, 1/4 = 2, ½ = 3, 3/4 = 4, and all brown = 5.

On the remaining plants in each meter, parameters 1 to 11 and 21 to 24 were measured in addition to talleying the number of vegetative vs. fruiting tillers.

VII. Yellow Crooked-neck squash

Squash (Cucurbita pepo var. condensa Bailey) were planted September 9, 1977 grown for 41 days and harvested just as they began to bear fruit because of cool weather, (Appendix I-3). The crop was sprayed twice for leaf minor with cygon and fertilized October 13 with 5.3 g of 20-20-20 fertilizer per 1.25 liters of water per meter (Table 2). UV-B enhancement was set for 3.1 UV-B $_{seu's}$ at the center of the first lamp and 3 mil cellulose acetate used (Table 4).

When the squash were thinned October 3, 1977 to 6 plants meter, each removed seedling was measured for 1) total leaf area, 2) leaf fresh and 3) dry weight, 4) stem fresh and 5) dry weight, 6) root fresh and 7) dry weight, 8) total fresh and 9) dry weight biomass 10) root:shoot ratio, 11) leaf density, 12) % leaves, 13) % stems 14) % roots and 15) height.

At final harvest, October 20, frost had damaged the leaves so leaf area was not taken. Data taken included: 1) leaf fresh and 2) dry weight 3) stem fresh and 4) dry weight, 5) root fresh and 6) dry weight 7) total

fresh and 8) dry weight biomass 9) root:shoot ratio, 10) % leaves, 11) % stems 12) % roots 13) number of fruit and 14) fresh weight of fruit and 15) mean weight per fruit.

VIII. Mustards

Mustards (Brassica juncea var. cripifolia) were planted September 20, 1977, grown for 63 days and harvested December 2, 1977 (Appendix I-4). The crop was sprayed November 2 with cygon for leaf miners and fertilized with 15-0-15 fertilizer November 14 at the rate of 10.5 g/meter in 1.25 liters of water (Table 1). UV-B enhancement was set for 3.5 UV-B $_{seu's}$ at the center of the first lamp and 3 mil cellulose acetate was used (Table 4). The mustards were thinned to 20 plants per meter on October 10, 1977. At harvest, data taken included 1) leaf area 2) leaf fresh and 3)dry weight 4) root fresh and 5) dry weight 6) total fresh and 7) dry weight biomass, 8) root: shoot ratio, 9) leaf density 10) % leaves, 11) % roots and 12) number of leaves per plant.

IX. 'Red globe'radish

'Red globe'radish seed (Raphanus sativus L.) were planted October 25, 1977, grown for 45 days and harvested December 9, 1977 (Appendix I-1). The crop was thinned to 50 plants per meter and fertilized November 14 with a 15-0-15 fertilizer at the rate of 10.5 g/meter in 1.25 liters of water (Table 2). UV-B enhancement was set for 2 solar units at the center of the first lamp and 3 mil cellulose acetate was used (Table 4). At harvest,data taken included 1) leaf area on the first 5 plants, 2) leaf fresh and 3) dry weight and 4) root fresh weight 5) total fresh weight, 6) leaf density and 7) number of leaves per plant.

Results

I. 'Irish'potatoes

The number of open flowers per plant peaked on May 4 and at this time the UV-B treated plants had considerably more open flowers than the control (Table 5). The duration of flowering was apparently longer on the control plants. Mean potato weight was consistently larger for the grade A large in the UV-B treated meters but the other grades were all similar (Table 6).

Significant linear relationships were found for total plant dry weight biomass and leaf dry weight among the UV-B meters (Table 7). The dry weights increased with increasing UV-B as approximated by the equations 88.6 + 26.8X and 211.9 + 57.3X for leaf dry weight and dry weight biomass, respectively. The other vegetative parameters were all similar.

II. 'Walter'tomatoes

Flowering on the second and third panicle (hand) was tallied since these reproductive buds were initiated under exposure to UV-B radiation. First panicle flowers were initiated prior to transplanting. The flowering pattern was similar among the meters except that the number of flowers on the second hand on May 4 of control plants was significantly greater than the UV-B irradiated plants (Table 8).

Exposure to UV-B significantly reduced the number and weight of tomatoes in the 5x6 size class at the second harvest (Tables 9, 10 and 11). The average of all UV-B treated plant was significantly less than the control for the following maturity classes:

1. Advanced Mature, Harvest 2, 5x6, number of tomatoes
2. Advanced Mature, Harvest 2, 5x6 weight of tomatoes
3. Mature Green, Harvest 2, 5x6, number of tomatoes
4. Mature Green, Harvest 2, 5x6 weight of tomatoes
5. Marketable, Harvest 2, 5x6, number of tomatoes
6. Marketable, Harvest 2, 5x6, weight of tomatoes
7. Advanced mature, total, 5x6, number of tomatoes
8. Advanced mature, total, 5x6, weight of tomatoes
9. Total weight, mature green, harvest 2

Table 5 Potato leaf area at harvest and number of flowers.[1]

Meter[2]	Leaf Area cm^2	Open Flowers per Plant		
		May 2	May 4	May 9
0	4496	7.5	13.1	10.7
1	6430	11.7	22.4	9.7
2	5196	17.6	26.7	10.6
3	6110	9.9	20.4	10.7
4	8586	7.1	9.9	11.3
5	6364	13.4	20.5	11.2
6	4372	13.9	25.3	13.5
7	3175	10.4	16.4	5.0
8	3770	9.2	20.0	9.6

[1]Means from 4 field beds, each with 9 meters and 6 plants per meter at harvest. Leaf area determined only on the first plant in each meter and flower number on all plants.

[2]Meter 0 = No UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

Table 6. Potato yields at harvest[1].

Meter Average by Grade

Meter[2]	A Large			A			B		
	Wt.(g)	x Wt.(g)	No.	Wt.(g)	x Wt.(g)	No.	Wt(g)	x Wt.(g)	No.
0	2683	173	15.5	2462	99	24.8	972	49	20.0
1	2138	191	11.2	2233	99	22.5	1163	47	24.5
2	2328	176	13.2	1899	101	18.8	714	48	14.8
3	1749	177	9.9	2329	100	23.2	1012	47	21.5
4	2316	178	13.0	2417	103	23.5	864	46	18.6
5	3216	190	16.9	1746	102	17.1	878	48	18.4
6	3178	195	16.3	2094	105	20.0	835	47	17.8
7	1880	177	10.6	2634	102	25.8	1290	51	25.1
8	2205	176	12.5	2521	99	25.4	835	48	17.4
$s_{\bar{x}}$	389.7		2.19	291.5		2.92	175.1		3.63

Meter[2]	C Creamer			Total		
	Wt.(g)	x Wt.(g)	No.	Wt.(g)	x Wt.(g)	No.
0	238	18	13.0	6355	87	78.2
1	340	17	19.5	5874	76	77.8
2	302	15	19.8	5244	79	66.5
3	407	16	24.9	5497	69	79.5
4	224	19	11.5	5822	87	66.6
5	333	18	18.3	6174	87	70.6
6	260	18	14.2	6368	93	68.2
7	292	20	14.4	6095	80	75.8
8	273	17	15.8	5833	82	71.1
$s_{\bar{x}}$	105.8		6.75	530.8		9.21

[1]Means from 4 field beds, each with 9 meters and 6 plants per meter at harvest.

[2]Meter 0 = No UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

Table 7. Potato plant harvest data.

	Root(g)		Stem(g)		Leaf(g)		Total(g)	
Meter	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
10	55.9	7.16	257	16.9	204	21.1	518	45.2
1	55.0	7.80	283	23.1	210	23.9	548	54.9
2	52.1	6.16	267	17.9	187	17.2	506	41.3
3	51.2	7.08	254	18.5	179	19.8	484	45.4
4	49.7	6.76	274	19.1	174	19.6	499	45.5
5	59.7	5.74	283	14.3	205	15.3	548	35.4
6	50.5	8.12	259	19.9	168	19.2	478	47.3
7	53.6	5.42	251	15.1	147	14.6	451	35.1
8	53.8	6.11	258	14.9	177	15.7	489	36.7
$s_{\bar{x}}$	5.228	0.823	25.88	2.055	22.13	2.327	49.22	4.813

[1]Means from 4 field beds, each with 9 meters and 6 plants per meter at harvest.

[2]Meter 0 = no UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

Table 8. Walter tomato leaf area at harvest and number of flowers on the second and third hand[1].

Meter[2]	Leaf Area	Number of Flowers per Plant							
		April 25		April 27[3]*		April 29		May 4	
		Second	Third	Second	Third	Second	Third	Second	Third
0	9734	4.1	1.3	3.5	1.5	2.5	2.8	2.1	1.6
1	8075	3.5	0.9	3.9	1.6	2.9	2.9	1.8	2.0
2	6810	3.5	1.9	3.5	1.5	2.4	2.5	1.1	2.5
3	9521	3.3	1.6	2.8	1.4	1.9	2.4	0.9	1.8
4	9054	3.3	1.8	2.4	1.4	2.6	2.2	0.9	1.9
5	8639	2.6	1.2	2.8	0.9	3.1	2.1	1.1	2.5
6	8705	3.9	2.2	3.4	1.8	1.9	2.1	0.8	2.2
7	7544	3.9	2.4	3.7	1.1	2.1	2.1	1.1	2.7
8	12660	2.5	1.0	2.4	0.7	2.6	2.1	1.0	1.8

[1]Means from 4 field beds, each with 9 meters and 3 plants per meter at harvest.

[2]Meter 0 = no UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

*Indicates average of all UV-B treatments was significantly less than control.

Table 9. Harvest data by USDA grading standards for Advanced Mature Walter tomatoes of the second harvest[1].

Advanced Mature, Harvest 1

	5x6[2]			6x6			6x7			7x7			Total		
Meter[3]	No.	$\bar{x}$Wt(g)	Wt(g)	No.	$\bar{x}$Wt(g)	Wt(g)	No.	$\bar{x}$Wt(g)	Wt(g)	No.	$\bar{x}$Wt(g)	Wt(g)	No.	$\bar{x}$Wt(g)	Wt(g)
0	22.8	211	4802	5.5	141	777	5.3	118	620	0.8	93	70	34.3	183	6270
1	19.1	200	3826	9.8	148	1442	3.8	113	422	1.5	64	96	34.1	170	5787
2	21.0	215	4519	7.0	144	1008	7.3	116	844	0.8	93	70	36.0	179	6440
3	18.8	209	3920	9.0	139	1254	3.8	115	430	1.0	45	45	32.5	174	5650
4	17.3	216	3724	4.0	144	576	6.0	116	693	2.8	31	85	30.0	169	5078
5	16.5	213	3515	6.5	144	934	3.0	117	352	2.0	78	156	28.0	177	4958
6	18.3	215	3925	9.5	141	1335	7.3	110	795	2.0	43	86	37.0	166	6141
7	20.5	209	4276	6.3	147	916	5.0	119	596	1.5	57	85	33.3	177	5873
8	16.8	220	3681	7.8	142	1099	3.5	114	400	1.3	74	92	29.3	180	5272
$s_{\bar{x}}$	2.740		622.2	1.760		250.1	1.775		205.7	0.883		41.8	3.442		608.4

Advanced Mature, Harvest 2

	5x6			6x6			6x7			7x7			Total		
Meter	No.[4]	$\bar{x}$Wt(g)*	Wt(g)*	No.	$\bar{x}$Wt(g)	Wt(g)	No.	$\bar{x}$Wt(g)	Wt(g)	No.	$\bar{x}$Wt(g)	Wt(g)	No.	$\bar{x}$Wt(g)	Wt(g)
0	14.5	208	3017	5.5	144	791	4.0	114	457	1.3	88	110	25.3	173	4374
1	7.5	194	1454	7.1	142	1011	1.9	110	206	0.4	92	35	16.9	160	2706
2	10.0	206	2061	6.5	145	941	5.5	113	622	2.5	86	214	24.5	157	3838
3	8.5	200	1699	5.3	141	740	4.8	112	532	1.3	90	112	19.8	156	3083
4	10.3	207	2122	5.3	139	732	1.5	110	165	0.5	92	46	17.5	175	3066
5	10.8	193	2072	5.8	143	822	2.8	116	318	1.5	87	130	20.8	161	3342
6	11.0	198	2180	6.5	142	924	4.8	115	548	3.5	87	303	25.8	154	3955
7	13.0	199	2583	5.5	140	772	2.0	113	226	0.8	89	67	21.3	192	3648
8	11.0	208	2288	7.3	145	1048	5.0	113	566	2.3	30	180	25.5	160	4082
$s_{\bar{x}}$	1.912		274.4	1.464		205.6	1.486		167.1	0.858		76.5	3.407		468.8

[1]Means from 4 field beds, each with 9 meters and 3 plants per meter at harvest.
[2]Grade 5x6 - over 220g; 6x6 = 150-200g; 6x7 = 100-150g; 7x7 = 50-100g.
[3]Meter 0 = no UV-B control; meter 1 = first meter under the UV-B gradient irradiator.
[4]* indicates average of all UV-B treatments was significantly less than the control.

Table 10. Harvest data by USDA grading standards for the second Walter tomato harvest according to marketable and mature green stages of development.[1]

Mature - Green Harvest[2]

Meter[3]	5x6			6x6			6x7			7x7			Total		
	No.	Ave.Wt(g)	Wt.	No.	Ave.Wt(g)	Wt.	No.	Ave.Wt(g)	Wt.	No.	Ave.Wt(g)	Wt.	No.	Ave.Wt(g)*	Wt.*
0	1.8	221	387	1.3	141	176	1.0	112	112	0.8	92	69	4.8	157	744
1	1.1	201	225	0.8	133	100	0.0	0	0	0.8	88	66	2.6	149	391
2	0.8	171	128	0.5	144	72	0.8	111	83	1.3	93	116	3.3	123	399
3	0.0	0	0	1.3	141	176	1.0	113	113	0.3	84	21	2.5	124	310
4	1.3	190	237	0.8	139	104	1.0	103	103	0.0	0	0	3.0	148	445
5	0.3	200	50	1.0	135	135	0.8	109	82	1.3	90	112	3.3	116	378
6	0.5	180	90	0.5	136	68	1.5	111	166	1.0	93	93	3.5	119	418
7	0.5	170	85	1.0	150	150	0.8	112	84	0.3	96	24	2.5	137	343
8	0.5	196	98	0.8	147	110	1.8	113	198	1.0	87	87	4.0	123	492
$s_{\bar{x}}$	0.471		98.0	0.594		81.3	0.490		55.6	0.446		39.8	0.985		147.7

Marketable, Harvest[2]

Meter	5x6			6x6			6x7			7x7			Total		
	No.*	Ave.Wt(g)*	Wt.*	No.	Ave.Wt(g)	Wt.	No.	Ave.Wt(g)	Wt.	No.	Ave.Wt(g)	Wt.	No.	Ave.Wt(g)*	Wt.*
0	16.3	209	3404	6.8	143	967	5.0	114	569	2.0	89	178	30.0	171	5119
1	8.6	195	1678	7.9	141	1111	1.9	110	206	1.1	90	101	19.5	159	3097
2	10.5	204	2190	7.0	145	1013	6.3	113	705	3.8	88	330	27.8	153	4237
3	8.5	200	1699	6.5	141	917	5.8	112	645	1.5	89	133	22.3	153	3394
4	11.5	205	2359	6.0	139	836	2.5	107	268	0.5	92	46	20.5	171	3510
5	11.0	193	2121	6.8	142	957	3.5	114	400	2.8	88	242	24.0	155	3720
6	11.5	197	2270	7.0	142	992	6.3	114	715	4.5	88	496	29.3	150	4373
7	11.5	198	2668	6.5	142	922	2.8	112	309	1.0	91	91	23.8	168	3991
8	11.5	207	2386	8.0	145	1157	6.8	113	764	3.3	82	267	29.5	155	4574
$s_{\bar{x}}$	1.722		347.2	1.765		246.5	246.5		174.2	0.983		87.1	3.444		453.6

[1]Means from 4 field beds, each with 9 meters and 3 plants per meter at harvest.
[2]Grade 5x6 = over 200g; 6x6 = 150-200g; 6x7 = 100-150g; 7x7 = 50-100g.
[3]Meter 0 = no UV-B control; meter 1 = first meter under the UV-B gradient irradiator.
[4]* indicates average of all UV-B treatments was significantly less than the control.

Table 11. Harvest data by USDA grading standards for Advanced mature Walter tomatoes of both harvests[1].

Advanced Mature, Harvest 1 and 2[2]

Meter[3]	5x6			6x6			6x7			7x7			Total		
	No.[*4]	Ave.Wt(g)[*]	Wt.[*]	No.	Ave.Wt(g)	Wt.	No.	Ave.Wt(g)	Wt.	No.	Ave.Wt(g)	Wt.	No.	Ave.Wt(g)	Wt.[*]
0	37.3	210	7820	11.0	143	1568	9.3	116	1077	2.0	90	180	59.5	179	10645
1	26.6	198	5280	16.9	145	2453	5.6	112	628	1.9	70	132	51.0	167	8493
2	31.0	212	6580	13.5	144	1948	12.8	115	1466	3.3	87	284	60.5	170	10278
3	27.3	206	5619	14.3	140	1995	8.5	113	962	2.3	70	157	52.3	167	8733
4	27.5	213	5846	9.3	141	1308	7.5	114	858	3.3	40	131	47.5	171	8144
5	27.3	205	5587	12.3	143	1756	5.8	117	670	3.5	82	286	48.8	170	8300
6	29.3	209	6105	16.0	141	2259	12.0	112	1343	5.5	71	389	62.8	161	10096
7	33.5	205	6859	11.8	144	1688	7.0	117	822	2.3	68	152	54.5	171	9521
8	27.8	215	5869	15.0	143	2146	8.5	114	966	3.5	78	272	54.8	171	9354
$s_{\bar{x}}$	3.021		660.2	2.318		322.8	2.703		308.5	1.325		88.5	4.680		648.6

[1]Means from 4 field beds, each with 9 meters and 3 plants per meter at harvest.

[2]Grade 5x6 - over 200g; 6x6 = 150-200g; 6x7 = 100-150g; 7x7 = 50-100g.

[3]Meter 0 = no UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

[4]* indicates average of all UV-B treatments was significantly less that the control.

10. Total weight, marketable, harvest 2
11. Total weight, total advanced mature

In addition, significant linear relationships existed among advanced mature 5x6 weight class, mature green 6x7 weight class and mature green 6x7 number of fruit for tomatoes in the second harvest. The regression equations of decreasing weight and number are indicated in Table 12.

With UV-$B_{seu's}$ of .44 or greater, the number of culls in the second harvest tended to be lower as did the number of defective fruits in the first harvest (Table 13).

At harvest all the plants were analysed for leaf, stem, root and total fresh and dry weight. Leaf area was taken on the first of each of the 3 plants in each meter. The stem and total dry weight for the control was significantly greater than the mean of all UV-B treatments (Table 14). In addition, significant quadratic relationships were found among the UV-B treatments for leaf fresh and dry weight, stem dry weight and total dry weight (Table 13).

III. 'Silverqueen' corn

The main stalk of control plants were found to be significantly taller than those of the UV-B treated plants (Table 15). This was reflected in significantly greater stalk and plant total fresh weight for the control. Main stalk dry weights and tassel lengths for the control plants were also greater but the magnitude was not statistically significant. Reductions in leaf fresh and dry weight were observed for UV-$B_{seu's}$ of .84 to .44 (meter 1-3 but were similar to the control for lower enhancement levels of .32 - .10 UV-B_{seu} (meters 4-8). Root fresh and dry weight were generally less than the controls for all but one meter. Tassel length on the main stalk, internode number and mean length were all similar among the treated and control plants. Leaf area was greater for the control plants except for the last UV-B treated meter receiving .11 UV-$B_{seu's}$ (Table 15). Main stalk

Table 12. Walter tomato fruit and plant responses showing significant relationships among the UV-B treatments and their corresponding regression equations[1].

Response	Equation
Advanced Mature, Harvest 2, 5x6 Wt.	$2469.8 - 538.5\ X$
Mature Green Harvest 2, 6x7 no.	$1.55 - 0.795\ X$
Mature Green, Harvest 2, 6x7 Wt.	$171.5 - 88.6\ X$
Leaf Fresh Weight	$395.8 - 210.1\ X + 105.6X^2$
Leaf Dry Weight	$56.6 - 32.3\ X + 16.7\ X^2$
Stem Dry Weight	$83.9 - 54.4\ X + 31.6\ X^2$
Total Dry Weight	$155.1 - 84.4\ X + 46.7\ X^2$

[1] X = UV-B enhancement in solar equivalent units (seu).

Table 13. Walter tomato harvest data for immature, defective and cull tomatoes[1].

	Harvest 1				Harvest 2		
	Culls		Defective		Immature	Culls	
Meter[2]	No.	Wt.(g)	No.	Wt. (g)	Wt. (g)	No.	Wt. (g)
0	0.25	20	7.3	1278	162	15.5	1314
1	0.38	30	6.4	831	131	12.8	968
2	0.50	40	4.3	600	281	14.3	1386
3	0.75	59	5.8	838	122	12.0	1202
4	0.00	0	5.0	786	59	14.5	1555
5	0.00	0	4.5	878	224	13.5	1147
6	0.75	50	8.5	1500	70	20.8	1914
7	0.00	0	6.5	1370	92	17.0	1583
8	0.00	0	4.8	808	182	19.0	1756
$s_{\bar{x}}$	0.270	19.7	1.343	317.2	88.4	3.009	366.4

[1]Means from 4 field beds, each with 9 meters and 3 plants per meter at harvest.

[2]Meter 0 = no UV-B control; meter 1 = first meter under the UV-B gradient irradiator.

Table 14. Walter tomato plant harvest data[1].

Meter[2]	Leaf (g)		Stem (g)		Root (g)		Total (g)	
	Fresh	Dry	Fresh	Dry*[3]	Fresh	Dry	Fresh*	Dry*
0	352	52	700	79	78	18	1131	150
1	345	50	635	85	60	15	1041	151
2	295	42	609	63	66	13	971	118
3	301	43	620	60	61	13	982	116
4	325	45	589	64	65	15	979	124
5	290	40	539	62	68	13	897	115
6	337	48	702	73	89	22	1127	143
7	296	43	606	66	77	17	979	126
8	380	53	662	72	57	12	1099	137
$s_{\bar{x}}$	21.97	3.303	39.10	5.376	8.177	2.646	57.4	9.22

[1]Means from 4 field beds, each with 9 meters and 3 plants per meter at harvest.

[2]Meter 0 = no UV-B control; meter 1 = first meter under the UV-B gradient irradiator.

[3]* indicates average of all UV-B treatments was significantly less than the control.

Table 15. Silverqueen corn main stalk harvest data[1].

	Length (cm)		Internode(cm)		Stalk Wt.(g)		Leaf Wt.(g)		Root Wt.(g)		Total Wt.(g)	
Meter	Stalk*[3]	Tassel	No.	Length	Fresh*	Dry	Fresh	Dry	Fresh	Dry	Fresh*	Dry
0	198	60	9.7	19.6	593	133	155	34	435	101	1183	269
1	191	54	9.6	19.9	492	94	144	31	209	64	846	189
2	187	58	9.6	19.6	550	116	148	32	245	76	943	224
3	198	56	9.8	20.3	588	130	154	34	338	98	1080	262
4	198	57	10.0	19.8	577	127	167	35	374	104	1119	266
5	195	60	9.7	20.2	576	130	156	33	244	73	973	236
6	189	63	9.7	19.5	572	142	159	34	287	79	1018	254
7	189	56	9.7	19.3	555	142	167	35	282	82	1004	260
8	184	56	9.5	19.4	540	123	146	33	294	97	981	253
$s_{\bar{x}}$	3.05	3.463	0.157	0.386	14.99	10.76	8.98	1.716	69.67	13.21	72.5	18.07

[1]Means from 4 field beds, each with 9 meters and 6 plants per meter at harvest.

[2]Meter 0 = no UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

[3]* indicates average of all UV-B treatments was significantly less than the control.

parameters showing significant relationships with increased UV-B enhancement and their regression equations are indicated in Table 16.

Analysis of the suckers on each plant showed that the number of suckers, height of the tallest sucker and number of silks per ear was significantly less for UV-B treated than control plants (Table 17). However, for other vegetative parameters of sucker stalks there were no significant differences observed (Table 18). Sucker stalk dry weight and total dry weight showed significant relationships within the UV-B enhancements which were estimated by the following equations: 32.0 - 7.5 X and 47.2 - 9.4X for stalk dry weight and total dry weight respectively when X is the $UV\text{-}B_{seu}$ enhancement.

On a whole plant basis the aberage of the control was found to be significantly higher than the average of the UV-B treatments for stalk fresh weight, leaf dry weight, total fresh weight and total dry weight (Table 19). Significant relationships were found for all 6 responses and the regression equations are found in Table 20. Stalk Dry weight decreased linerly with UV-B enhancement.

Harvest data on the ears included length, diameter of entire and trimmed ear and percent fill values. All of parameters were decreased at .84 $UV\text{-}B_{seu}$ but not at lesser UV-B enhancement levels. No significant differences were observed for plants from any of the meters in the regression analysis (Table 21) but an F - test to compare the 0.84 $UV\text{-}B_{seu}$ enhancement vs just the control meter indicated that weight of the entire ear and diameter was significantly decreased.

IV. Southern Peas

Seven to 19 seedlings per meter were removed 31 days after planting, leaving 6 plants per meter to mature. The treatment means and the estimates of their standard errors are given in Table 22. Leaf, stem, root and total fresh and dry weights tended to be less in the treated than control meters.

Table 16. Silverqueen corn main stalk parameters showing significant relationships among the UV-B treatments and their corresponding repression equations[1].

Response	Equation
Stalk Length	$179.4 + 33.6X - 17.0X^2$
Stalk Fresh Weight	$502.5 + 201.2X - 122.8X^2$
Stalk Dry Weight	$144.4 - 24.6X$
Total Fresh Wieght	$886.8 + 436.8X - 276.8X^2$
Total Dry Weight	$274.1 - 40.6X$

[1] X = UV-B enhancement in solar equivelent units (seu).

Table 17. Harvest data for Silverqueen corn main and sucker stalks[1].

Meter[2]	Lf Area cm^2	No. Suckers*	No. Silks	Tallest Sucker Height (cm)						
				Pl 1*	Pl 2*	Pl 3*	Pl 4*	Pl 5*	Pl 6*	Ave.
0	3957	3.4	2.0	74	76	75	76	75	73	75
1	3445	3.8	1.6	53	52	50	57	64	61	56
2	3743	2.7	1.8	54	64	55	58	58	52	57
3	3305	2.7	1.7	48	54	61	55	71	53	57
4	3697	2.6	1.6	64	63	47	52	50	55	55
5	3901	2.7	1.8	50	41	58	52	66	67	57
6	3639	2.9	1.9	67	58	65	58	56	74	63
7	3947	2.8	1.4	58	65	56	56	61	59	59
8	3655	2.5	1.6	61	61	61	53	59	50	59

[1]Means from 4 field beds, each with 9 meters and 6 plants per meter at harvest. Leaf area for main stalk only. * indicates average of all UV-B treatments was significantly less than the control.

[2]Meter 0 = no UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

Table 18. Silverqueen corn harvest data on sucker stalks[1].

Meter[2]	Length (cm)		Stalk Wt. (g)		Leaf Wt. (g)		Total Wt. (g)	
	Stalk	Tassel	Fresh	Dry	Fresh	Dry	Fresh	Dry
0	95	24	137	27	58	13	195	40
1	89	24	89	18	47	11	136	29
2	100	24	131	24	59	13	190	37
3	106	28	135	26	63	14	197	40
4	107	33	127	22	67	16	194	38
5	105	28	130	27	55	13	185	40
6	109	28	146	30	62	14	208	44
7	107	36	151	32	74	16	224	49
8	99	29	125	30	52	12	177	42
$s_{\bar{x}}$	14.24	5.205	19.83	4.586	7.042	1.745	25.20	5.991

[1]Means from 4 field beds, each with 9 meters and 6 plants per meter at harvest.

[2]Meter 0 = no UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

Table 19. Silverqueen corn whole plant harvest data[1].

Meter[2]	Stalk Wt(g)		Leaf Wt(g)		Total Wt(g)	
	Fresh[*3]	Dry	Fresh	Dry*	Fresh*	Dry*
0	306	194	274	62	1697	376
1	597	116	199	43	1017	226
2	754	154	241	53	1276	290
3	820	175	262	58	1450	339
4	766	161	267	58	1440	331
5	798	177	247	56	1329	315
6	806	196	253	56	1396	344
7	741	183	252	55	1318	332
8	752	173	235	54	1307	329
$s_{\bar{x}}$	44.44	13.83	15.68	3.467	104.5	22.88

[1]Means from 4 field beds, each with 9 meters and 6 plants per meter at harvest.

[2]Meter 0 = no UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

[3]* indicates average of all UV-B treatments was significantly less than the control

Table 20. Silverqueen corn whole plant parameters showing significant relationships among the UV-B treatments and their corresponding repression equations[1].

Response	Equation
Stalk Fresh Weight	$665.1 + 370.3X - 238.5X$
Stalk Dry Weight	$197.4 - 40.1X$
Leaf Fresh Weight	$211.1 + 129.1X - 80.5X^2$
Leaf Dry Weight	$48.7 + 24.0X - 15.81X^2$
Total Fresh Weight	$1138.6 + 744.7X - 480.9X^2$
Total Dry Weight	$304.6 + 106.7X - 89.5X^2$

[1] X = UV-B enhancement in solar equivalent units (seu).

Table 21. Silverqueen corn harvest data[1].

Meter[2]	Entire	Trim	Entire	Trim	Diam(cm)	%Fill
0	308	216	31.6	17.1	4.49	91
1	292	207	30.6	17.0	4.38	90
2	327	234	31.5	17.6	4.53	95
3	313	220	31.4	17.3	4.45	95
4	344	244	31.0	17.9	4.50	95
5	324	228	31.3	17.4	4.52	92
6	324	227	32.2	17.6	4.53	90
7	289	204	30.7	17.1	4.38	92
8	310	225	30.5	17.2	4.47	99
$s_{\bar{x}}$	15.40	11.45	0.716	0.450	0.079	2.324

[1]Means from 4 field beds, each with 9 meters and 6 plants per meter at harvest.

[2]Meter 0 = no UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

Table 22. Seedling data for Southern peas[1].

Meter[2]	Leaf(g) Fresh	Leaf(g) Dry	Stem(g) Fresh	Stem(g) Dry	Root(g) Fresh	Root(g) Dry	Total Fresh	Dry Weight Biomass
0	14.3	1.626	14.2	1.139	1.18	0.224	29.3	2.99
1	10.2	1.338	10.7	0.834	1.03	0.191	21.9	2.36
2	13.6	1.697	14.6	1.128	1.41	0.254	29.6	3.08
3	11.6	1.470	11.8	0.956	1.17	0.229	24.3	2.58
4	11.1	1.429	12.1	0.949	1.07	0.203	24.8	2.58
5	12.3	1.570	13.3	1.065	1.18	0.224	26.8	2.86
6	12.8	1.614	13.4	1.070	1.21	0.247	24.4	2.93
7	11.2	1.521	11.6	0.977	0.98	0.203	23.8	2.70
8	9.8	1.333	9.2	0.778	1.03	0.211	20.0	2.32
$s_{\bar{x}}$	1.09	0.117	1.12	0.096	0.99	0.208	2.95	0.404

Meter	% Lf.	% St.	% Rt.	Leaf Area (cm^2)	Density (g/dm^2)	Root: Shoot Ratio
0	55	38	7	558	0.282	0.081
1	57	35	8	460	0.282	0.088
2	55	37	8	616	0.279	0.090
3	55	36	9	560	0.267	0.095
4	55	37	8	522	0.274	0.086
5	55	37	8	550	0.285	0.085
6	55	37	8	572	0.280	0.092
7	56	36	8	522	0.294	0.081
8	57	36	7	446	0.300	0.100
$s_{\bar{x}}$				39.23	0.020	0.006

[1]Means from 4 field beds, each with 9 meters and 7 to 19 plants/meter. Plants were thinned 31 days after planting.

[2]Meter 0 = no UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

The most pronounced decreases were observed in the first meter receiving 1.55 $UV\text{-}B_{seu}$. leaf area was not reduced.

Leaf density and root:shoot ratios were higher under UV-B enhancement regimes. Slightly more biomass was partitioned into the leaves at the expense of stems under UV-B enhancement. The estimated regression equations for leaf area and stem fresh weight under UV-B enhancement were $354.2 + 5.72 x^2$ and $7.2 + 1.94 - .147X^2$, where $X = UV\text{-}B_{seu}$.

Significant reductions in the mean of the UV-B treated plants from the mean of the control plants was found in Southern pea stem fresh and dry weight, root dry weight and total biomass (Table 23). In general, leaf area was also lower. Southern pea fruit yield was also significantly reduced (Table 24). The mean of the treated meters had significantly reduced numbers of peas in the third and the final harvest and pea weight was significantly less in the third and fourth and in total harvest. Other reductions were evident, but often restricted to those meters receiving the higher levels of $UV\text{-}B_{seu}$.

V. 'Florunner' Peanuts

A. Seedlings: Five to 8 seedlings per meter were removed 6 weeks after planting, leaving 6 plants per meter to mature to harvest. Significant linear regression relationships for decreasing leaf area, leaf, stem, root ant total fresh and dry weights with increasing UV-B enhancement as the independent variable were found (Table 25). The linear regression appears to fit fairly well except meter 6. This means that after six weeks, any UV-B enhancement in the field tended to decrease 'Florunner' peanut leaf area, leaf fresh and dry weight, stem fresh and dry weight and total biomass (Table 26). Biomass partitioning, leaf density and root:shoot ratios were not strongly

Table 23. Plant harvest data for Southern pea.[1]

Meter	Area	Leaf		Stem		Root		Bio-	R:S	Leaf
		Fresh	Dry	Fresh*[3]	Dry*	Fresh	Dry*	mass*	Ratio	Dens.
0	174	48	6.9	93	17.5	10.8	1.8	26	.079	.0108
1	167	46	7.3	72	13.5	10.2	1.4	22	.070	.0125
2	170	39	6.4	68	12.8	6.8	1.6	21	.084	.0147
3	163	39	6.6	67	12.8	6.8	1.5	21	.080	.0141
4	132	52	6.3	79	12.0	8.8	1.4	20	.082	.0133
5	147	39	6.4	66	12.9	7.5	1.8	21	.095	.0140
6	127	31	5.5	56	11.1	6.5	1.7	18	.105	.0150
7	106	31	5.1	52	9.8	6.8	1.5	16	.109	.0144
8	156	45	6.6	69	11.8	7.1	1.4	20	.081	.0133
$s_{\bar{x}}$	20.4	7.28	0.582	9.49	0.95	1.92	0.132	1.49	.0072	.0007

[1]Means from 4 field beds, each with 9 meters and 6 plants per meter at harvest.

[2]Meter 0 = no UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

[3]* indicates average of all UV-B treatments was significantly less than the control.

Table 24. Southern pea fruit yield[1].

Meter[2]	Harvest 1			Harvest 2			Harvest 3			Harvest 4			Harvest 5			Total		
	No	Wt	Ave	No	Wt	Ave	No* [3]	Wt*	Ave*	No	Wt*	Ave	No	Wt	Ave	No*	Wt*	Ave*
0	15.8	84	5.3	14.2	67	4.7	27.8	122	4.4	19.8	82	4.1	19.8	88	4.4	88.0	402	5.6
1	7.3	37	5.1	18.0	88	4.9	17.5	81	4.6	14.5	60	4.1	23.3	98	4.2	74.8	340	4.5
2	15.3	67	4.4	19.8	91	4.6	14.3	60	4.2	10.5	39	3.7	13.7	57	4.2	70.0	301	4.0
3	9.0	46	5.1	13.0	68	5.2	18.0	80	4.4	16.5	65	3.9	17.7	87	4.9	69.8	324	4.6
4	10.0	50	5.0	16.3	75	4.6	12.5	52	4.2	13.0	50	3.8	20.7	77	3.7	67.3	285	4.2
5	12.3	62	5.0	17.5	81	4.6	24.0	86	3.6	14.0	55	3.9	8.0	28	3.5	73.8	303	4.1
6	11.3	55	4.9	21.8	98	4.5	15.5	59	3.8	9.0	28	3.1	8.3	30	3.6	63.8	264	4.1
7	10.3	54	5.2	17.0	77	4.5	15.5	53	3.4	11.0	38	3.4	11.0	36	3.3	62.0	249	4.0
8	8.5	43	5.1	13.5	64	4.8	21.8	95	4.4	19.8	70	3.5	19.0	77	4.1	77.8	329	4.2
$s_{\bar{x}}$	3.68	18.30		2.71	12.64		2.74	11.6		3.57	13.66		4.06	18.32		6.12	26.0	

[1]Means from 4 field beds, each with 9 meters and 6 plants per meter at harvest.

[2]Meter 0 = no UV-B, control; meter; meter 1 = first meter under the UV-B gradient irradiator.

[3]* indicates average of all UV-B treatments was significantly less than the control.

Table 25. Equations for linear responses of thinned Florunner peanuts to UV-B enhancement under the field gradient irradiator

Response	Equation
Leaf Area	436.90 - 13.81X
Leaf Fresh Weight	8.6573 - 0.2427X
Leaf Dry Weight	1.5728 - 0.0476X
Stem Fresh Weight	8.2592 - 0.2310X
Stem Dry Weight	1.1813 - 0.0333X
Total Fresh Weight	19.750 - 0.5455X
Total Dry Weight	3.3366 - 0.0948X

Table 26. Seedling data for Florunner peanuts[1].

Meter[2]	Leaf (g) Fresh	Leaf (g) Dry	Stem (g) Fresh	Stem (g) Dry	Root (g) Fresh	Root (g) Dry	Total Fresh	Dry Weight Biomass
0	9.3	1.591	8.9	1.206	3.1	0.591	21.4	3.39
1	6.4	1.077	5.9	0.846	2.0	0.446	14.4	2.37
2	6.7	1.159	6.0	0.877	2.4	0.482	14.7	2.52
3	6.4	1.221	6.4	0.900	1.9	0.404	14.7	2.53
4	7.6	1.274	7.4	1.004	2.1	0.416	17.2	2.70
5	10.1	1.712	9.5	1.313	3.3	0.659	22.9	3.68
6	7.3	1.355	7.3	1.020	2.8	0.585	17.4	2.96
7	7.6	1.442	7.0	1.094	2.8	0.617	17.5	3.15
8	7.6	1.389	7.1	1.025	2.4	0.478	17.0	2.89
$s_{\bar{x}}$	0.83	0.122	0.851	0.100	0.307	0.059	1.90	0.263

Meter	% Lf.	% St.	% Rt.	Leaf Area (cm^2)	Density (g/dm^2)	Root Shoot Ratio
0	47	36	17	432	0.401	0.213
1	45	36	19	298	0.398	0.244
2	46	35	19	311	0.383	0.238
3	48	36	16	316	0.419	0.214
4	47	37	16	388	0.392	0.206
5	46	36	18	491	0.354	0.232
6	46	34	20	370	0.381	0.276
7	46	34	20	373	0.428	0.282
8	48	36	16	381	0.384	0.210
$s_{\bar{x}}$				40.72	0.033	0.023

[1]Means from 4 field beds, each with 0 meters and 5-8 plants/meter. Plants were thinned 40 days after planting.

[2]Meter 0 = no UV-B control; meter 1 = first meter under the UV-B gradient irradiator.

affected at this time.

B. Harvest: At harvest, significant linear regression relationships were found for leaf fresh and dry weight and leaf area and in all cases the responses increased with UV-B enhancement. The estimated equations are 12.43 + 0.919X, 3.34 + 0.190X and 294.45 + 142.870X for leaf fresh weight, dry weight and leaf area, respectively. Since only the first plant in each meter was measured for leaf area, this parameter and leaf specific thickness are based on 4 rather than 24 plants. In general, the peanuts receiving the 1.55 UV-B_{seu} showed higher leaf fresh and dry weight, higher stem fresh and dry weight but a reduction in root fresh and dry weight and the number of larger peanuts. These plants were also taller, with a greater biomass and leaf area but a much lower root to shoot ratio than the control plants (Table 27). Decreasing the dose of UV-B irradiation resulted in the opposite effects.

VI. 'Star Bonnet' Rice

Rice was thinned 41 days after planting to 10 plants per meter. In averaging all UV-B treatments it was found that the root dry weight was significantly less for plants from treated than the control meters. Leaf, root and biomass dry weight were all lower for seedlings from meters receiving 1.55 to .28 UV-B_{seu} (between meter 1 to 5) but parameters measured in plants with lesser UV-B_{seu} were similar to the controls. Leaf density was slightly higher at the lower UV-B levels .21 to .09 UV-B_{seu} (meters 6 to 8). Biomass tended to be partitioned more into the leaves and stems than the roots for all UV-B treated plants (Table 28).

At harvest of mature plants, significant linear relationships were found for 6 of the parameters measured on the tillers (Table 29). Reductions in spike fresh and dry weight were found under the 1.55 UV-B_{seu} of 1.55 to 0.61 (meter 1 and 2). Spike maturity was delayed under UV-B_{seu} 1.55 (meter 1).

Table 27. Harvest data for Florunner peanut plants[1].

Meter[2]	Leaf (g) Fresh	Leaf (g) Dry	Stem (g) Fresh	Stem (g) Dry	Root (g) Fresh	Root (g) Dry	Total Frech(g)	Dry Weight % Biomass(g)	% Lf.	% St.	% Rt.
0	19.6	4.803	45.9	9.98	4.7	1.232	70.2	16.01	30	62	8
1	23.7	5.578	51.9	11.25	4.2	1.088	79.8	17.92	31	63	6
2	17.1	4.560	42.9	9.73	4.7	1.275	64.7	15.57	29	63	8
3	21.6	5.264	48.2	10.14	5.3	1.248	75.1	16.65	32	61	7
4	14.4	3.332	39.9	8.38	3.9	1.225	58.2	12.94	26	65	9
5	15.8	3.897	43.4	9.45	4.2	1.028	63.4	14.37	27	66	7
6	12.9	3.290	43.0	9.33	4.3	1.018	60.2	13.55	23	69	8
7	18.9	4.950	56.6	13.24	5.1	1.324	80.6	19.52	25	68	7
8	12.9	3.637	40.2	9.04	4.1	1.049	57.2	13.72	26	66	8
$s_{\bar{x}}$	2.53	0.608	6.04	1.42	0.562	0.178		2.06			

Meter	Leaf Area	Density (cm^2) (cm^2)	Root Shoot Ratio	Big Peanuts No.	Big Peanuts Wt.(g)	Pop Peanuts No.	Pop Peanuts Wt.(g)	Ht. (cm.)
0	986	.436	.088	50.5	51.22	3.5	1.921	36.7
1	2211	.432	.060	44.8	46.92	3.3	2.500	49.6
2	1367	.489	.099	44.1	50.12	4.0	2.942	36.6
3	701	.426	.107	47.5	50.49	4.1	2.367	37.7
4	750	.445	.120	39.8	40.81	3.6	2.058	36.8
5	891	.480	.081	45.5	46.10	3.1	1.800	37.3
6	512	.399	.087	45.3	47.95	2.9	1.642	35.0
7	1094	.522	.084	49.9	54.70	2.9	1.800	39.2
8	697	.454	.096	38.6	43.67	4.1	2.253	37.9
$s_{\bar{x}}$	381.0	.000455	.0163	3.62	4.88	0.829	0.551	2.22

[1]Means from 4 field beds, each with 9 meters and 6 plants per meter at harvest.

[2]Meter 0 = no UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

Table 28. Seedling data for rice plants[1].

Meter[2]	Leaf(g) Fresh	Leaf(g) Dry	Root(g) Fresh	Root(g) Dry[3]	Total Fresh(g)	Dry Weight Biomass (g)
0	35.9	9.09	9.65	2.51	45.5	11.60
1	30.7	7.41	5.93	1.54	36.6	8.95
2	32.5	8.06	8.55	2.15	41.0	10.21
3	36.7	8.50	9.15	2.30	45.8	10.80
4	29.2	6.86	6.15	1.54	35.3	8.40
5	28.4	7.13	6.60	1.63	35.0	8.76
6	40.8	10.63	8.37	2.39	49.1	13.02
7	36.4	9.71	7.96	2.25	44.3	11.96
8	32.9	8.44	6.16	1.80	39.0	10.24
$s_{\bar{x}}$	4.72	0.98	11.06	2.22	15.09	3.01

Meter	% Lf.	% Rt.	Leaf Area	Density g/dm^2
0	78	22	83	0.117
1	83	17	67	0.115
2	79	21	75	0.114
3	79	21	91	0.100
4	81	19	69	0.108
5	81	19	60	0.120
6	82	18	82	0.132
7	81	19	77	0.132
8	82	18	68	0.133
$s_{\bar{x}}$			11.71	0.131

[1]Means from 4 field beds, each with 9 meters and 5-26 plants/meter. Plants were thinned 42 days after planting.

[2]Meter 0 = no UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

[3]Indicates mean of UV-B treatments was significantly less than the control.

Table 29. Rice tiller data showing significant relationships among the UV-B treatments and their corresponding regression equations[1].

Response	
Spike Dry Weight	2.78 - 0.0773X
Spike Stage	3.48 - 0.1834X
Spike Length	21.44 + 0.2140X
Flag Fresh Weight	2.64 + 0.2157X
Flag Dry Weight	0.14 + 0.0065X
Flag Length	20.84 + 0.6437X

[1] X = UV-B enhancement in solar equivalent units (seu).

and progressively increased in the next two meters of less exposure. The most marked response was the increase in the number of leaves per tiller under UV-B enhancement.

Flag leaf length, area, fresh and dry weight were increased under UV-B of 1.55 to .34 (meter 1 to 3) but fresh and dry weight of the spike were less than the controls (Table 30). Spike length, however, remained fairly constant. Spike fresh and dry weight and root dry weight were reduced in the meter receiving 1.55 UV-B_{seu} and spike maturity was delayed in this meter also.

On a whole plant basis, rice in the UV-B treated meters tended to decrease in biomass and stem fresh and dry weight (Table 31). The number of fruiting and vegetative tillers was unaltered from the control meters but the number of tillers was somewhat reduced, at least in the 1.55 UV-B_{seu} meters. The average root:shoot ratio in treated meters was significantly less than that in the control meters. Significant relationships within the UV-B treated meters were found for 5 parameters and these are given in Table 32.

Height growth of the 'Star Bonnet' Rice was exponential until the 9th week after planting when is slowed tremendously (Table 33). A growth curve equation was computed for each meter and fit the data well (Table 34).

VII. Yellow-crooked-neck squash

A. Seedlings: Five to seven seedlings per meter were removed 3 weeks after planting, leaving 6 plants per meter to mature. A total of 11 responses were measured on the removed seedlings and means are given on a per plant basis with the standard error of each mean (Table 35). In averaging all UV-B treatments, there was a significant difference in reduction between all UV-B treated plots and the control plot at the 10% level for leaf fresh and dry weight, root fresh and dry weight and total biomass. The root:shoot ratio

Table 30. Harvest data for rice tillers by plant[1].

Meter[2]	Leaf (g)		Stem (g)		Spike				# Lvs./ Tiller
	Fresh	Dry	Fresh	Dry	Fresh (g)	Dry (g)	Stage[3]	Pl. Ht. to Spike (cm)	
0	2.38	1.13	9.57	2.73	3.97	2.54	2.8	71	4.4
1	2.75	1.15	10.51	2.99	3.13	1.74	1.3	66	6.2
2	2.54	1.03	9.29	2.47	3.72	2.25	2.1	64	6.0
3	2.24	1.08	9.43	2.62	3.69	2.43	2.5	71	6.1
4	1.86	1.01	8.95	2.58	3.44	2.41	2.9	70	6.1
5	2.81	1.31	12.45	3.82	4.80	3.11	2.6	71	6.4
6	2.07	0.94	8.11	2.25	3.57	2.35	2.7	64	6.2
7	2.07	0.95	8.03	2.21	3.64	2.35	3.1	67	6.2
8	2.04	1.13	9.27	2.68	3.61	2.45	3.1	73	6.6
$s_{\bar{x}}$	0.193	0.071	1.21	0.316	0.459	0.300	0.322	3.38	0.280

Meter	Area (cm^2)		Flag Leaf			Spike Length (cm)	Density (g/dm^2)	
	All Lvs.	Flag	Length (cm)	Fresh (g)	Dry (g)		Leaf	Flag
0	148	24	22.5	.030	.0159	22.9	0.76	0.76
1	157	33	27.6	.046	.0215	23.9	0.79	0.74
2	158	33	25.7	.050	.0181	22.6	0.64	0.55
3	154	30	25.8	.037	.0177	23.7	0.70	0.68
4	119	23	24.8	.031	.0162	22.5	0.85	0.73
5	171	27	22.7	.039	.0162	22.4	0.77	0.73
6	124	26	23.2	.033	.0152	22.0	0.76	0.60
7	126	22	21.5	.035	.0162	20.9	0.95	0.73
8	138	22	22.0	.024	.0146	22.2	0.85	0.69
$s_{\bar{x}}$	10.5	2.14	0.87	0.65	0.020	0.56	0.0009	0.0010

[1]Means from 4 field beds, each with 9 meters and all the tillers of each of the first 3 plants at the time of harvest.
[2]Meter 0 = no UV-B, control, meter 1 = fritst meter under the UV-B gradient irradiator.
[3]State of maturity; 0 = all of spike green; 2 = ¼, 3 = ½, 4 = 3/4 and 5 = all of spike brown.

Table 31. Whole plant harvest data for rice.[1]

Meter	No. of Tillers			Leaf Wt. (g)		Stem Wt. (g)	
	Fruit	Veg	Total	Fresh	Dry	Fresh	Dry
0	8.9	1.8	10.7	38	13.8	105	30.1
1	7.6	1.2	8.8	36	11.6	87	24.2
2	8.8	2.1	10.9	45	13.1	101	27.5
3	8.8	1.0	9.9	34	13.5	95	26.2
4	7.3	0.8	8.1	28	11.1	81	23.7
5	8.7	1.9	10.6	35	13.3	101	28.0
6	8.9	2.1	11.0	32	13.6	100	28.4
7	9.1	1.7	10.8	34	13.3	102	27.7
8	7.6	1.4	9.0	29	11.6	87	26.6
$s_{\bar{x}}$	0.641	0.315	0.80	4.53	1.12	9.9	2.67

Meter	Spike Wt(g)		Root Wt.(g)		Bio-mass	R:S Ratio*[3]	Stage
	Fresh	Dry	Fresh	Dry			
0	37	24.1	48	15.8	84	1.545	3.2
1	24	14.0	39	11.6	62	0.013	1.7
2	33	20.6	50	14.6	76	1.218	2.7
3	34	23.1	48	15.5	78	0.734	3.2
4	28	18.5	44	14.1	68	0.698	3.0
5	33	21.6	42	12.8	76	0.560	3.2
6	35	24.2	44	15.0	81	0.629	3.6
7	34	22.4	58	19.0	83	0.927	3.2
8	28	17.6	62	19.8	76	1.129	2.9
$s_{\bar{x}}$	2.89	1.83	6.77	2.14	6.93	0.193	0.229

[1]Means from 4 field beds, each with 9 meters and 6 plants per meter at harvest.
[2]Meter 0= no UV-B, control; meter 1= first meter under the UV-B gradient irradiator.
[3]* indicates average of all UV-B treatments was significantly less than the control.

Table 32. Star Bonnet rice whole plant responses showing significant relationships among the UV-B treatments and their corresponding regression equations.[1]

Response	Equation
Leaf Fresh Weight	$28.269 + 1.181X$
Root Dry Weight	$18.442 - 0.614X$
Spike Fresh Weight	$22.738 + 4.151X - 0.376X^2$
Spike Dry Weight	$13.700 + 3.449X - 9.324X^2$
Spike Stage	$2.383 + 0.398X - 0.044X^2$

[1] X = UV-B enhancement in solar equivalent units (seu).

Table 33. Mean Star Bonnet rice heights.

	Meter Number								
Week	0[2]	1	2	3	4	5	6	7	8
2	07	08	08	08	08	07	08	07	08
3	12	12	12	13	12	10	11	12	12
4	19	20	20	21	18	18	20	21	21
5	29	29	30	31	27	26	30	30	27
6	55	56	57	57	55	55	58	57	55
7	67	69	70	71	69	68	71	70	68
8	82	86	88	87	86	87	89	87	86
9	92	96	99	97	97	99	99	99	95
10	94	97	99	98	100	101	102	102	97
11	95	98	99	100	100	102	102	103	97
12	103	99	103	105	103	103	105	106	98
13	111	107	113	113	111	110	113	113	106
14	112	109	113	114	112	111	113	114	107
15	112	109	113	114	113	111	114	114	107
16	112	109	113	114	113	111	114	114	106

[1]Each number is the mean of 40 plants, 10 per meter replicated in 4 field beds.

[2]Meter 0 = no UV-B control; meter 1 = first meter under the UV-B gradient irradiator.

Table 34. Star Bonnet Rice growth curve equation and regression coefficients for each meter[1].

Growth Curve Equation	Regression Coefficients		
	Meter	A	B
Height = $Ae^{-B/t}$	0	19.72	7.87
where t = time in weeks	1	18.80	7.34
	2	19.65	7.49
	3	19.63	7.46
	4	20.01	7.81
	5	19.80	7.73
	6	19.79	7.48
	7	19.93	7.56
	8	18.28	7.24

Table 35. Seedling data for squash[1].

Meter[2]	Leaf (g) Fresh[3]	Leaf (g) Dry[3]	Stem(g) Fresh	Stem(g) Dry	Root(g) Fresh[3]	Root(g) Dry[3]	Total[3] Fresh(g)	Dry Weight[3] Biomass (g)
0	17.8	2.921	69.9	3.859	3.1	0.438	90.8	7.22
1	13.9	2.293	54.3	2.888	2.2	0.283	70.4	5.46
2	12.1	2.126	50.8	2.964	2.5	0.355	65.4	5.45
3	13.1	2.206	53.0	3.090	2.5	0.358	68.6	5.65
4	14.1	2.395	55.8	2.886	2.3	0.303	72.2	5.58
5	13.9	2.262	53.8	2.804	2.3	0.338	70.0	5.40
6	13.2	2.290	53.4	3.108	2.5	0.383	69.1	5.78
7	13.2	2.215	50.1	2.953	2.5	0.320	65.8	5.49
8	10.9	1.993	42.0	2.533	2.5	0.360	55.4	4.89
$s_{\bar{x}}$	2.58	0.385	10.28	0.542	0.366	0.048		0.959

Meter	% Lf.	% St.	% Rt.	Leaf Area	Density g/dm^2	Root Shoot Ratio	Ht.(cm.)
0	40	54	6	986	0.292	0.072	24.9
1	42	53	5	792	0.312	0.058	24.7
2	39	54	7	680	0.330	0.079	22.3
3	39	55	6	706	0.317	0.080	21.9
4	43	52	5	754	0.379	0.075	21.7
5	42	52	6	755	0.316	0.107	21.9
6	39	54	7	742	0.354	0.088	22.2
7	40	54	6	736	0.340	0.069	23.2
8	41	52	7	622	0.352	0.085	20.6
$s_{\bar{x}}$				146.9	0.0003	0.1620	1.43

[1]Means from 4 field beds, each with 9 meters and 5-7 plants/meter. Plants were thinned 24 days after planting.
[2]Meter 0=no UV-B control; meter 1=first meter under the UV-B gradient irradiator.
[3]Indicates mean of UV-B treatments significantly (10% level) less then control.

was increased for all UV-B treated plants. Biomass partitioning was not significantly altered by enhanced UV-B radiation.

B. Harvest: Frost damage to the squash plants forced early harvest. In all meters, there was a significant reduction by the UV-B dose in relation to the control for leaf, fruit and root fresh weight, root dry weight, and numbers of fruit. Stem and total plant fresh and dry weights were reduced under all levels of UV-B enhancement. A greater number of fruit and total fruit biomass was found on control plants than on UV-B treated ones. An occassional large fruit in the meter gradient 4 and 5 resulted in a larger weight/fruit number. The significantly greater number of fruit in the control meter may indicate a delay in flowering under enhanced UV-B radiation. The root:shoot ratio was reduced under the highest UV-B enhancement but increased under others (Table 36). Biomass partitioning was not significantly altered by enhanced UV-B radiation.

VIII. Mustard

At harvest the leaf fresh and dry weight, total biomass and leaf density of the control plants were all significantly greater than the mean of the UV-B treated meters (Table 37). Total fresh weight was lower under the UV-B radiation regimes also. Root fresh and dry weight and the total number of leaves showed the most reduction under $UV\text{-}B_{seu's}$ of 3.1 to 1.2 (meter 1 to 2). Plants receiveing UV-B irradiation at lesser flux level were similar to the control for these 3 parameters. Leaf area was drastically reduced at $UV\text{-}B_{seu}$ of 3.1 (meter 1) from 1330 to 443cm^2. Biomass partitioning was not altered by UV-B enhancement. Significant linear and quadratic relationships were observed for 5 parameters (Table 38).

IX. 'Red Globe' Radish

Leaf fresh and dry weight and leaf area were all significantly greater under UV-B treatment than the control radish plants. However, in the first

Table 36. Harvest data for squash[1].

Meter[2]	Leaf (g) Fresh	Leaf (g) Dry	Stem (g) Fresh	Stem (g) Dry	Root (g) Fresh[3]	Root (g) Dry[3]	Total Fresh (g)	Dry Weight Biomass
0	58.6	7.419	25.1	1.733	7.1	0.952	90.8	10.10
1	43.9	5.921	19.7	1.352	5.6	0.702	69.6	7.98
2	39.7	5.307	17.7	1.212	5.8	0.715	63.2	7.23
3	45.1	6.392	18.9	1.331	6.1	0.863	70.1	8.59
4	47.0	6.282	19.8	1.351	6.1	0.805	72.9	8.44
5	31.1	4.769	16.2	1.065	5.0	0.635	52.3	6.47
6	39.7	5.673	19.5	1.380	5.6	0.801	64.8	7.85
7	36.0	5.423	17.6	1.254	6.0	0.853	59.6	7.53
8	32.9	4.839	16.0	1.115	5.2	0.695	54.1	6.65
$s_{\bar{x}}$	7.65	0.961	3.27	0.232	0.475	0.073		1.25

Meter	% Lf.	% St.	% Rt.	Root Shoot Ratio	Fruit No.[3]	Fruit Wt. (g)[3]	Wt./Fruit (g)
0	74	17	9	0.127	1.17	8.95	5.23
1	74	17	9	0.100	0.75	2.88	3.64
2	73	17	10	0.134	0.50	1.41	2.58
3	75	15	10	.135	0.75	2.21	3.31
4	74	16	10	0.120	0.67	7.73	3.07
5	74	16	10	0.130	0.21	4.09	9.60
6	72	18	10	0.135	0.63	2.06	1.84
7	72	17	11	0.137	0.58	0.91	1.03
8	73	17	10	0.130	0.38	1.12	1.72
$s_{\bar{x}}$				0.016	0.224	2.263	2.43

[1]Means from 4 field beds, each with 0 meters 6 plants per meter at harvest.

[2]Meter 0 = no UV-B,control; meter 1 = first meter under the UV-B gradient irradiator.

[3] Indicates mean of UV-B enhancement meters was significantly less then the control.

Table 37. Harvest data for mustards[1].

Meter[2]	Leaf(g) Fresh[3]	Leaf(g) Dry[3]	Root(g) Fresh	Root(g) Dry	Total(g) Fresh	Dry Weight Biomass (g)[3]
0	63.6	4.837	6.5	0.812	70.1	5.65
1	36.5	2.741	3.8	0.430	40.3	3.17
2	51.4	3.934	5.8	0.702	57.2	4.64
3	57.1	4.405	6.2	0.779	63.3	5.18
4	51.1	4.271	6.6	0.685	56.7	4.96
5	52.1	4.008	6.0	0.694	58.1	4.70
6	52.8	3.946	5.8	0.630	58.6	4.57
7	57.8	4.229	6.3	0.728	64.1	4.96
8	49.5	3.835	4.8	0.605	54.3	4.44
$s_{\bar{x}}$	5.64	0.400	0.592	0.076		0.465

Meter	%Lf.	% Rt.	Leaf Area(cm^2)	Density[3] g/dm^2	Root Shoot Ratio	No. of Leaves
0	86	14	1330	0.370	0.172	8.25
1	86	14	443	0.310	0.176	5.83
2	85	15	1355	0.330	0.182	7.67
3	85	15	1348	0.340	0.179	8.17
4	86	14	1253	0.360	0.184	8.00
5	85	15	1155	0.320	0.178	7.58
6	86	14	1393	0.320	0.181	8.33
7	85	15	1175	0.310	0.186	8.08
8	86	14	1047	0.340	0.168	8.42
$s_{\bar{x}}$			184.8	0.0001	0.011	0.50

[1]Means from 4 field beds, each with 9 meters and 20 plants per meter at harvest.

[2]Meter 0 = no UV-B control; meter 1 = first meter under the UV-B gradient irradiator.

[3]Indicates the mean UV-B enhancement meters were significantly less than the control.

Table 38. Regression equations for mustard to UV-B enhancement under the field gradient irradiator.

Response	Equation
Leaf Dry Weight	$3.07 + 0.49X - 0.049X^2$
Number of Leaves	$8.83 - 0.209X$
Leaf Area	$571.3 + 304.7X - 28.7X^2$
Root Fresh Weight	$3.69 + 0.954X - 0.0883X^2$
Biomass	$3.50 + 0.609X - 0.0595X^2$

meter which received 3.1 $UV\text{-}B_{seu}$ The root fresh weight was 3.34g vs. 5.05g for the control. The number of leaves remained constant and there were no significant differences in leaf density (Table 39).

Discussion

Other studies on the effects of UV-B radiation on plants have shown that net carbon exchange was reduced (see section 5). This would result in decreased biomass production. The present field work demonstrated that biomass reductions are not equally proportioned between shoots and roots and organs on the shoots, resulting in very different biomass allocation patterns. The percent of plant dry weight found in leaves was in general, increased at the expense of stems (stunting) and sometimes root dry weight. Because root dry weight proportions may decrease it appears that not only photosynthesis but phloem translocation of photosynthate may be impaired by increases in UV-B irradiance levels. Thus, the longer it takes a crop to produce a martetable product, the more pronounced the deleterious effects of UV-B radiation could become. Translocation to fruits would also be expected to be impaired resulting in lower yields. In addition, leaf expansion is decreased as the plants become autotrophic from seed-stored organic and mineral reserves. The implications for perennial plants, especially evergreens, is obvious, as these effects may accumulate and become magnified.

Of the underground root and tuber crops grown, only the radishes had reduced root biomass under 3.1 $UV\text{-}B_{seu}$. These radishes had increased leaf fresh and dry weights over the controls but decreased root weight, possibly again indicating an impaired translocation from shoot to root. However, in all the other levels of UV-B treatment the radishes not only had greater leaf biomass, but root biomass as well. Increased leaf weights were a re-

Table 39. Harvest data for radishes[1].

Meter[2]	Leaf (g) Fresh	Leaf (g) Dry[3]	Root Fresh(g)	Total Fresh	Leaf Area (cm^2)[3]	Density g/dm^2	No. of Leaves
0	2.6	0.311	5.1	7.7	72	0.43	7.15
1	3.4	0.338	3.3	6.7	90	0.38	8.15
2	4.4	0.434	7.1	11.5	106	0.41	7.45
3	4.4	0.450	8.7	13.1	107	0.42	7.25
4	4.7	0.433	7.8	12.5	121	0.36	8.10
5	5.1	0.471	10.6	15.7	132	0.36	8.00
6	4.5	0.434	8.2	12.7	109	0.40	7.50
7	4.0	0.421	9.4	13.4	87	0.48	7.70
8	2.9	0.314	5.1	8.0	87	0.36	8.35
$s_{\bar{x}}$	0.526	0.042	1.36		13.75		0.52

[1] Means from 4 field beds, each with 0 meters and 50 plants/meter at harvest.

[2] Meter 0 = no UV-B, control; meter 1 = first meter under the UV-B gradient irradiator.

[3] Indicates mean of UV-B treated meters was significantly greater then the control.

flection of a greater number of leaves and leaf area but lower leaf densities. 'Irish' potatoes under all UV-B_{seu} had increases in number of fruit and total weight of the smaller creamer grade size fruits. Overall yields as rated by total weight of fruit from UV-B treatment were less than the controls. This was primarily due to potatoes of larger sizes.

For peanuts, as with the potatoes, there was an inverse relationship for above ground biomass and below ground biomass at the higher (1.55 UV-B_{seu}) UV-B irradiance levels. Leaf and stem weights and leaf area were all higher than controls at these levels but with lower root weight, peanut number and yield. The smaller peanuts from UV-B treatment weighted more than equivalent size fruits from the controls. Correspondingly the root:shoot ratios was also reduced under the higher UV-B enhancement level.

Mustards were the only crop grown for commercial harvest of the leaf. All parameters measured on the UV-B treated plants were lower than the control but the reductions were proportional since biomass partitioning was not altered. The number of leaves and leaf area in the 3.1 UV-B_{seu} meter was drastically reduced. Even the smaller reductions in fresh weight of the other UV-B treated plants may have serious implications for commercial production of this crop.

That detrimental UV-B effects are accumulative was shown in the flowering and fruiting of tomatoes. The first panicle of flowers was initiated before transplanting the second shortly after transplanting into the field beds under the UV-B gradient irradiator. Flowering on the third hand was earlier on control plants. The dalay in flowering of treated plants was more evident as reflected in the harvest data. Tomato weight was lowered in the first harvest when only mature green tomatoes were harvested, but in the second harvest the yield differences between control and UV-B treated meters was enen more pronounced on a weight basis. Interestingly, the weight

of cull and immature fruit in the second harvest was lower than the controls in the .84 $UV\text{-}B_{seu}$ treated meters. This indicates not only weight of tomatoes was reduced, but also the number of fruit.

Height reduction was the most obvious effect of UV-B radiation on corn as both main and sucker stalks were reduced. In addition leaf area, leaf weights, and number of silks on both main and sucker stalks and root weights were reduced, especially at the higher UV-B levels. However, these reductions in vegetative parameters were not reflected in the final yield of corn. The other monocot (rice) did not have the same paterns of response as corn to enhanced UV-B radiation. Height and fruit weights were reduced, but leaf area was increased both for total leaves and for the flag leaf. The total number of leaves was also increased. If translocation was reduced, this could partially account for the larger leaf biomass in UV-B treated plants and in spike weights. Spike maturity was also delayed. This could be due to an effect on bolting but data was not taken that would allow an unequivical discernment of this parameter on rice.

Thinning data was taken for Southern peas, peanuts, rice and squash. All species showed decreases in leaf, stem and root weights and, except for peas, reduced leaf area from enhanced UV-B radiation at this earlier time of measurement . Leaf density was also consistently increased by UV-B radiation, except in peanuts. Although reduced root:shoot ratios were found in mature plants, only the UV-B treated seedling rice had reduced root:shoot ratios while the ratio was increased for young squash and pea plants. Since the indications are that leaves are affected first by UV-B radiation and the effects on roots are manifest by a reduction in translocations of photosynthates, one would expect the ratio to increase in seedlings and then decrease as roots may become increasingly affected. The close anatomical relationship

of roots to seed storage reserves could be preventing an earlier effect on root development. Some alterations in biomass partitioning were beginning to become evident on rice seedlings since both had increases in leaf weight at the seedling harvest stage.

ment combinations (Table 1) throughout the course of the experiment. These 16 treatments consisted of 4 flux levels of PAR and UV-B irradiances in all possible combinations. UV-B radiation was supplied by pre-burnt Westinghouse FS 40 sunlamps.[1] A fixture containing 2 filtered lamps each was suspended above the plants in each treatment. This radiation was filtered on all lamps by plastic films of either Mylar S (complete absorption of radiation below 320 nm) or 3 mil cellulose acetate (transmission of UV-B to 292 nm). Due to solarization, filters were routinely changed every three days to maintain transmission of the desired spectral qualities. The 4 UV-B irradiances were obtained by matching each lamp with the proper combination of filters and by adjusting the lamp distance above the plants. Thereafter, the distance between the lamps and the plants was maintained by raising the lamps as the plants grew.

UV-B irradiances employed were equivalent to zero (mylar control) 1/2, 1, and 2 solar equivalents.[2] The lamps were programmed with a timer for six house irradiance during the middle of the natural photoperiod, between 10 am and 4 pm. The 4 PAR levels were obtained by using a combination of commercially available neutral density shading materials. These were positioned over a frame constructed above the lamps in each treatment, covering all four sides and the top. Plastic films of Mylar S separated each treatment to prevent any UV-B scatter between treatments. The 4 shade levels used in the experiment were 0 (unshaded), 33, 55, and 88% shading. Due to the lamp configuration and overhead flowing water used to minimize the effects of

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[1] Lamps were illuminated for 100 hours prior to use to insure uniformity of UV-B irradiance throughout the course of the experiment. Previous studies have shown that lamp aging becomes somewhat linear after 100 hours of use, with a change of less than 5% total irradiance from approximately 100 to 600 hours of a neutral density characteristic (see methods in Section I).

[2] UV-B enhancement in solar equivalent units (seu).

Table 1. Optronics reading for PAR/UV-B irradiance study Sept. 6 thru Oct. 6, 1977. One 2 lamp fixture/treatment.

Treatment	Optronics Reading	UV-B Enhancement[1]	Z[2](cm)	% Shade[3]
1	4.6	x1	38.0	unshaded
2	6.2	x2	41.0	unshaded
3	6.2	x2	33.5	33
4	2.5	x½	60.0	unshaded
5	-	Mylar	50.0	unshaded
6	2.5	x½	60.5	33
7	-	Mylar	50.0	33
8	2.5	x½	69.0	55
9	6.2	x2	36.0	88
10	6.2	x2	34.0	55
11	4.6	x1	40.0	88
12	4.6	x1	40.5	33
13	4.6	x1	38.0	55
14	2.5	x½	72.0	88
15	-	Mylar	50.0	55
16	-	Mylar	50.0	88

[1] UV-B Enhancement in solar equivalent units (seu)

[2] Z measured from bottom of lamp to plant ht.

[3] Shade levels obtained by neutral density screening 33%, 55% and 88%. Average maximum daily unshaded irradiance = 1600 $\mu Em^{-2} sec^{-1}$ PAR.

shadows, the unshaded or full sun irradiance was somewhat lower than field levels, but higher than normal greenhouse irradiances. The maximum daily photon flux density measured at the top of the plants was approximately 1600 $\mu E \cdot m^{-2} \cdot sec^{-1}$ PAR. Therefore, the corresponding maximum daily PAR flux under each shade treatment would be 1600, 1408, 880, and 528 $\mu E \cdot m^{-2} \cdot sec^{-1}$, respectively.

Leaf temperatures remained at ambient air temperature (±3°C) in all 16 treatments.

Gas Exchange and Growth Measurements

For soybean, net carbon exchange (NCE), transpiration, and dark respiration were measured at two different physiological ages on single, attached leaves using a cuvette similar to that described by Patterson et al. (1977). CO_2 was measured in an open system using a Beckman 215B infrared gas analyzer in a differential mode. Water vapor concentrations were monitored with a Cambridge Systems EG & G Model 880 Dewpoint Hygrometer. All gas exchange measurements were done at a leaf temperature of 30°C, ambient CO_2 concentrations of 320 µl/l and a vapor pressure deficit of 10 mb.

Light was supplied by a General Electric cool beam incandescent lamp, filtered through water. Irradiance to the leaf was varied by placing a series of neutral density filters between the light source and the cuvette. Leaves were exposed to irradiances of 1300, 840, 480, and 170 $\mu E\ m^{-2}\ sec^{-1}$ PAR. At each irradiance, CO_2 and water vapor fluxes were continuously monitored until equilibration. After each series of light response measurements, dark respiration rates were measured. Photon flux densities in the PAR region were measured at the leaf surface with a Lambda Instruments LI-190S Quantum Sensor.

Diffusive resistances to water vapor were calculated following conventional resistance analysis (Gaastra, 1959). Resistances to CO_2 were calculated according to Nobel (1977). These resistances were related to one another in the following manner:

$$J_{H_2O} = \frac{\Delta H_2O}{R^{gas}_{H_2O}} \quad \text{where} \quad R^{gas}_{H_2O} = R^{air}_{H_2O} + R^{stomata}_{H_2O}$$

$$J_{CO_2} = \frac{\Delta CO_2}{R^{gas}_{CO_2} + R^{liquid}_{CO_2}} \quad \text{where} \quad R^{gas}_{CO_2} = R^{air}_{CO_2} + R^{stomata}_{CO_2}$$

$$\text{assuming } R^{gas}_{CO_2} = 1.56\ R^{gas}_{H_2O} \quad \text{(see Nobel, 1976)}$$

$$\text{then } R^{liquid}_{CO_2} = \frac{\Delta CO_2 - 1.56\ R^{gas}_{CO_2}}{J_{CO_2}}$$

where J_{H_2O} and J_{CO_2} are fluxes for water vapor and CO_2, and ΔH_2O is the difference in water vapor concentrations between the leaf and air (assuming the leaf to be saturated at leaf temperature). $R^{gas}_{H_2O}$ is the total leaf resistance to water vapor and can be partitioned into $R^{air}_{H_2O}$, or boundary layer resistance and $R^{stomata}_{H_2O}$ or resistance to water vapor movement out of the leaf by stomata. $R^{air}_{H_2O}$ was calculated using a filter paper leaf replica in the cuvette. ΔCO_2 is the difference between the CO_2 concentration in ambient air and the site of carboxylation. Since this latter concentration has been assumed to be equal to 0, $R^{liquid}_{CO_2}$ contains all the resistances other than boundary layer and stomatal resistances.

The first series of measurements were begun after the soybeans received a six hour radiation flux of UV-B for 14 days (84 hrs). Gas exchange responses were monitored on an attached unifoliate leaf after the plants had been fully watered. This procedure was repeated on the soybeans after 49 days of a six hour radiation flux (294 hrs) of UV-B. Gas exchange measurements were monitored on the center leaflet of the third fully expanded trifoliate leaf.

Immediately following this second series of measurements, these same leaves were exposed to a compressed gas mixture containing 2% oxygen, 350 µl/l CO_2, and the balance nitrogen. Before entering the cuvette, this air stream was humidified to achieve a vapor pressure deficit of 10 mb at a leaf temperature of 30°C. Light response measurements of CO_2 and H_2O vapor were performed as described earlier.

In addition to these gas exchange data, measurements were made on plant heights at weekly intervals. At the end of the experiment, plants were harvested and separated into roots, stems and leaves for soybeans, and roots, shoots, and inflorescences for wheat. Total leaf areas were measured with a Lambda LI-3000 leaf area meter. Plant parts were dried in a ventilated oven at 60°C to constant weight. UV-B damage was visually assessed for leaf chlorosis and interveinal wrinkling on a scale ranging between 0 and 9 (Table 2). The leaves used in the gas exchange experiments were removed and analysed for total chlorophyll, chlorophyll a and b, and total protein. Chlorophyll was determined by the method of Arnon (1949) and total proteins by Lowry (1951).

Computations were facilitied by the use of the Northeast Regional Data Center Amdahl 470 V/6 II Computer located at the University of Florida. Statistical analysis employed use of stored programs in the Statistical Analysis Systems (SAS 76.5).

Table 2. Criteria used to rate the degree of UV-B associated leaf chlorosis and interveinal wrinkling.

Index Value	Leaf Chlorosis	Interveinal Wrinkling
0	no damage, green leaves	no damage, healthy leaves
2	yellow leaves present	very slight puckering between leaves
4	yellow leaves with some spots of intense yellow	definite puckering
6	yellow leaves with brown patches	pronounced wrinkling
9	leaf margins dried and curled over, much of leaf dried	pronounced wrinkling and leaf curl evident

Results

Gas Exchange

Net carbon exchange (NCE) was light saturated at an irradiance of 1300 $\mu E\ m^{-2}\ sec^{-1}$ in all three experiments (Figures 1, 9, and 16). Therefore, an analysis of variance (ANOVA) was performed at this irradiance to test the effects of UV-B dose and PAR level during growth on net carbon exchange, transpiration, and the associated diffusive resistances. A separate analysis was done for dark respiration. A summary of these analyses are presented on Table 3.

At the end of a two-week exposure, both UV-B and PAR flux levels were associated with significant ($P < 0.05$) interactions in nearly all the variables examined. This was indicative of the complex nature of the combined effects. UV-B-associated reductions and enhancements after two weeks of UV-B treatment were expressed as a percentage of the mylar control responses in Table 4. NCE on a leaf weight basis was significantly ($P < 0.05$) reduced in plants exposed to 2 $UV\text{-}B_{seu}$ and reduced PAR levels incident during growth. However, NCE is not significantly ($P > 0.05$) affected by UV-B when plants were grown in full sunlight (compare Figure 1a with Figures 1b and c). Similar results were obtained for NCE on a leaf area basis (Figure 2). At the lowest PAR growth regime, NCE was equally reduced in plants exposed to any UV-B treatment.

Moderate fluxes of UV-B radiation resulted in enhancements of NCE when plants were grown under high PAR levels (Figures 1a and b and 2a and b). These enhancements were most pronounced under non-saturated irradiances (PAR less than 1300 $\mu E\ m^{-2}\ sec^{-1}$).

Table 3. Summary of 2 way ANOVA on the effects of UV-B and PAR on soybean NCE, transpiration, dark respiration, and the associated diffusive resistances.[1]

	2 weeks UV-B exposure						6 weeks UV-B exposure					
	UV-B		PAR		UV-BxPAR		UV-B		PAR		UV-BxPAR	
	df	F	df	F	df	F	df	F	df	F	df	F
NCE (mg $CO_2 \cdot dm^{-2} \cdot hr^{-1}$)	3	6.42***[2]	3	8.72***	8	1.74ns	3	6.47***	3	20.30***	8	0.81ns
NCE (mg $CO_2 \cdot g^{-1} hr^{-1}$)	3	6.72***	3	8.91***	8	3.20**	3	12.60***	3	2.38ns	8	1.03ns
Transpiration (g H_2O $dm^{-2} \cdot hr^{-1}$)	3	7.62***	3	13.41***	8	3.10**	3	3.50*	3	2.66ns	8	1.96ns
Transpiration (g H_2O $g^{-1} \cdot hr^{-1}$)	3	11.77***	3	70.50***	8	4.02***	3	15.11***	3	18.94***	8	4.49***
$R_{CO_2}^{stomata}$ ($sec \cdot cm^{-1}$)	3	5.16**	3	8.46***	8	2.34*	3	3.05*	3	1.89ns	8	1.59ns
$R_{CO_2}^{liquid}$ ($sec \cdot cm^{-1}$)	3	12.53***	3	7.17***	8	7.15***	3	2.88*	3	7.22***	8	0.48ns
$R_{CO_2}^{leaf}$ ($sec \cdot cm^{-1}$)	3	12.90***	3	5.85***	8	6.66***	3	3.23*	3	6.93***	8	0.48ns
$R_{H_2O}^{stomata}$ ($sec \cdot cm^{-1}$)	3	5.16**	3	8.46***	8	2.34*	3	3.05*	3	1.89ns	8	1.59ns
Dark respiration (mg CO_2 $dm^{-2} hr^{-1}$)	3	1.57ns	3	20.29***	8	1.93ns	3	0.56ns	3	3.00*	8	0.98ns
Dark respiration (mg CO_2 $g^{-1} hr^{-1}$)	3	2.13ns	3	1.10ns	8	0.99ns	3	0.60ns	3	1.25ns	8	1.19ns

[1]Irradiance at the leaf surface was 1300 $\mu Em^{-2} sec^{-1}$ PAR; ambient CO_2 and O_2 concentrations

[2]* = significant at $P < 0.05$
** = significant at $P < 0.01$
*** = significant at $P < 0.001$
ns = not significant

Table 4. Mean effects of 4 UV-B irradiances and 4 shade levels on soybean NCE, transpiration, and the associated diffusive resistances after two weeks exposure.[1] Data in parenthesis are expressed as percent mylar control.

	Shade[2]														
	% = 0				% = 33				% = 55				% = 88[3]		
UV-B $_{seu}$	0	½	1	2	0	½	1	2	0	½	1	2	½	1	2
NCE (mg $CO_2 g^{-1} hr^{-1}$)	56.57 a[4]	72.91 a (128.9)	56.94 a (100.7)	62.68 a (110.8)	74.18 ab	90.98 a (122.6)	70.07 ab (94.5)	55.82 b (75.2)	100.12 a	92.49 a (92.4)	90.90 a (90.8)	27.71 b (27.7)	72.76 ab	80.80 a	61.39 b
NCE (mg $CO_2 dm^{-2} hr^{-1}$)	15.87 a	17.23 a (108.6)	15.68 a (98.8)	14.96 a (94.3)	12.14 ab	15.60 a (128.5)	14.62 a (120.4)	9.86 b (81.2)	13.07 a	13.90 a (106.4)	15.78 a (120.7)	5.54 b (42.4)	11.33 a	11.00 a	9.27 a
Transpiration (g H_2O $g^{-1} hr^{-2}$)	13.67 ab	16.97 a (124.1)	12.36 ab (90.4)	9.72 b (71.1)	18.54 b	24.97 a (134.7)	15.25 bc (82.3)	11.87 c (64.0)	32.16 a	34.92 a (108.6)	24.34 b (75.7)	19.57 b (60.9)	24.43 ab	22.49 b	29.27 a
Transpiration (g H_2O $dm^{-2} hr^{-1}$)	3.81 a	4.22 a (110.8)	3.36 ab (88.2)	2.32 b (60.9)	3.02 b	4.28 a (141.7)	3.13 b (103.6)	2.09 c (69.2)	4.20 b	5.25 a (125.0)	4.28 b (101.9)	3.88 b (92.4)	3.82 a	3.06 b	4.42 a
$R^{leaf}_{CO_2}$ ($sec \cdot cm^{-1}$)	14.75 a	15.31 a (103.8)	14.74 a (99.9)	15.19 a (103.0)	19.50 ab	14.61 b (74.9)	16.55 b (84.9)	23.48 a (120.4)	18.37 a	16.74 a (91.1)	15.51 a (84.4)	48.65 b (264.8)	20.14 a	21.06 a	24.60 a
$R^{stomata}_{CO_2}$ ($sec \cdot cm^{-1}$)	1.17 b	0.98 b (83.8)	1.69 ab (144.4)	2.42 a (206.8)	1.68 b	0.97 b (57.7)	1.71 b (101.8)	2.78 a (165.5)	0.91 ab	0.62 b (68.1)	0.93 ab (102.2)	1.08 a (118.7)	1.14 ab	1.71 a	0.85 b
$R^{liquid}_{CO_2}$ ($sec \cdot cm^{-1}$)	13.06 a	13.81 a (105.7)	12.53 a (95.9)	12.24 a (93.7)	17.30 a	13.12 a (75.8)	14.31 a (82.7)	20.17 a (116.6)	16.94 a	15.59 a (92.0)	14.05 a (82.9)	47.05 b (277.7)	18.47 b	18.83 b	23.22 a
$R^{stomata}_{H_2O}$ ($sec \cdot cm^{-1}$)	0.75 b	0.63 b (84.0)	1.08 ab (144.0)	1.55 a (206.7)	1.08 b	0.62 b (57.4)	1.10 b (101.9)	1.78 a (164.8)	0.58 ab	0.40 b (69.0)	0.59 ab (101.7)	0.69 a (119.0)	0.73 a	1.09 a	0.55 a
Water use efficiency (g H_2O lost/g CO_2 fixed)	246.60 a	293.4 a (119.0)	208.77 a (84.7)	155.0 a (62.9)	253.20 a	273.6 a (108.1)	224.9 a (88.8)	213.0 a (84.1)	334.4 b	384.3 b (114.9)	286.8 b (85.8)	302.7 a (240.0)	338.4 b	278.7 c	477.9 a

[1] Plants accumulated UV-B for 14-17 days. Means for leaf irradiance = 1300 $\mu Em^{-2} sec^{-1}$ PAR_2 ambient CO_2 = 320 μLL^{-1}
[2] Expressed as percent incident radiation shaded. Mean daily unshaded maximum = 1600 $\mu Em^{-2} sec^{-1}$ PAR
[3] Mylar control plants could not be measured
[4] Values in rows under each level of shade with the same letter are not statistically different at the 95% level

Figure 1. Effects of four UV-B irradiances and four PAR levels on net carbon exchange (NCE) in soybeans after 14 days exposure. Plotted are the mean NCE rates on a leaf dry weight basis (MPSW) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. MPSW is expressed in mg $CO_2 \cdot g^{-1} \cdot hr^{-1}$. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.

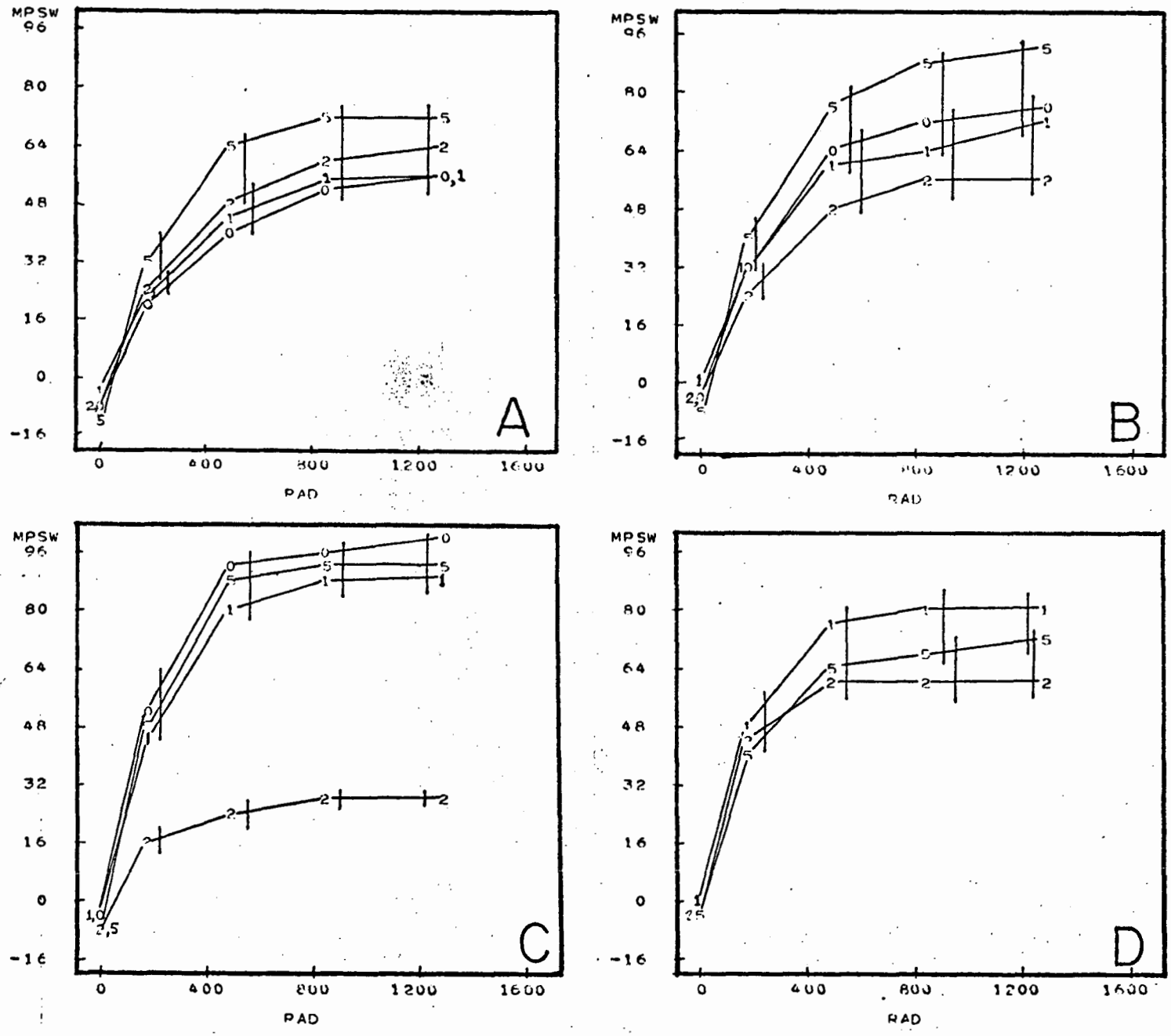
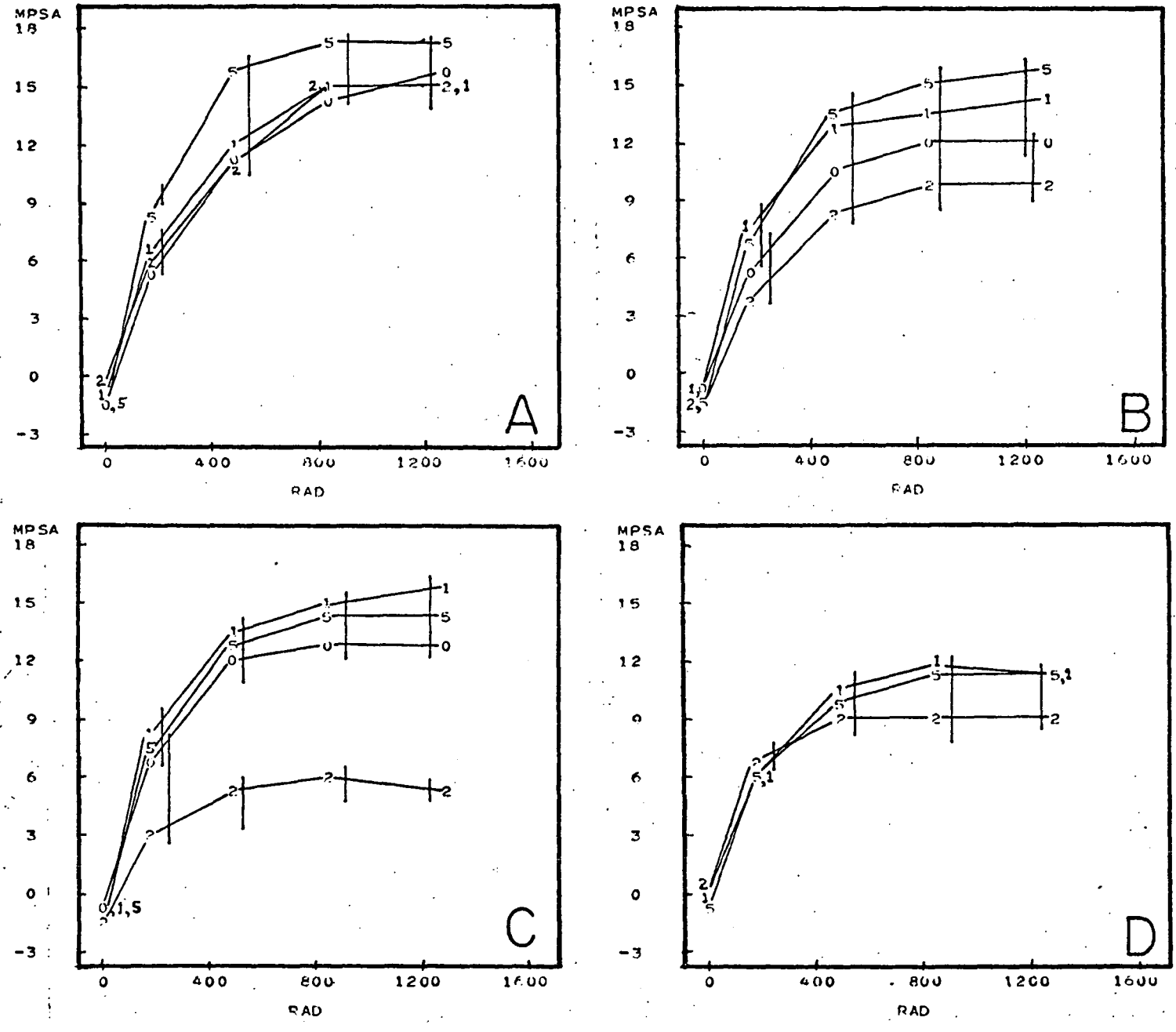

MPSW
96
80
64
48
32
16
0
-16
0
400
800
1200
1600
RAD
A
B
C
D

Figure 2. Effects of four UV-B irradiances and four PAR levels on net carbon exchange (NCE) in soybeans after 14 days exposure. Plotted are the mean NCE rates on a leaf area basis (MPSA) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. MPSA is expressed in mg $CO_2 \cdot dm^{-2} \cdot hr^{-1}$. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.


MPSA
18
15
12
9
6
3
0
-3
0
400
800
1200
1600
RAD
A
B
C
D

The total leaf resistance to the diffusion of CO_2, $R_{CO_2}^{leaf}$, was greatest in plants exposed to 2 $UV\text{-}B_{seu}$ and intermediate PAR flux levels (Figure 3). Between PAR irradiances of 0 and 33% shade, UV-B flux had no effect on $R_{CO_2}^{leaf}$. However, $R_{CO_2}^{leaf}$ from soybeans grown in irradiances of 33% shade and below were increasingly affected by 2 $UV\text{-}B_{seu}$ (Table 4). $R_{CO_2}^{liquid}$ accounted for 80% to 90% of the total leaf resistance to CO_2 (15 to 25 cm^{-1}). Therefore, the responses of $R_{CO_2}^{liquid}$ were reflected in $R_{CO_2}^{leaf}$ (Figure 4). $R_{CO_2}^{liquid}$ was significantly ($P < 0.05$) greater in plants grown under 2 $UV\text{-}B_{seu}$ and moderate to low PAR levels (Table 4).

Stomatal resistance to CO_2 diffusion, $R_{CO_2}^{stomata}$ accounted for approximately 10 to 20% of $R_{CO_2}^{leaf}$ (Figure 5). $R_{CO_2}^{stomata}$ was greatest in those soybeans grown under 2 $UV\text{-}B_{seu}$ and between 0 and 33% shade (Table 4). $R_{CO_2}^{stomata}$ of soybeans exposed to 1/2 $UV\text{-}B_{seu}$ was always less than that of controls. UV-B fluxes greater than this resulted in a significant increase in $R_{CO_2}^{stomata}$. Therefore, 2 $UV\text{-}B_{seu}$ resulted in both higher $R_{CO_2}^{liquid}$ and $R_{CO_2}^{stomata}$, but these resistances were greatest under different PAR regimes. At the high PAR irradiances, increased UV-B flux affected NCE primarily by increase of $R_{CO_2}^{stomata}$. Therefore, despite relatively lower $R_{CO_2}^{liquid}$, NCE remained essentially unaffected. However, when grown in lower irradiances, $R_{CO_2}^{liquid}$ became increasingly more important in restricting NCE. The UV-B associated enhancements in NCE seemed primarily to be due to decreases in the stomatal resistances of soybeans exposed to 1/2 $UV\text{-}B_{seu}$ (Table 4).

After a two week treatment, transpiration on both an area and a weight basis was significantly ($P < 0.01$) affected by the interaction between UV-B flux and PAR level (Table 3). In general, transpiration on an area basis was greater in soybeans grown under higher PAR flux levels (Figure 7). Transpiration in soybeans grown under high PAR levels varied inversely with

Figure 3. Effects of four UV-B irradiances and four PAR levels on total leaf resistance to CO_2 ($R^{leaf}_{CO_2}$) in soybeans after 14 days exposure. Plotted are the mean $R^{leaf}_{CO_2}$ in $sec \cdot cm^{-1}$ (MRCCELL) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.

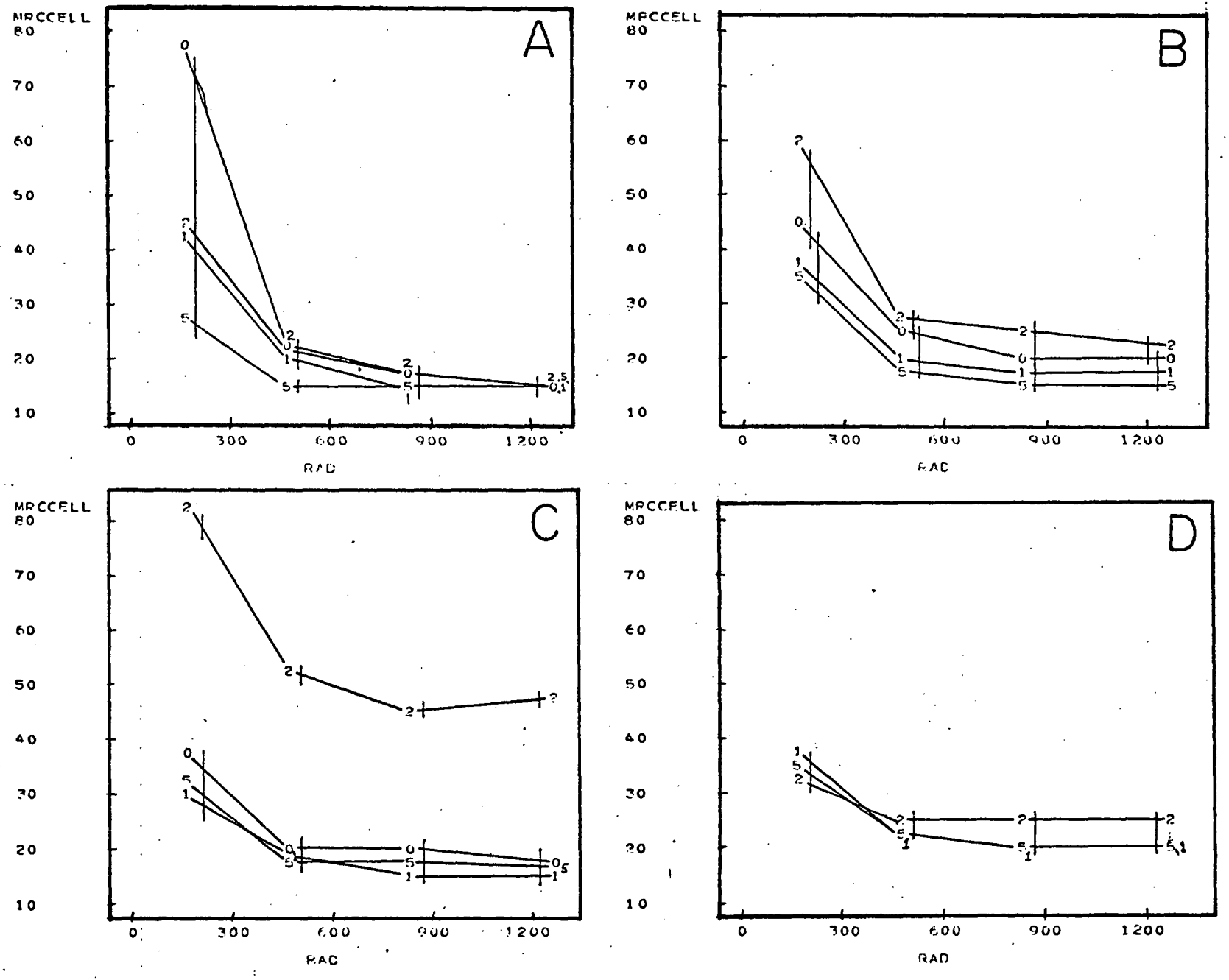

A
B
C
D
MRCCELL
80
70
60
50
40
30
20
10
0
300
600
900
1200
RAD

Figure 4. Effects of four UV-B irradiances and four PAR levels on liquid phase resistances to CO_2 ($R_{CO_2}^{liquid}$) in soybeans after 14 days exposure. Plotted are the mean $R_{CO_2}^{liquid}$ in $sec \cdot cm^{-1}$ (MRCLIQ) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ UV-B_{seu}, 1=1 UV-B_{seu}, 2=2 UV-B_{seu}. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.

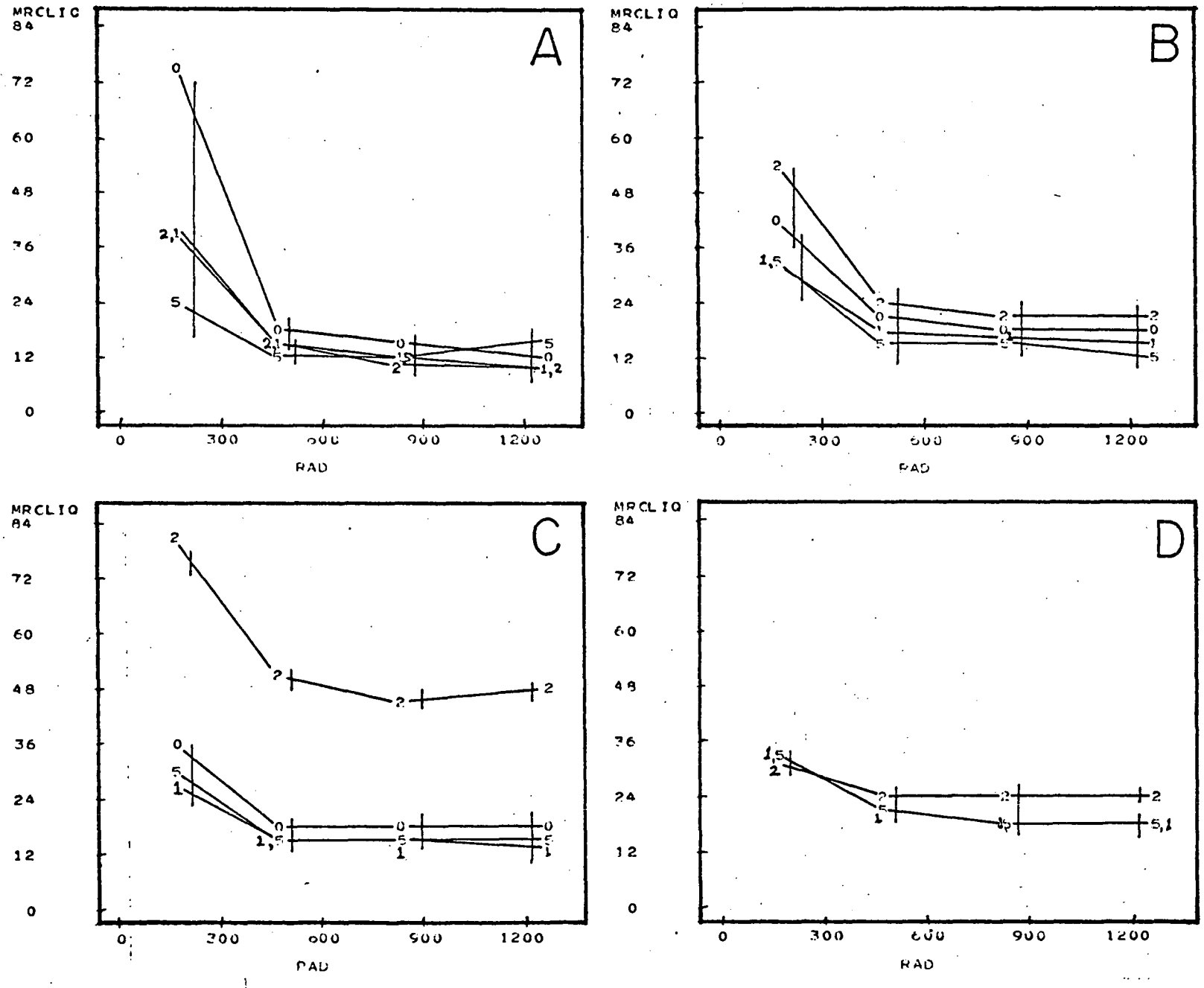

MRCLIC
84
72
60
48
36
24
12
0
A
B
C
D
0
300
600
900
1200
RAD

Figure 5. Effects of four UV-B irradiances and four PAR levels on stomatal resistances to CO_2 ($R_{CO_2}^{stomata}$) in soybeans after 14 days exposure. Plotted are the mean $R_{CO_2}^{stomata}$ in $sec \cdot cm^{-1}$ (MRCSTOM) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.

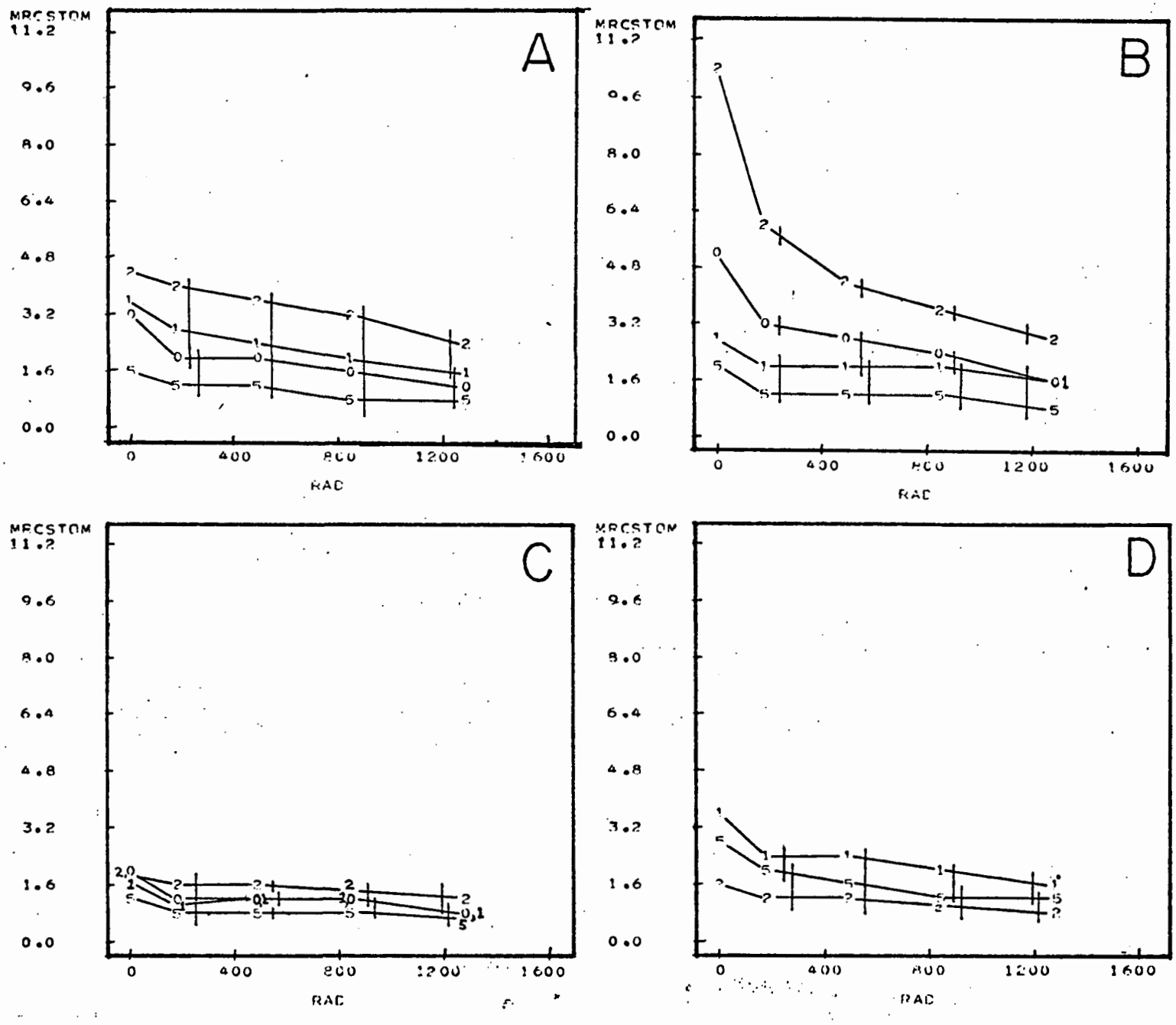

MRCSTOM
11.2
9.6
8.0
6.4
4.8
3.2
1.6
0.0
A
B
C
D
0
400
800
1200
1600
RAD

Figure 6. Effects of four UV-B irradiances and four PAR levels on leaf transpiration in soybeans after 14 days exposure. Plotted are the mean transpiration rates on leaf dry weight basis (MTSW) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. Transpiration was expressed in g $H_2O \cdot g^{-1} \cdot hr^{-1}$. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ UV-B $_{seu}$, 1=1 UV-B_{seu}, 2=2 UV-B_{seu}. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.

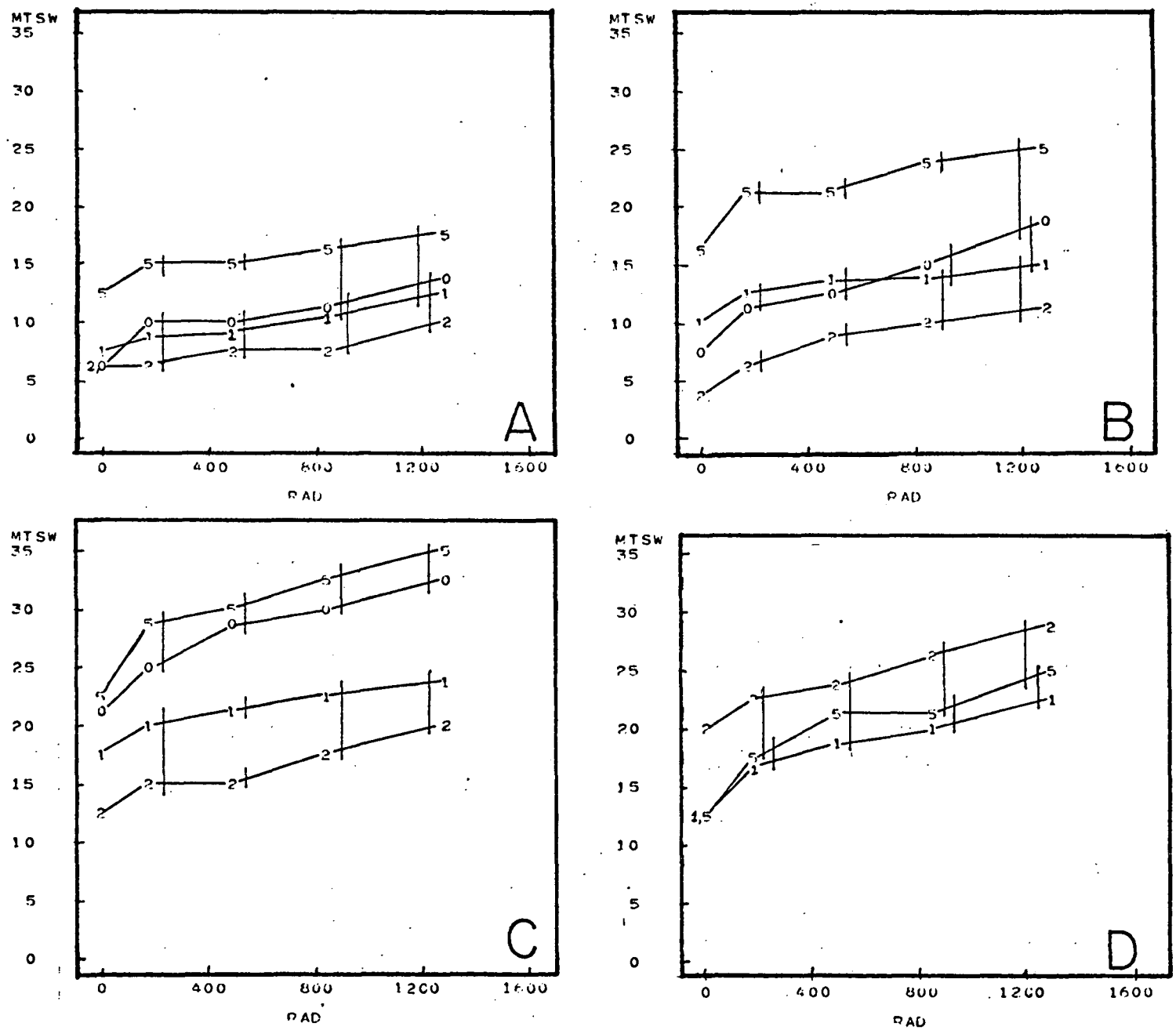
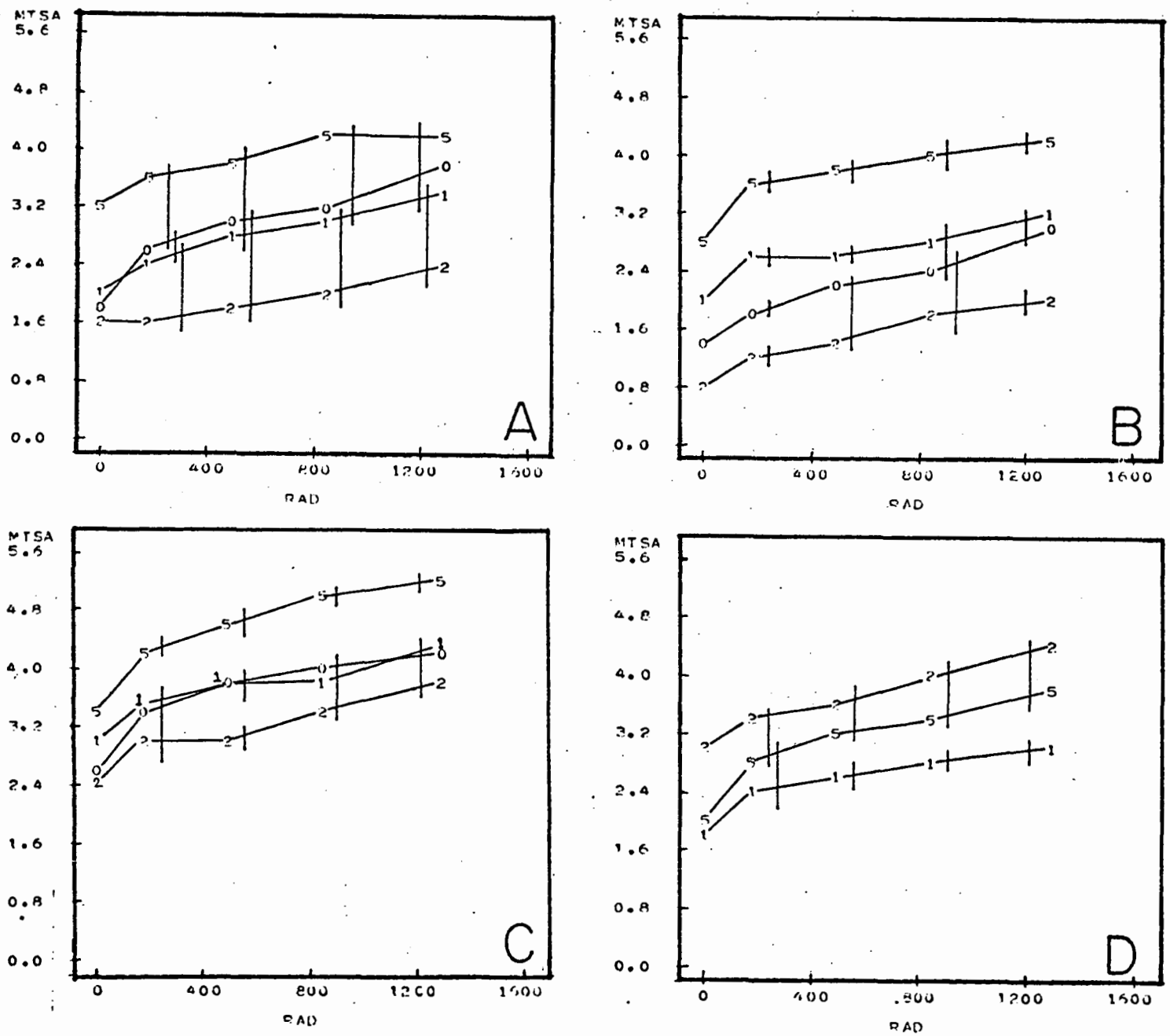

MTSW
35
30
25
20
15
10
5
0
0
400
800
1200
1600
RAD
A
B
C
D

Figure 7. Effects of four UV-B irradiances and four PAR levels on leaf transpiration in soybeans after 14 days exposure. Plotted are the mean transpiration rates on a leaf area basis (MTSA) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. MTSA is expressed m g $H_2O \cdot dm^{-2} \cdot hr^{-1}$. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.


MTSA
5.6
4.8
4.0
3.2
2.4
1.6
0.8
0.0
0
400
800
1200
1600
RAD
A
B
C
D

UV-B flux and was intermediate for the mylar controls and lowest for plants exposed to 2 $UV\text{-}B_{seu}$. However, this relationship changed in soybeans grown under the lowest PAR flux level (Figures 6d and 7d). In this reduced PAR regime, transpiration was lower in soybean exposed to 1 than those exposed to 2 $UV\text{-}B_{seu}$.

Stomatal resistances to the diffusion of water vapor, $R_{H_2O}^{stomata}$, were greatest in plants exposed to 2 $UV\text{-}B_{seu}$ in high to moderate PAR conditions (Table 4). The effects of UV-B and PAR on stomatal resistances resulted in a greater water use efficiency in soybeans grown under high PAR levels and 2 $UV\text{-}B_{seu}$. However, when PAR levels were reduced, water use efficiency for soybeans exposed to 2 $UV\text{-}B_{seu}$ was reduced by diminishing NCE rates (Table 4).

Dark respiration was unaffected by UV-B flux on both a leaf weight and on a leaf area basis (Table 3). However, dark respiration on an area basis was strongly affected by PAR. Specific leaf thickness increased with level of PAR during growth. Therefore, dark respiration is more a function of cell volume or weight rather than leaf surface area.

By the end of six weeks of exposure, the UV-B x PAR interaction changed, as indicated by the decrease in the number of significant UV-B and PAR interaction terms (Table 3). NCE on a leaf weight basis was reduced by UV-B enhancement in all PAR regimes, particularly becoming pronounced at intermediate irradiances (Figure 8). The reduction in NCE was directly related to UV-B flux. Even UV-B fluxes approximating those commonly experienced in the field resulted in decreased NCE rates (Table 5). Similar results were obtained for NCE on a leaf area basis (Figure 9). NCE on a leaf area basis was additionally reduced as a function of PAR available to the plant during growth.

Figure 8. Effects of four UV-B irradiances and four PAR levels on net carbon exchange (NCE) in soybeans after 49 days exposure. Plotted are the mean NCE rates on a leaf dry weight basis (MPSW) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ UV-S_{seu}, 1=1 UV-B_{seu}, 2=2 UV-B_{seu}. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.

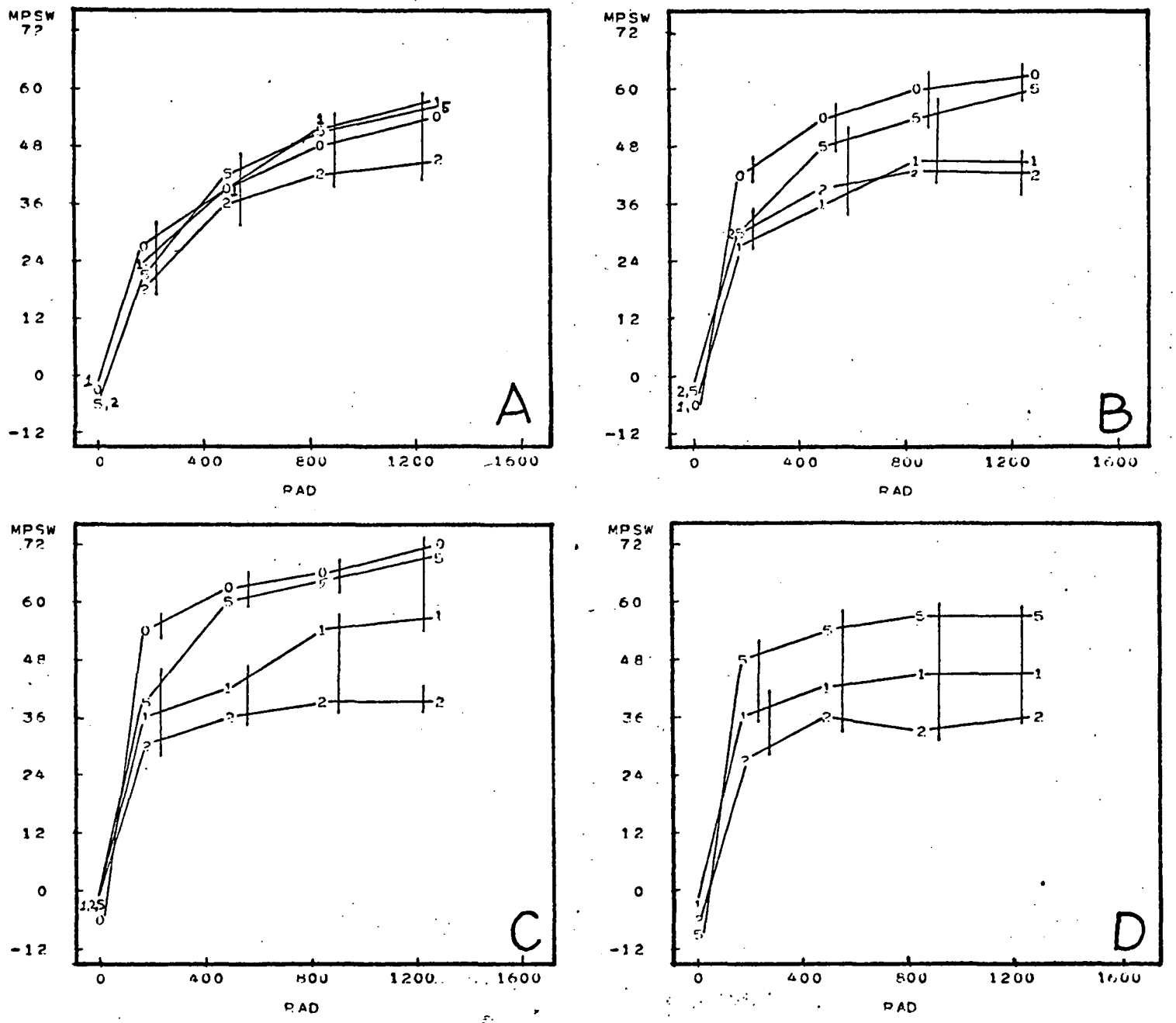
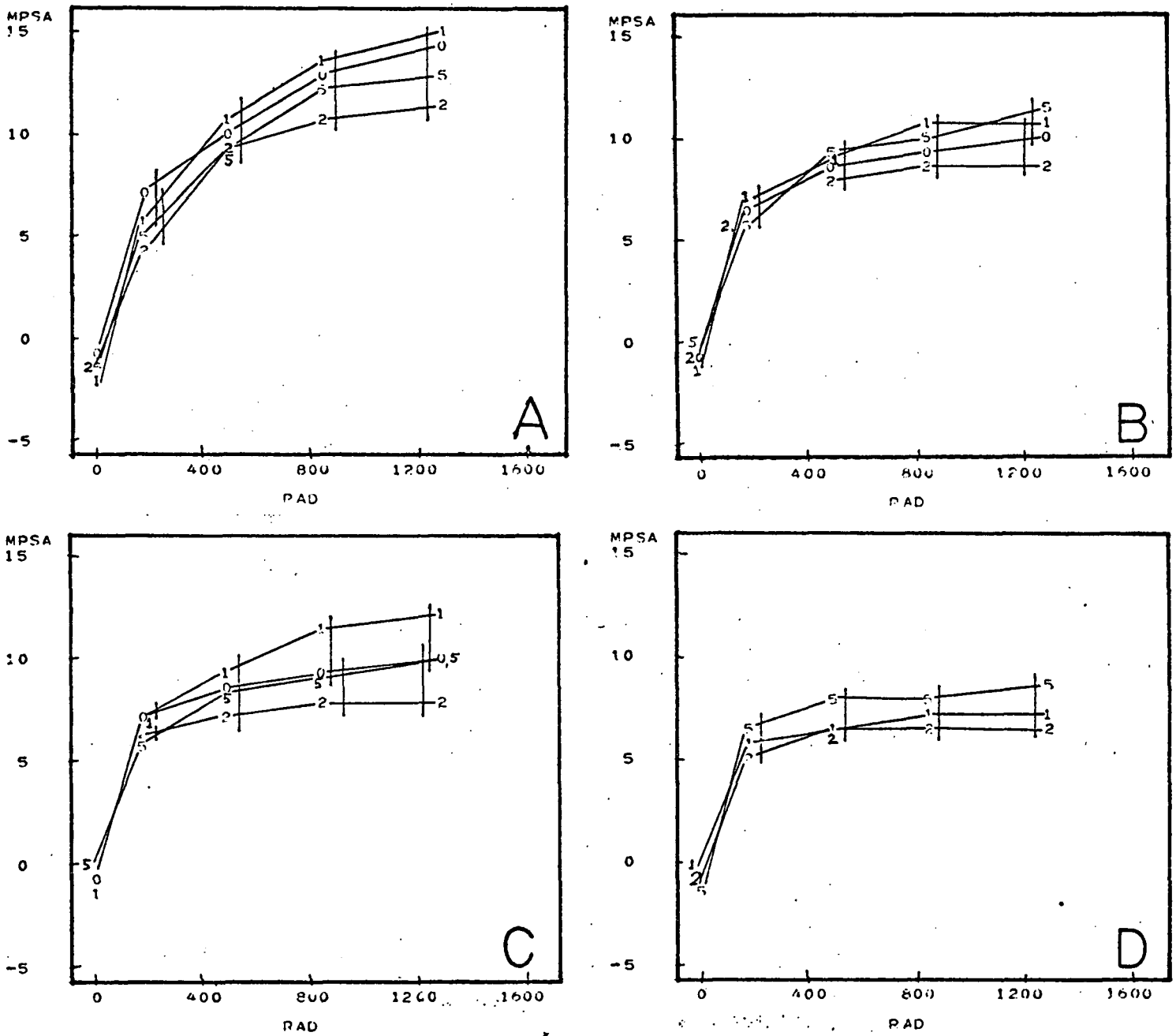

MPSW
72
60
48
36
24
12
0
-12
0
400
800
1200
1600
RAD
A
B
C
D

Table 5. Mean effects of 4 UV-B irradiances and 4 shade levels on soybean NCE, transpiration, and the associated diffusive resistances after 6 weeks of treatment.[1] Data in parenthesis are expressed as percent mylar control.

	Shade[2]															
	% = 0				% = 33				% = 55				% = 88[3]			
UV-B$_{seu}$	0	½	1	2	0	½	1	2	0	½	1	2		½	1	2
NCE (mg $CO_2 g^{-1} hr^{-1}$)	54.00	54.2	56.20	44.83	62.20	60.76	44.86	42.61	70.94	70.13	56.13	39.50		56.97	45.71	35.01
	a[4]	a	a	a	a	a	b	b	a	a	a	b		a	a	a
		(100.4)	(104.1)	(83.0)		(97.7)	(72.1)	(68.5)		(98.9)	(79.1)	(55.7)				
NCE (mg $CO_2 dm^{-2} hr^{-1}$)	14.29	12.96	15.17	11.64	9.77	11.64	10.97	8.42	10.05	10.04	12.08	7.88		8.27	7.30	6.44
	a	a	a	a	ab	a	ab	b	ab	ab	a	b		a	a	a
		(90.7)	(106.2)	(81.5)		(119.1)	(112.3)	(86.2)		(99.9)	(120.2)	(78.4)				
Transpiration (g H_2O $g^{-1} hr^{-1}$)	14.87	19.55	16.23	15.34	27.92	17.80	15.68	14.83	31.63	24.18	18.52	17.36		32.57	23.04	19.64
	b	a	ab	ab	a	b	b	b	a	b	c	c		a	b	b
		(131.5)	(109.1)	(103.2)		(63.8)	(56.2)	(53.1)		(76.4)	(58.6)	(54.9)				
Transpiration (g H_2O $dm^{-2} hr^{-1}$)	3.94	4.68	4.38	3.98	4.39	3.42	3.81	2.94	4.50	3.45	3.94	3.45		4.75	3.68	3.64
	a	a	a	a	a	ab	ab	b	a	ab	b	b		a	a	a
		(118.8)	(111.2)	(101.0)		(77.9)	(86.8)	(67.0)		(76.7)	(87.6)	(76.7)				
$R_{CO_2}^{leaf}$ (sec cm^{-1})	16.58	17.76	15.01	19.65	23.43	19.81	21.44	27.93	23.40	23.00	196.4	29.79		28.10	31.54	48.81
	a	a	a	a	ab	b	ab	a	ab	ab	b	a		a	a	a
		(107.1)	(90.5)	(118.7)		(84.5)	(91.5)	(119.2)		(98.3)	(83.9)	(124.7)				
$R_{CO_2}^{stomata}$ (sec cm^{-1})	2.83	2.13	2.22	2.66	2.26	3.28	2.62	4.18	2.11	3.17	2.52	2.94		2.03	2.71	3.12
	a	a	a	a	b	ab	ab	a	b	a	ab	a		a	a	a
		(75.3)	(78.4)	(94.0)		(145.1)	(115.9)	(185.0)		(150.2)	(119.4)	(139.3)				
$R_{CO_2}^{liquid}$ (sec cm^{-1})	13.23	15.11	12.27	16.47	20.65	16.01	18.30	23.23	20.76	19.31	16.59	25.72		25.55	28.30	45.16
	ab	ab	b	a	ab	b	ab	a	ab	ab	b	a		a	a	a
		(114.2)	(92.7)	(109.0)		(77.5)	(88.6)	(112.5)		(93.0)	(79.9)	(123.9)				
$R_{H_2O}^{stomata}$ (sec cm^{-1})	1.81	1.37	1.43	1.71	1.45	2.10	1.68	2.68	1.35	2.03	1.62	1.89		1.30	1.74	2.00
	a	a	a	a	b	ab	ab	a	b	a	ab	a		a	a	a
		(75.7)	(79.0)	(94.5)		(144.8)	(115.9)	(184.8)		(150.4)	(120.0)	(140.0)				
Water use efficiency (g H_2O lost/g CO_2 fixed)	272.7	363.7	291.3	343.8	450.7	299.9	359.8	348.0	462.8	341.9	336.3	445.5		582.1	517.5	707.4
	c	a	bc	ab	a	b	ab	ab	a	ab	b	ab		a	a	a
		(133.4)	(106.8)	(126.1)		(66.5)	(79.8)	(77.2)		(73.9)	(72.7)	(96.3)				
Chlorophyll a (mg Chl dm^{-2})	1.97	1.48	1.88	1.88	1.35	1.45	1.65	1.80	1.27	1.13	1.58	1.25	0.95	1.27	1.32	1.21
	a	a	a	a	b	b	ab	a	ab	b	a	ab	b	a	a	ab
		(75.1)	(95.4)	(95.4)		(107.4)	(122.2)	(133.3)		(89.0)	(124.4)	(98.4)				
Chlorophyll b (gm Chl dm^{-2})	0.75	0.54	0.68	0.68	0.53	0.59	0.62	0.73	0.50	0.46	0.59	0.50	0.39	0.56	0.52	0.48
	a	b	ab	ab	b	ab	ab	a	a	a	a	a	b	a	a	ab
		(72.0)	(90.7)	(90.7)		(111.3)	(117.0)	(137.7)		(92.0)	(118.0)	(100)				
Total chlorophyll (mg Chl dm^{-2})	2.72	2.03	2.56	2.48	1.88	2.04	2.26	2.53	1.77	1.59	2.17	1.75	1.34	1.83	1.84	1.69
	a	a	a	a	b	a	ab	a	a	a	a	a	b	a	a	ab
		(74.6)	(94.1)	(91.2)		(108.5)	(120.2)	(134.6)		(89.8)	(122.6)	(98.9)				
Total proteins (mg g^{-1} fr wt)	6.30	3.59	7.45	8.86	8.34	5.85	3.58	9.45	2.87	3.85	8.51	3.82	6.47	3.50	5.96	6.43
	a	a	a	a	a	a	a	a	b	ab	a	ab	a	a	a	a
		(56.9)	(118.3)	(140.6)		(70.1)	(42.9)	(113.3)		(134.1)	(296.5)	(133.1)				

[1]Plants accumulated UV-B for 40-42 days. Means for leaf irradiance = 1300 $\mu Em^{-2}sec^{-1}$ PAR_l, ambient CO_2 = 320 μLL^{-1}
[2]Expressed as percent incident radiation shaded. Mean daily unshaded maximum = 1600 $\mu Em^{-2}sec^{-1}$ PAR
[3]Mylar control plants could not be measured
[4]Values in rows under each level of shade with the same letter are not statistically different at the 95% level

Figure 9. Effects of four UV-B irradiances and four PAR levels on net carbon exchange (NCE) in soybeans after 49 days exposure. Plotted are the mean NCE rates on a leaf area basis (MPSA) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$ 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.


MPSA
15
10
5
0
-5
0
400
800
1200
1600
RAD
A
B
C
D

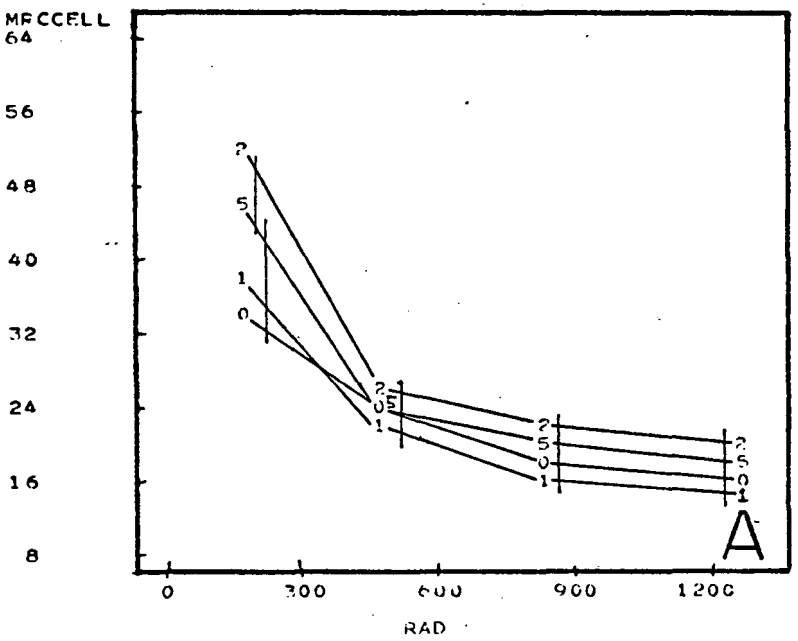
$R_{CO_2}^{leaf}$ was significantly affected both by UV-B flux ($P < 0.05$) and PAR irradiance ($P < 0.001$). $R_{CO_2}^{leaf}$ was greatest in soybeans exposed to 2 $UV\text{-}B_{seu}$ in all PAR treatments and varied inversely with PAR level (Figure 10). $R_{CO_2}^{liquid}$ contained most of the total leaf resistance to CO_2 and increased directly with UV-B flux and inversely with PAR (Figure 11). In general, $R_{CO_2}^{stomata}$ was unaffected by PAR level but was significantly ($P < 0.05$) increased by increasing UV-B. $R_{CO_2}^{stomata}$ was greatest in those plants exposed to 2 $UV\text{-}B_{seu}$. This is particularly evident in soybeans grown in reduced PAR levels (Figure 12).

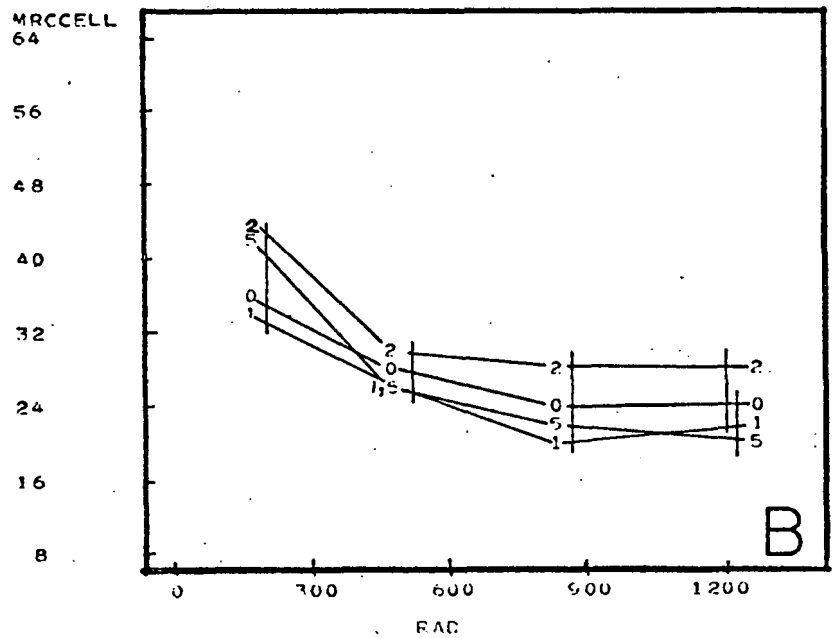
After six weeks exposure, transpiration on a leaf area basis was significantly ($P < 0.05$) affected by UV-B flux but not by PAR (Table 3). Soybeans grown in moderate to low PAR levels and exposed to UV-B had reduced transpiration rates compared with controls on both a leaf weight and area basis (Figures 13 and 14). Under the highest PAR regime, UV-B had no significant ($P > 0.05$) effect on transpiration. The reduction in transpiration with increasing UV-B flux was reflected in increasing stomatal resistances, $R_{H_2O}^{stomata}$ (Figure 15).

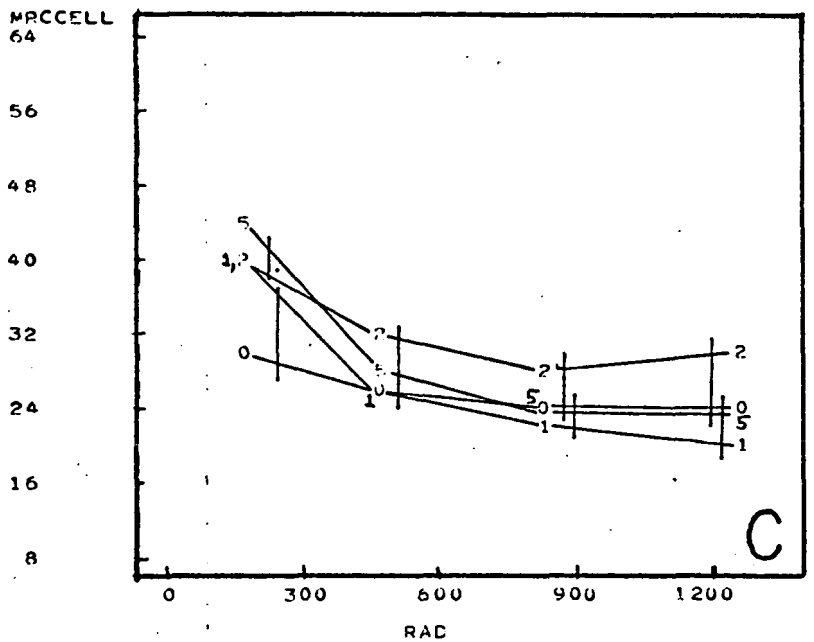
When grown under unshaded conditions the greater NCE rates of control plants resulted in a significantly ($P < 0.05$) greater water use efficiency. Water use efficiency was reduced in control soybeans when grown under lower PAR levels due to both increased $R_{CO_2}^{stomata}$ and lower NCE rates. Dark respiration was unaffected by UV-B exposure after 6 weeks.

Leaf protein and chlorophyll contents are shown on Table 5. After seven weeks of treatment, leaf total protein on a weight basis was unaffected by UV-B or PAR. Chlorophyll b was associated with a significant ($P < 0.05$) UV-B x PAR interaction, which was also reflected in total chlorophyll. In general, total chlorophyll decreased as PAR was reduced. Under high PAR

Figure 10. Effects of four UV-B irradiances and four PAR levels on total leaf resistance to CO_2 ($R^{leaf}_{CO_2}$) in soybeans after 49 days exposure. Plotted are the mean $R^{leaf}_{CO_2}$ in $sec \cdot cm^{-1}$ (MRCCELL) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.


MRCCELL
64
56
48
40
32
24
16
8
0
300
600
900
1200
RAD
A


MRCCELL
64
56
48
40
32
24
16
8
0
300
600
900
1200
RAD
B


MRCCELL
64
56
48
40
32
24
16
8
0
300
600
900
1200
RAD
C

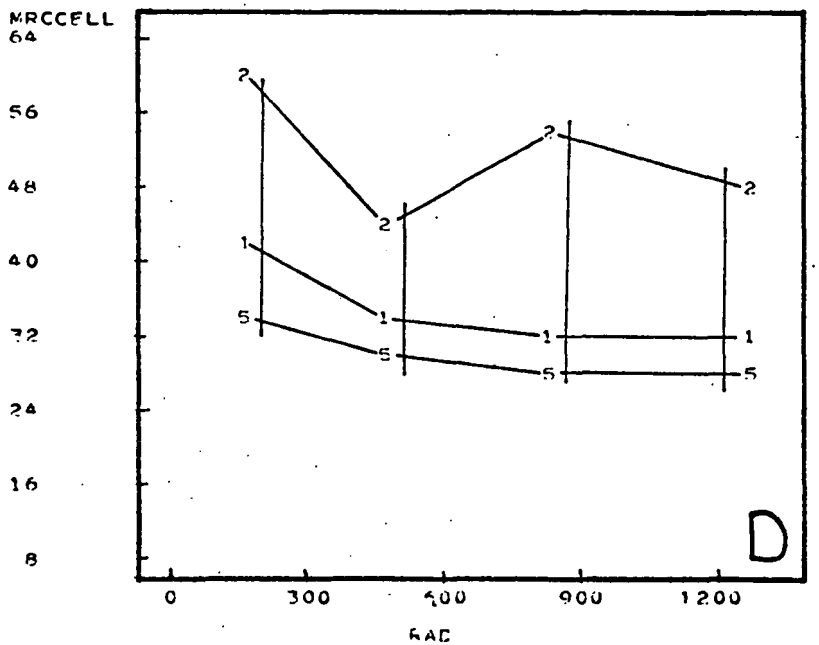

MRCCELL
64
56
48
40
32
24
16
8
0
300
600
900
1200
RAD
D

Figure 11. Effects of four UV-B irradiances and four PAR levels on liquid phase resistances to CO_2 ($R_{CO_2}^{liquid}$) in soybeans after 49 days exposure. Plotted are the mean $R_{CO_2}^{liquid}$ in $sec \cdot cm^{-1}$ (MRCLIQ) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$ 1=1 $UV\text{-}U_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.

Figure 12. Effects of four UV-B irradiances and four PAR levels on stomatal resistances to CO_2 ($R_{CO_2}^{stomata}$) in soybeans after 49 days exposure. Plotted are the mean $R_{CO_2}^{stomata}$ in $sec \cdot cm^{-1}$ (MRCSTOM) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.

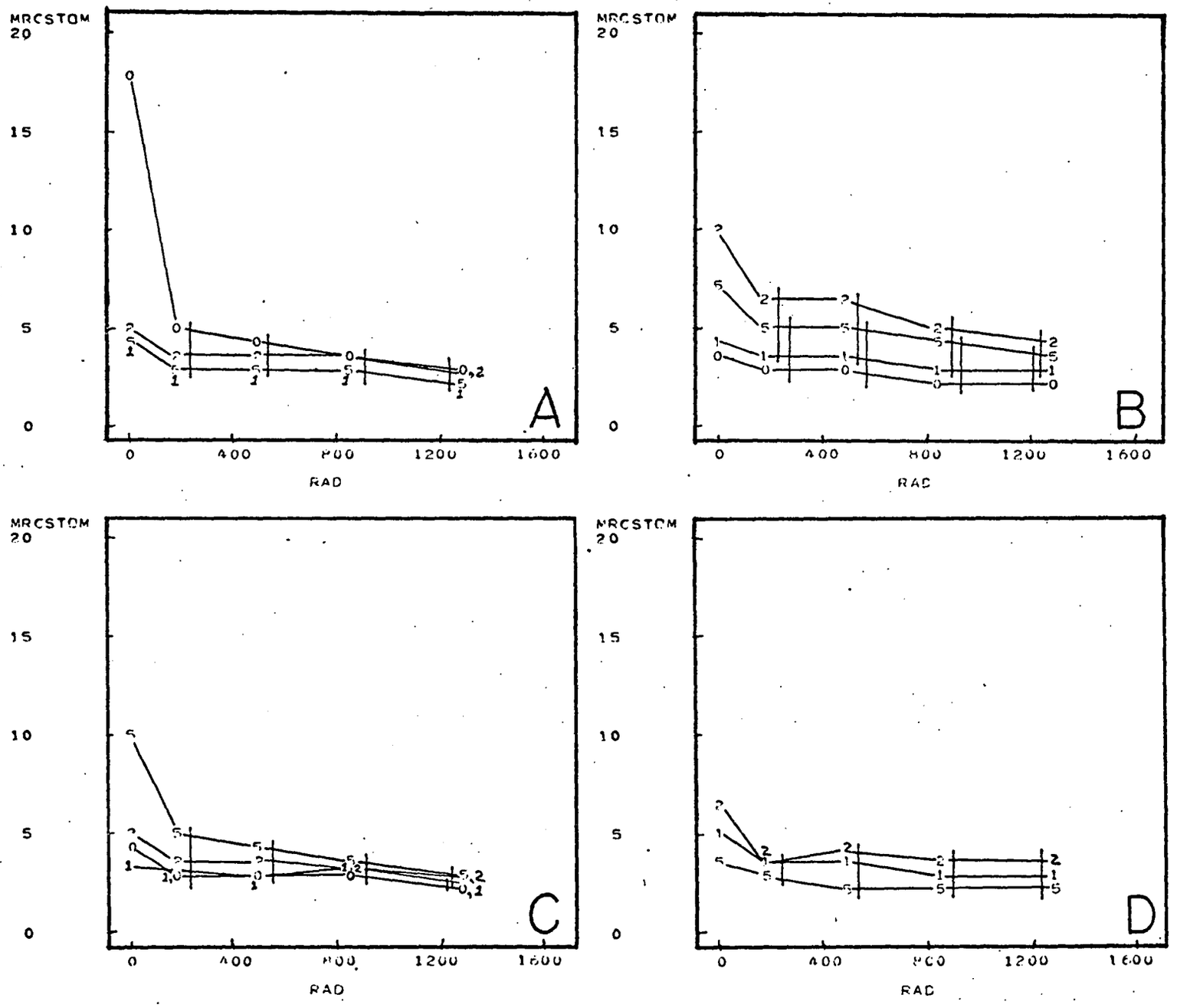

MRCSTOM
20
15
10
5
0
0
400
800
1200
1600
RAD
A
B
C
D

Figure 13. Effects of four UV-B irradiances and four PAR levels on leaf transpiration in soybeans after 49 days exposure. Plotted are the mean transpiration rates on a leaf dry weight basis (MTSW) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. MTSW is expressed in g $H_2O \cdot g^{-1} \cdot hr^{-1}$. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.

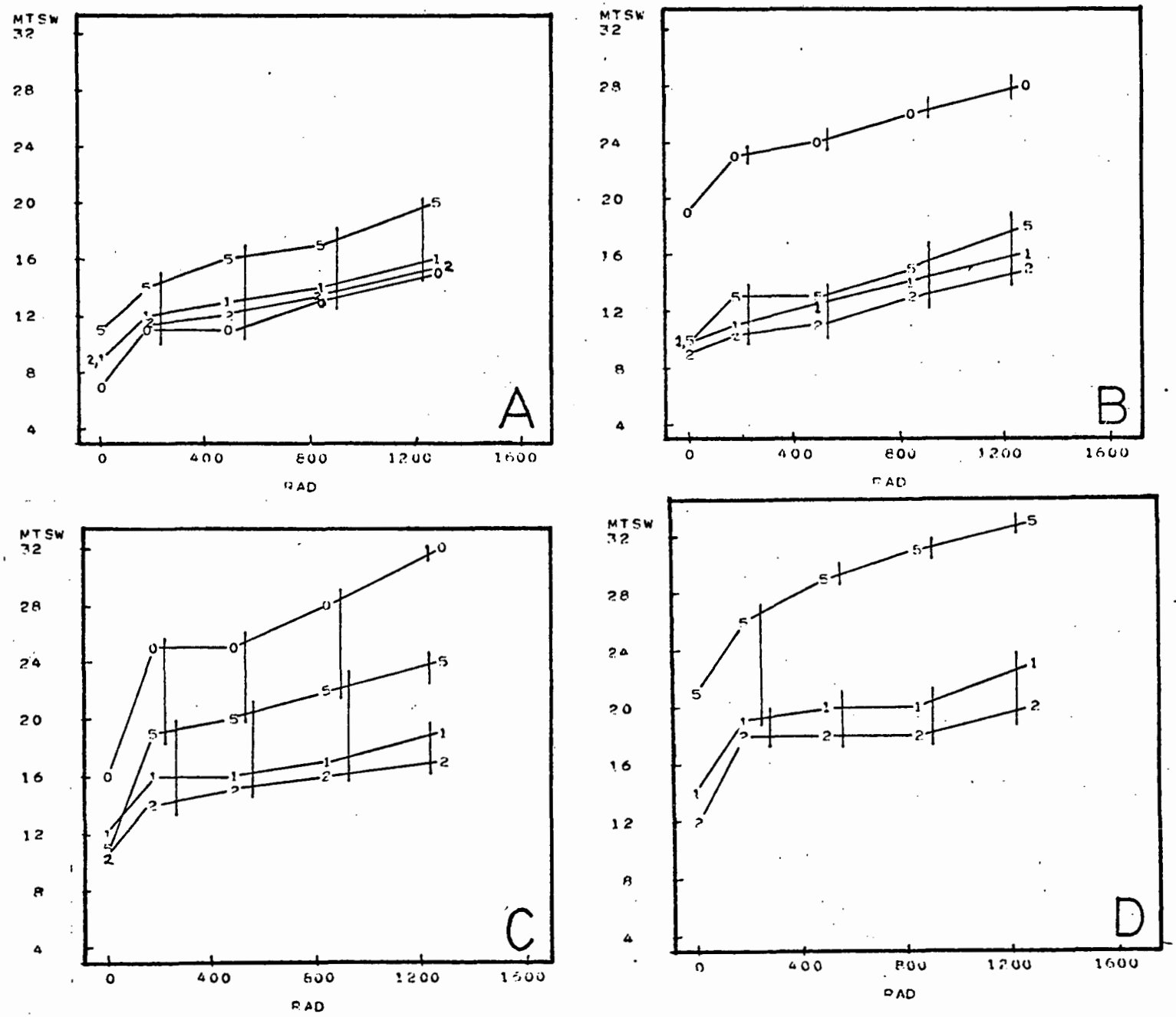

MTSW
32
28
24
20
16
12
8
4
0
400
800
1200
1600
RAD
A
B
C
D

Figure 14. Effects of four UV-B irradiances and four PAR levels on leaf transpiration in soybeans after 49 days exposure. Plotted are the mean transpiration rates on a leaf area basis (MTSA) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. MTSA is expressed in g $H_2O \cdot dm^{-2} \cdot hr^{-1}$. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, C, and D were grown under 33, 55, and 88% shade, respectively.

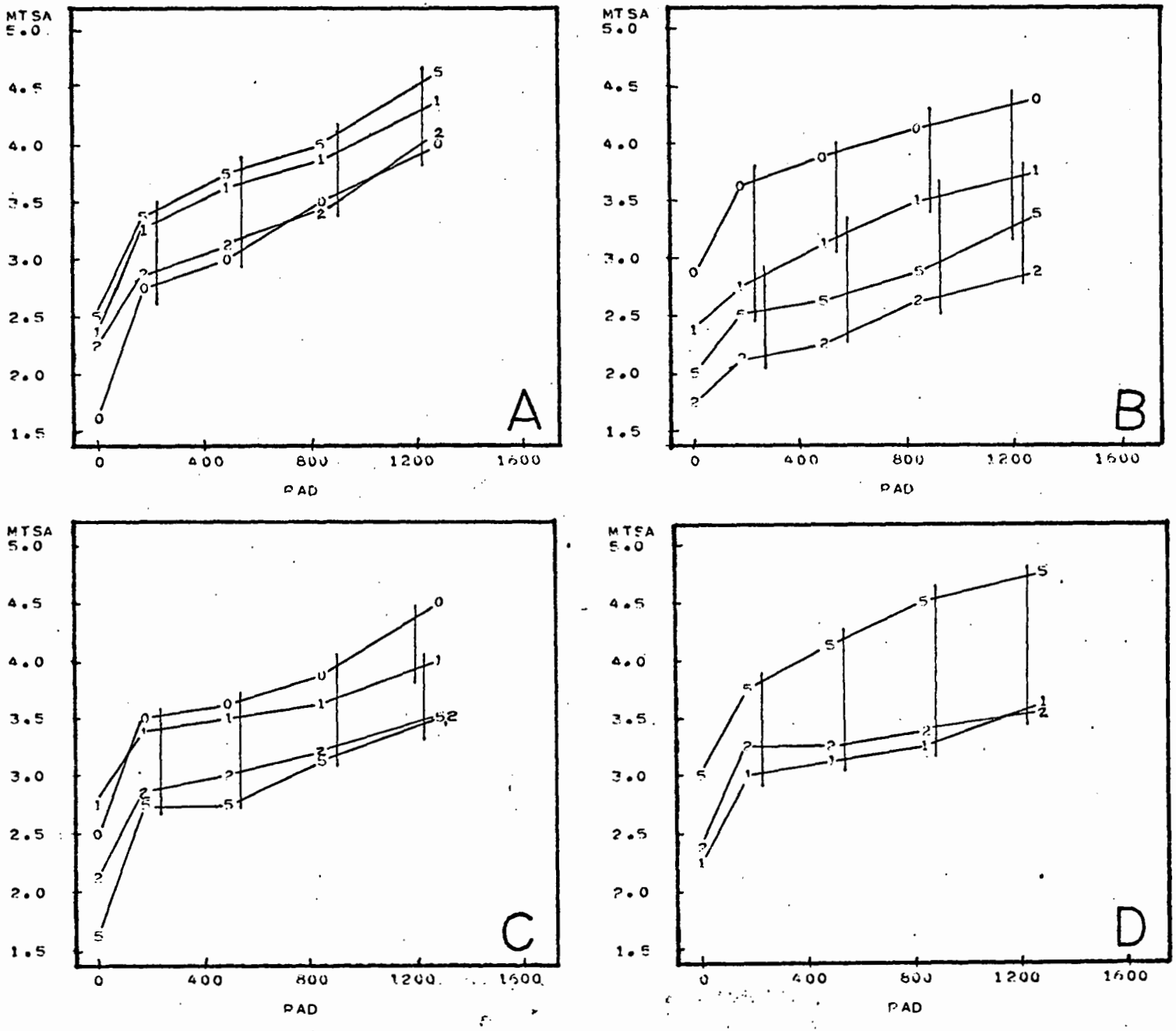
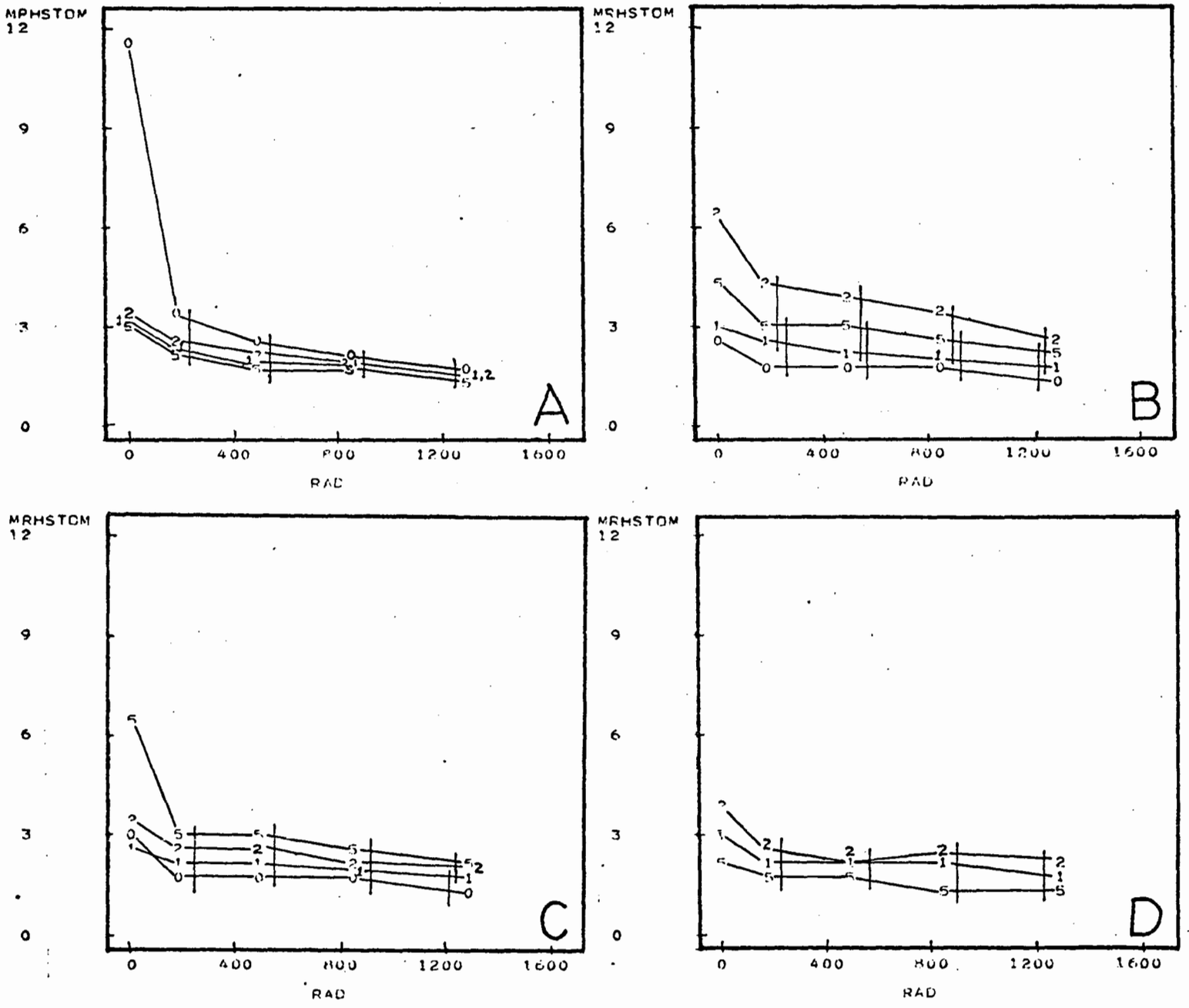

MTSA
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
0
400
800
1200
1600
PAD
A
B
C
D

Figure 15. Effects of four UV-B irradiances and four PAR levels on stomatal resistances to water vapor ($R_{H_2O}^{stomata}$) in soybeans after 49 days exposure. Plotted are the mean $R_{H_2O}^{stomata}$ in $sec \cdot cm^{-1}$ (MRHSTOM) against irradiance supplied to the leaf surface (RAD) in uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 4-5 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level. In Figure 1A plants were grown under unshaded ambient irradiances in a temperature controlled greenhouse. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Figures 1B, c, and D were grown under 33, 55, and 88% shade, respectively.


MRHSTOM
12
9
6
3
0
0
400
800
1200
1600
RAD
A
B
C
D

regimes, chlorophyll b was lower in soybean leaves exposed to UV-B than those grown under mylar. However, under reduced PAR levels, this relationship reversed. Chlorophyll a was significantly affected both by UV-B ($P < 0.01$) and PAR ($P < 0.001$). UV-B had no effect on chlorophyll a content under high PAR levels. However, when PAR was reduced, significant UV-B associated effects were produced. In 33% shade, chlorophyll a content was greatest in soybeans exposed to 2 $UV\text{-}B_{seu}$ and least when exposed to 1/2 $UV\text{-}B_{seu}$ or no UV-B treatment. Soybeans grown in 55% shade had the greatest chlorophyll a content in leaves exposed to 1 $UV\text{-}B_{seu}$ and the least in those exposed to 1/2 $UV\text{-}B_{seu}$. At the lowest PAR level, chlorophyll a was greatest in plants exposed to 1/2 or 1 $UV\text{-}B_{seu}$ and least in mylar controls.

A summary of the gas exchange measurements made in 2% O_2 are presented in Table 6. Except for plants grown in 33% shade, NCE on both a leaf area and leaf weight basis was greatest for soybeans exposed to 1/2 $UV\text{-}B_{seu}$. Soybeans grown under 55 and 88% shade levels and exposed to 1/2 $UV\text{-}B_{seu}$ resulted in significantly greater ($P < 0.05$) NCE rates than those of other UV-B treatments or the mylar controls. In full sunlight, this increase in NCE was not significant. In all three of these PAR regimes, there were no significant differences between plants exposed to 0 (mylar), 1 or 2 $UV\text{-}B_{seu}$. All UV-B exposures resulted in decreased NCE rates when soybeans were maintained in 33% shade. Increases in NCE were primarily due to decreased $R_{CO_2}^{liquid}$, but contributions also came from decreasing $R_{CO_2}^{stomata}$.

Transpiration rates followed patterns similar to those of NCE, again reflecting the stomatal contribution through diffusive resistances.

Tabel 6. Mean effects of 4 UV-B irradiances and 4 shade levels on NCE, transpiration, and the associated diffusive resistances in soybeans measured in 2% oxygen[1]. Data in parenthesis expressed as percent mylar control.

	Shade[2]															
	% = 0				% = 33				% = 55				% = 88			
$UV\text{-}B_{seu}$	0	½	1	2	0	½	1	2	0	½	1	2	0	½	1	2
NCE ($mg\ CO_2 \cdot g^{-1} \cdot hr^{-1}$)	32.77	45.46	33.54	33.67	82.80	47.14	59.64	58.12	64.58	97.44	47.14	46.64	37.73	62.40	28.10	20.65
	a	a	a	a	a	b	b	b	b	a	b	b	b	a	b	b
		(138.7)	(102.3)	(102.7)		(56.9)	(72.0)	(72.0)		(150.9)	(73.0)	(72.2)		(165.4)	(74.5)	(54.7)
NCE ($mg\ CO_2 \cdot dm^{-2} \cdot hr^{-1}$)	8.80	10.85	9.07	8.73	13.01	9.08	14.77	11.47	9.17	14.07	9.55	9.29	7.99	9.05	4.50	3.75
	a	a	a	a	ab	b	a	ab	b	a	b	b	a	a	b	b
		(123.3)	(103.1)	(99.2)		(69.9)	(113.5)	(88.2)		(153.4)	(103.9)	(101.3)		(113.3)	(56.3)	(46.9)
Transpiration ($g\ H_2O \cdot g^{-1} \cdot hr^{-1}$)	4.88	10.27	5.04	7.62	23.03	11.69	12.46	11.10	20.07	24.82	7.80	15.29	10.64	19.55	7.44	8.62
	c	a	c	b	a	b	b	b	b	a	a	c	b	a	b	b
		(210.5)	(103.3)	(156.4)		(50.8)	(54.1)	(48.2)		(123.7)	(38.9)	(76.2)		(183.6)	(70.0)	(81.0)
Transpiration ($g\ H_2O \cdot dm^{-2} \cdot hr^{-1}$)	1.30	2.46	1.37	1.98	3.62	2.42	3.06	2.19	2.86	3.57	1.58	3.04	2.23	2.85	1.19	1.56
	b	a	b	a	a	b	a	b	b	a	c	ab	ab	a	c	bc
		(189.2)	(105.4)	(152.3)		(61.9)	(84.5)	(60.5)		(124.8)	(55.2)	(106.3)		(127.8)	(53.4)	(70.0)
$R_{CO_2}^{leaf}$ ($sec \cdot cm^{-1}$)	32.57	24.87	28.99	29.44	20.03	28.87	18.00	22.61	27.98	18.57	27.10	29.65	32.45	28.64	63.36	102.38
	a	a	a	a	b	a	b	ab	a	b	a	a	b	b	ab	a
		(76.4)	(89.0)	(90.4)		(144.1)	(89.9)	(112.9)		(66.4)	(96.9)	(106.0)		(88.3)	(195.3)	(315.6)
$R_{CO_2}^{stomata}$ ($sec \cdot cm^{-1}$)	8.12	3.76	9.10	4.91	2.19	4.23	2.82	4.31	3.17	2.23	6.79	2.84	4.28	3.19	11.75	7.27
	ab	b	a	ab	b	a	b	a	b	b	a	b	b	b	a	ab
		(46.3)	(112.1)	(60.5)		(193.2)	(128.8)	(196.8)		(70.3)	(214.2)	(89.6)		(74.5)	(274.5)	(169.9)
$R_{CO_2}^{liquid}$ ($sec \cdot cm^{-1}$)	23.92	20.58	19.36	24.00	17.31	24.12	14.65	17.78	27.98	18.57	27.10	29.65	27.65	24.93	51.08	94.58
	a	a	a	a	ab	a	b	ab	a	b	a	a	b	b	b	a
		(86.0)	(80.9)	(100.3)		(168.6)	(102.4)	(124.2)		(65.1)	(81.5)	(108.2)		(90.2)	(184.8)	(342.1)
$R_{H_2O}^{stomata}$ ($sec \cdot cm^{-1}$)	5.21	2.41	5.84	3.15	1.40	2.71	1.81	2.76	2.04	1.43	4.35	1.82	2.74	2.04	7.54	4.66
	ab	b	a	ab	b	a	b	a	b	b	a	b	b	b	a	ab
		(46.3)	(112.1)	(60.5)		(192.2)	(128.4)	(195.7)		(70.1)	(213.2)	(89.2)		(74.5)	(275.2)	(170.1)
Water use efficiency ($g\ H_2O/g\ CO_2$)	161.21	234.13	146.67	225.82	282.72	254.02	214.03	193.55	315.31	261.16	164.20	340.77	279.90	315.65	254.82	593.85
	bc	a	c	ab	a	ab	ab	ab	a	a	b	a	b	b	b	a
		(145.2)	(91.0)	(140.1)		(89.8)	(75.7)	(68.4)		(82.8)	(52.1)	(108.1)		(112.8)	(91.0)	(212.1)

[1]Plants were exposed to UV-B for 49 days

[2]Expressed as percent incident irradiance shaded. Average daily maximum unshaded irradiance = 1600 $\mu Em^{-2}sec^{-1}$ PAR

Plant Growth

Soybean growth after seven weeks of treatment was affected both by PAR level and UV-B flux (Table 7). Biomass production declined linearly with decreasing PAR levels during growth. UV-B fluxes up to 1 $UV\text{-}B_{seu}$ had little affect on total plant biomass, particularly at high levels of PAR during growth. However, 2 $UV\text{-}B_{seu}$ treatments resulted in reduced total biomass accumulation at all PAR levels (Figure 16a). This trend was also reflected in biomass allocation to leaves, stems and roots (Figures 16b, c and d).

The total leaf area varied indirectly with UV-B enhancement and was a good indicator of total plant biomass production. In control soybeans approximately the same total leaf area was maintained in shade levels between 0 and 55% (Figure 17a). Total leaf area was significantly ($P < 0.05$) reduced in shade treatments below 55%. Soybeans exposed to 1/2 $UV\text{-}B_{seu}$ had leaf area reductions in PAR irradiances less than 33% shade. Greater UV-B fluxes resulted in a leaf area reductions in irradiances less than full sun. Therefore, total leaf area was more responsive to light-limiting leaf area reductions when exposed to UV-B.

When biomass was partitioned into leaves, stems and roots and expressed as a percentage of total dry weight, significant interaction terms were resolved, indicating the complex nature of these responses (Table 7). Percent leaves in soybeans grown under moderate to high levels of PAR was unaffected by UV-B fluxes up to 1 $UV\text{-}B_{seu}$ (Table 8). Below shade levels of 55%, leaves of the controls were significantly ($P < 0.05$) reduced compared with soybean exposed to UV-B radiation (Figure 17d). However, under high to moderate PAR levels, 2 $UV\text{-}B_{seu}$ resulted in a significantly ($P < 0.05$) greater leaf production. This shift in allocation patterns was most evident in soybeans

Table 7. Summary of 2 way ANOVA on the effects of 4 UV-B irradiances and 4 levels of PAR on soybean and wheat growth and biomass accumulation.

	soybean[1]						wheat[2]					
	UV-B		PAR		UV-BxPAR		UV-B		PAR		UV-Bx PAR	
	df	F	df	F	df	F	df	F	df	F	df	F
Total leaf area (cm^2)	3	4.55**	3	24.74***	9	1.92*	3	6.75***	3	90.33***	9	5.65***
Total no. leaves	3	6.10***	3	127.72***	9	14.07***	3	8.70***	3	228.79***	9	4.33***
Leaf dry wt (g)	3	2.10ns	3	37.47***	9	0.64ns	3	8.98***	3	133.66***	9	3.69***
Root dry wt (g)	3	3.57**	3	75.76***	9	0.71ns	3	39.21***	3	397.17***	9	16.63***
Stem dry wt (g)	3	3.08*	3	29.28***	9	0.74ns		--		--		--
Inflorescence dry wt (g)		--		--		--	3	111.79***	3	690.45***	9	27.37***
Specific leaf thickness (g)	3	8.09***	3	21.75***	9	13.17***	3	24.10***	3	349.25***	9	9.03***
Total dry wt biomass (g)	3	2.74*	3	40.53***	9	0.55ns	3	92.17***	3	820.90***	9	27.34***
Root-shoot ratio	3	22.65***	3	328.40***	9	11.17***	3	39.96***	3	273.53***	9	13.66***
% stems	3	18.08***	3	166.58***	9	6.16***		--		--		--
% roots	3	22.17***	3	301.31***	9	12.36***	3	45.26***	3	313.25***	9	14.43***
% leaves	3	108.08***	3	47.66***	9	23.72***	3	113.33***	3	494.90	9	27.57***
% inflorescences		--		--		--	3	34.53***	3	98.22***	9	21.65***
Index of chlorosis	3	101.82***	3	0.23ns	9	2.29ns		--		--		--
Index of wrinkling	3	90.27***	3	1.67ns	9	1.86ns		--		--		--

[1]Soybeans harvested after 50 days UV-B exposure
[2]Wheat harvested after 43 days UV-B exposure

* = significant at $P < 0.05$
** = significant at $P < 0.01$
*** = significant at $P < 0.001$
ns = not significant

Figure 16. Effects of four UV-B irradiances and four PAR levels on total plant biomass accumulation (XTOTDWT), stem dry weight (XDWSTEM), root dry weight (XDWROOT), and leaf dry weight (XDWLF) in soybeans after seven weeks. Means expressed in grams are plotted for each variable against level of shade (PAR) in which plants were grown. 0=unshaded, 3=33% shade, 5=55% shade, and 8=88% shade. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 9 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5= ½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level.

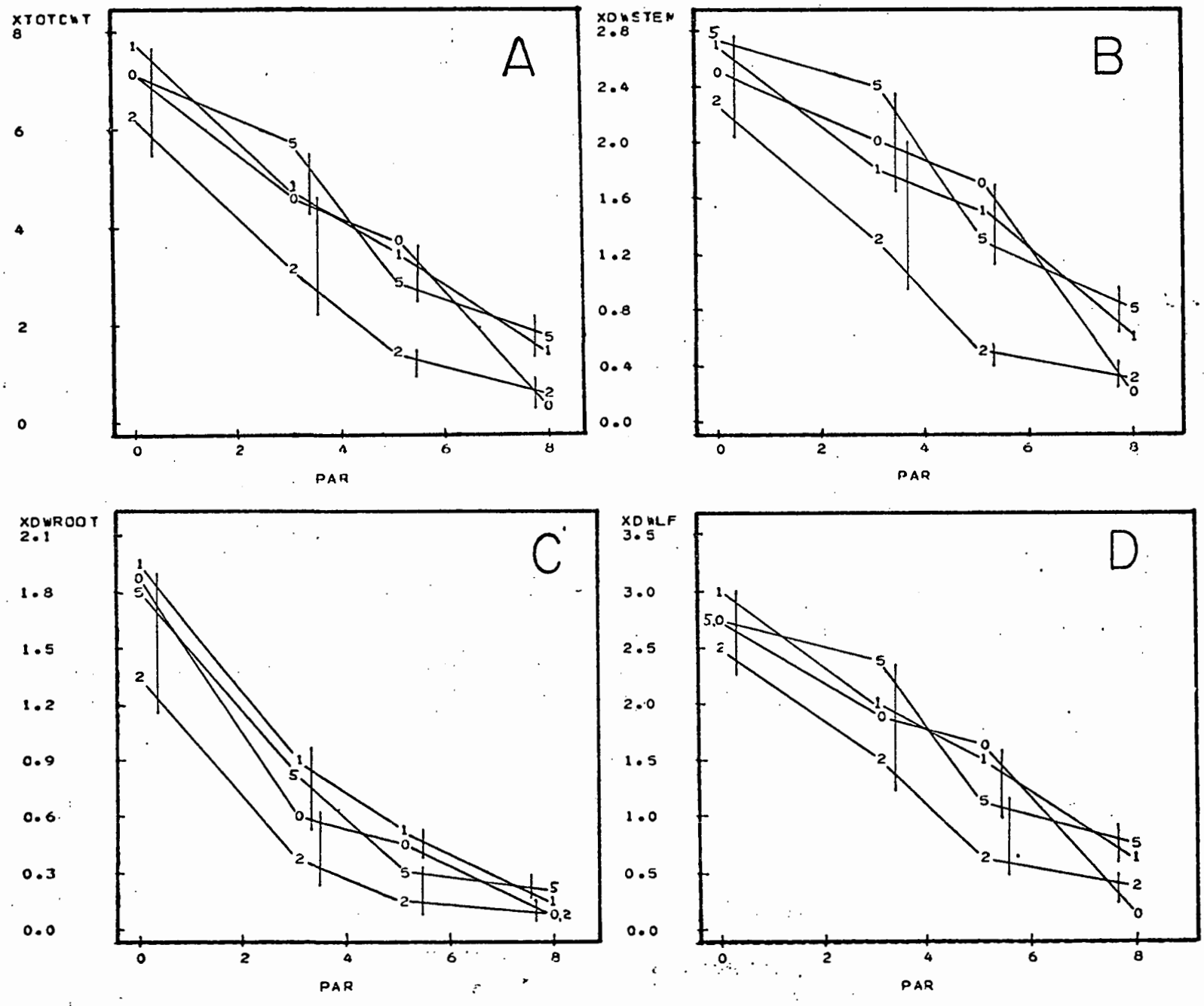

XTOTCWT
A
XDWSTEM
B
XDWROOT
C
XDWLF
D
PAR
PAR
PAR
PAR

Figure 17. Effects of four UV-B irradiances and four PAR levels on leaf areas (XLFAREA), % stems (XPCSTEM), % roots (XPCROOT), and % leaves (XPCLF) in soybeans after seven weeks. Leaf areas are expressed in cm^2. Means for each variable are plotted against level of shade (PAR) in which plants were grown. 0=unshaded, 3=33% shade, 5=55% shade, and 8=88% shade. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 9 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$; 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level.

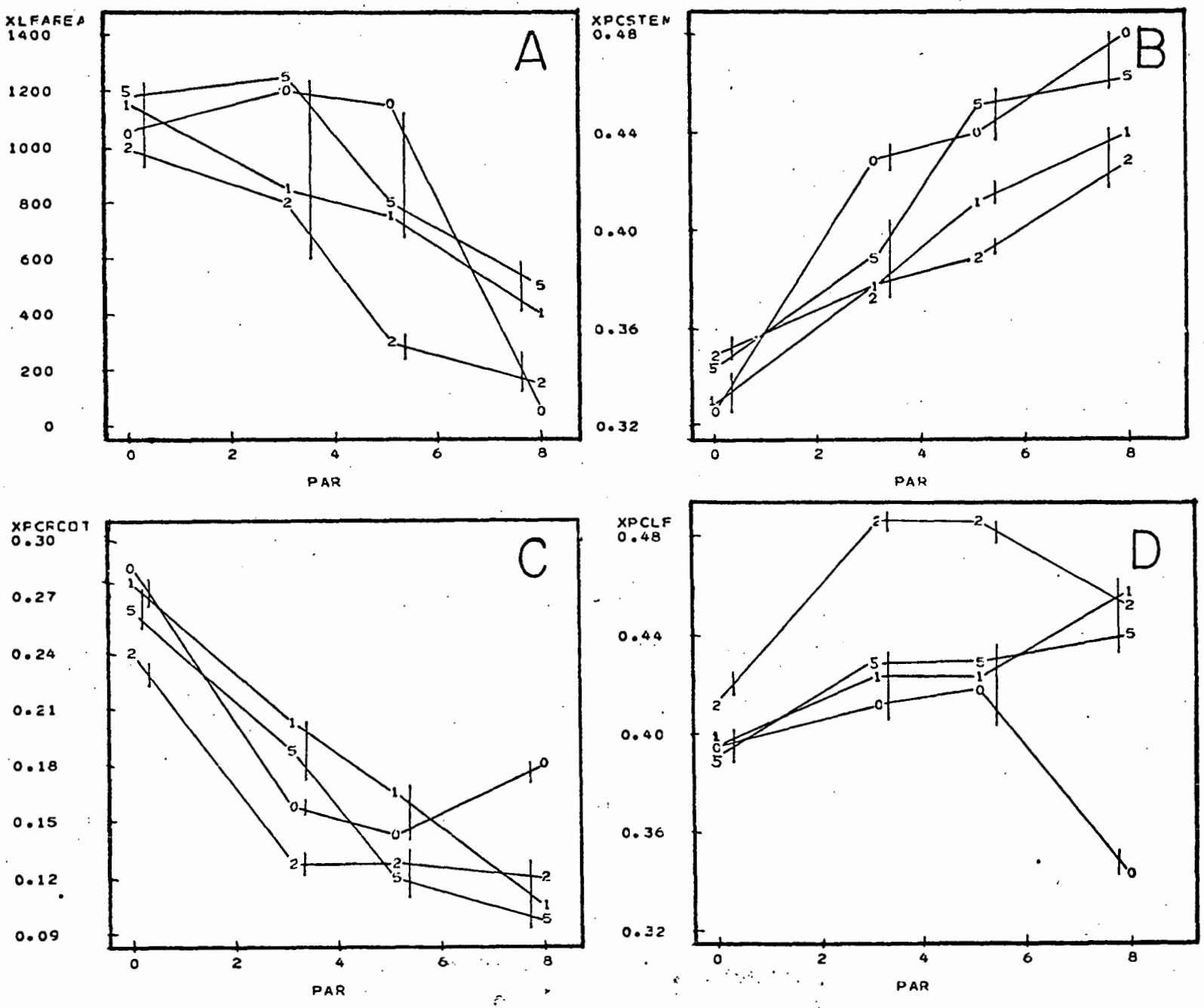

A
XLFAREA
1400
1200
1000
800
600
400
200
0
0
2
4
6
8
PAR
B
XPCSTEM
0.48
0.44
0.40
0.36
0.32
0
2
4
6
8
PAR
C
XPCRCOT
0.30
0.27
0.24
0.21
0.18
0.15
0.12
0.09
0
2
4
6
8
PAR
D
XPCLF
0.48
0.44
0.40
0.36
0.32
0
2
4
6
8
PAR

Table 8. Mean effects of 4 UV-B irradiances and 4 shade levels on soybean growth and biomass accumulation after 7 weeks of exposure.[1] Data in parenthesis are expressed as percent of mylar control.

	Shade[2]															
	% = 0				% = 33				% = 55				% = 88			
$UV\text{-}B_{seu}$	0	½	1	2	0	½	1	2	0	½	1	2	0	½	1	2
Leaf area (cm^2)	1034.22	1170.31	1146.10	997.46	1182.12	1272.3	829.0	775.75	1131.49	806.77	762.71	295.68	45.93	489.8	385.87	168.42
	a[3]	a	a	a	a	a	a	a	a	a	a	b	b	a	a	b
		(113.2)	(110.8)	(94.4)		(107.6)	(70.1)	(65.6)		(71.3)	(67.4)	(26.1)		(1066.4)	(840.1)	(366.7)
Total no. leaves	20.5	19.75	21.25	19.5	20.0	20.75	17.75	23.5	19.25	18.0	20.25	13.25	7.75	13.25	15.0	10.25
	a	a	a	a	b	b	c	a	ab	b	a	c	b	a	a	b
		(96.3)	(103.7)	(95.1)		(103.8)	(88.8)	(117.5)		(93.5)	(105.2)	(68.8)		(171.0)	(193.5)	(132.3)
Leaf dry wt (g)	2.81	2.78	3.04	2.50	1.86	2.42	1.91	1.54	1.60	1.18	1.48	0.62	0.12	0.72	0.64	0.31
	a	a	a	a	a	a	a	a	a	ab	a	b	b	a	a	b
		(98.9)	(108.2)	(89.0)		(130.1)	(102.7)	(82.8)		(73.8)	(92.5)	(38.8)		(600.0)	(533.3)	(258.3)
Root dry wt (g)	1.91	1.77	1.97	1.37	0.62	0.91	0.93	0.38	0.45	0.28	0.51	0.14	0.06	0.16	0.14	0.08
	a	a	a	a	ab	a	a	b	a	b	a	b	b	a	a	b
		(92.7)	(103.1)	(71.7)		(146.8)	(150.0)	(61.3)		(62.2)	(113.3)	(31.1)		(266.7)	(233.3)	(133.3)
Stem dry wt (g)	2.45	2.69	2.67	2.32	2.02	2.39	1.79	1.26	1.68	1.28	1.47	0.54	0.16	0.76	0.62	0.29
	a	a	a	a	ab	a	ab	b	a	a	a	b	b	a	a	b
		(109.8)	(109.0)	(94.7)		(118.3)	(88.6)	(62.4)		(76.2)	(87.5)	(32.1)		(475.0)	(387.5)	(181.3)
Specific leaf thickness (gdm^{-2})	.00275	.00234	.00255	.00236	.00157	.00186	.00214	.00202	.00141	.00149	.00183	.00222	.00333	.00148	.00171	.00189
	a	c	b	c	c	b	a	a	c	c	b	a	a	b	b	b
		(85.1)	(92.7)	(85.8)		(118.5)	(136.3)	(128.7)		(105.7)	(129.8)	(157.4)		(44.4)	(51.4)	(56.8)
Total dry wt biomass (g)	7.18	7.24	7.68	6.20	4.49	5.72	4.63	3.19	3.74	2.74	3.46	1.30	0.34	1.64	1.40	0.68
	a	a	a	a	ab	a	ab	b	a	a	a	b	b	a	a	b
		(100.8)	(107.0)	(86.4)		(127.4)	(103.1)	(71.0)		(73.3)	(92.5)	(34.8)		(482.4)	(411.8)	(200.0)
Root-Shoot ratio	0.39	0.36	0.39	0.31	0.19	0.23	0.25	0.15	0.17	0.14	0.20	0.14	0.22	0.11	0.11	0.14
	a	b	ab	c	b	a	a	c	ab	b	a	b	a	b	b	b
		(92.3)	(100.0)	(79.5)		(121.1)	(131.6)	(78.9)		(82.4)	(117.6)	(82.4)		(50.0)	(50.0)	(63.6)
% Stem	32.4	34.6	32.7	35.1	42.8	39.1	37.5	37.6	43.99	45.2	41.1	38.7	47.74	46.2	44.1	42.8
	b	ab	b	a	a	b	b	b	a	a	b	c	a	a	b	b
		(106.8)	(100.9)	(108.3)		(91.4)	(87.6)	(87.9)		(102.8)	(93.4)	(88.0)		(96.8)	(92.4)	(89.7)
% Root	28.2	26.1	27.7	23.8	15.8	18.5	20.2	13.0	14.47	12.1	16.3	12.6	17.94	10.0	10.2	12.0
	a	b	ab	c	b	a	a	c	ab	b	a	b	a	b	b	b
		(92.6)	(98.2)	(84.4)		(117.1)	(127.8)	(82.3)		(83.6)	(112.6)	(87.1)		(55.7)	(56.9)	(66.9)
% Leaf	39.4	39.2	39.6	41.1	41.3	42.5	42.2	49.4	41.54	42.6	42.6	48.7	34.31	43.8	45.7	45.2
	b	b	b	a	b	b	b	a	b	b	b	a	b	a	a	a
		(99.5)	(100.5)	(104.3)		(102.9)	(102.2)	(119.6)		(102.6)	(102.6)	(117.2)		(127.7)	(133.2)	(131.7)
Index of Chlorosis[4]	0.11	1.44	5.13	4.67	0.11	1.06	5.33	4.00	0	0	4.00	6.39	0	1.00	4.33	4.89
	b	b	a	a	b	b	a	a	c	c	b	a	b	b	a	a
		(14.4)	(51.3)	(46.7)		(10.6)	(53.3)	(40.0)		(0)	(40.0)	(63.9)		(10.0)	(43.3)	(48.9)
Index of wrinkling[4]	1.11	1.44	3.38	4.00	1.06	1.19	4.28	5.11	0	0.78	4.17	6.11	0	0.78	3.44	4.78
	b	b	a	a	b	b	a	a	c	c	b	a	c	c	b	a
		(14.4)	(33.8)	(40.0)		(11.9)	(42.8)	(51.1)		(7.8)	(41.7)	(61.1)		(7.8)	(34.4)	(47.8)

[1] Harvest after 50 days UV-B exposure
[2] Expressed as percent incident radiation shaded. Mean daily unshaded maximum = 1600 $\mu Em^{-2}sec^{-1}$ PAR
[3] Values in rows under each level of shade with the same letter are not significantly different at the 95% level
[4] Mean index value with maximum range between 0 and 9

grown under shade levels between 33 and 55% where nearly 50% of the total biomass was found in leaves compared with 40% in the mylar controls. At the lowest PAR level, all three UV-B treatments resulted in a significantly ($P < 0.05$) greater allocation to leaf production.

In high to moderate PAR levels, 2 $UV\text{-}B_{seu}$ resulted in a reduction in the proportion of dry weight allocated to roots as compared to the controls (Figure 17c). A greater proportion of dry weight accumulated in roots of soybeans exposed to moderate PAR levels and up to the 1 $UV\text{-}B_{seu}$ treatment. This shift in allocation was at the expense of stems rather than leaves. However, under lower PAR levels, all three UV-B treatments resulted in a reduced root biomass when compared with controls.

Biomass accumulation in stems responded somewhat differently from leaves and roots (Figure 17b). Only under full sunlight did UV-B treatment result in an increase in allocation to stem dry weight. Under all other reduced PAR levels, UV-B treatment resulted in a reduction in stem tissue dry weight. Therefore, under high PAR levels and 2 $UV\text{-}B_{seu}$ exposure, biomass was reduced in roots and allocated to stems and leaves. In moderate PAR levels, more biomass was allocated from stems to leaves. Under the lowest PAR level, biomass from stems and roots both were allocated to leaves.

These biomass allocation patterns were also reflected in root-shoot ratios (Table 8). In high to moderate PAR regimes, up to 1 $UV\text{-}B_{seu}$ had little effect. However, 2 $UV\text{-}B_{seu}$ treatments resulted in a significant ($P < 0.05$) reduction in the root-shoot ratios. In moderate PAR levels and low UV-B fluxes, more dry weight was allocated to roots than shoots. However, when soybeans were grown in low PAR levels any exposure to UV-B resulted in a considerable reduction in the root-shoot ratios compared with the mylar control.

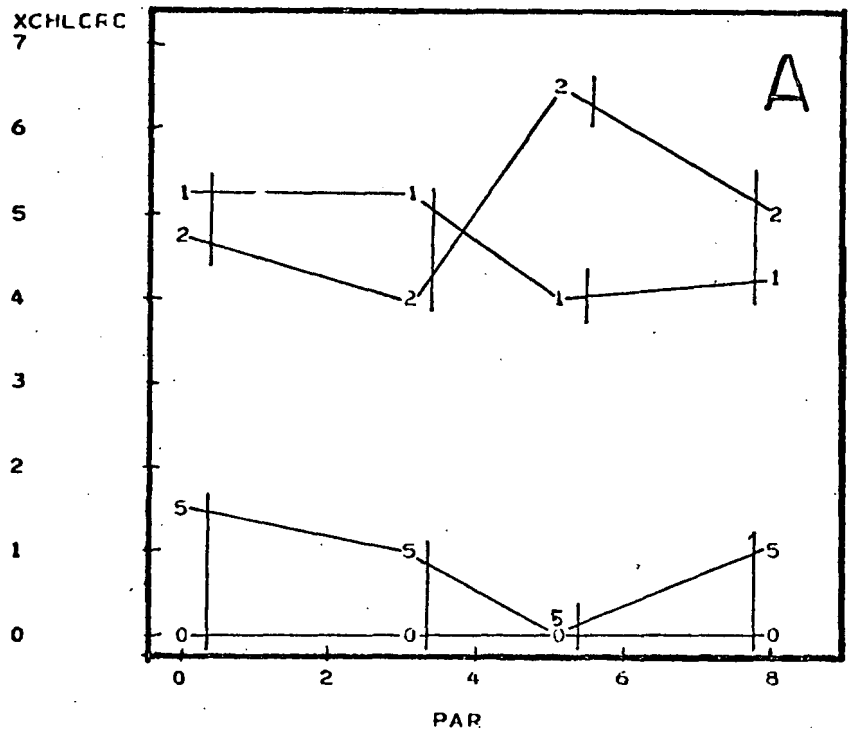
Two index values, leaf chlorosis and leaf interveinal wrinkling were used to visually assess the UV-B flux-related damage. Both of these indices were independent of PAR, and directly related to UV-B flux (Table 8). As shown in Figures 18a and b, these indices were good indicators of the amount of UV-B received by soybeans regardless of PAR level. These figures also indicated that soybean sensitivity to UV-B greatly increased between 1/2 and 1 $UV\text{-}B_{seu}$ exposure, possibly suggesting a threshold effect.

The effects of UV-B on soybean growth in terms of plant height are shown in Table 9. With the exception of week 4, soybeans maintained a greater growth rate in full sunlight when exposed to some level of UV-B. In this high PAR regime, however, there were no consistent differences between UV-B fluxes. As PAR levels were reduced to 33 and 55% of incident radiation, simultaneous exposure to UV-B resulted in a reduction in growth rates. In general, the amount of reduction was directly related to the UV-B flux. When PAR was further reduced to 88% shade, soybeans again maintained higher growth rates when exposed to UV-B.

As presented in Table 7 the responses of wheat to a combination of 4 UV-B flux levels and 4 PAR levels was much more complex than that of soybean. All of the growth variables examined were associated with highly significant ($P < 0.001$) interactions between UV-B irradiance and PAR. Effects on wheat growth as indicated by biomass accumulation after six weeks exposure, are shown in Figure 19A. The greatest UV-B associated biomass differences were found in the high irradiance (unshaded PAR regimes). These differences diminished as PAR was reduced, but were still evident in wheat grown in 88% shade.

Wheat exposed to 1 $UV\text{-}B_{seu}$ accumulated a significantly ($P < 0.05$) greater dry weight biomass in all 4 PAR regimes (Table 10). In the control wheat

Figure 18. Effects of four UV-B irradiances and four PAR levels on indices of leaf chlorosis (XCHLORO) and interveinal wrinkling (XWRINK) in soybean after seven weeks. Indices range from 0 to 9 (see Table 2) and are plotted against level of shade (PAR) in which plants were grown. 0=unshaded, 3=33% shade, 5=55% shade, and 8=88% shade. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 9 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level.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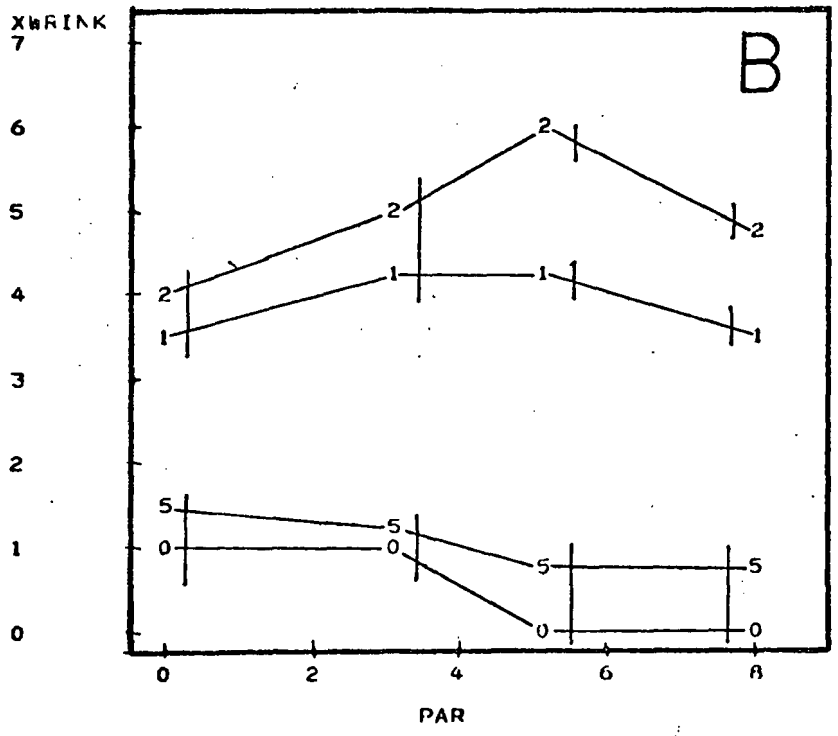
XWRINK
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5
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B
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PAR

Table 9. Mean effects of 4 UV-B irradiances and 4 shade levels on soybean and wheat growth rates. Data in parenthesis are expressed as percent mylar control.

	Shade[1]															
	% = 0				% = 33				% = 55				% = 88			
UV-B seu	0	½	1	2	0	½	1	2	0	½	1	2	0	½	1	2
Soybean growth (mm·day^{-1})	6.34	8.08	8.16	11.49	31.49	22.29	17.11	16.74	36.40	35.62	24.59	15.74	4.56	31.48	26.42	21.68
	c[2]	b	b	a	a	b	c	c	a	a	b	c	c	a	ab	b
Week 2		(127)	(129)	(181)		(71)	(54)	(53)		(98)	(68)	(43)		(690)	(579)	(475)
	3.83	5.70	4.88	6.52	28.48	18.52	10.95	13.80	27.72	24.23	16.20	9.99	1.77	20.07	16.53	10.48
	b	ab	ab	b	a	b	c	bc	a	a	b	b	c	a	ab	b
Week 3		(149)	(127)	(170)		(65)	(38)	(48)		(87)	(58)	(36)		(1134)	(934)	(592)
	24.73	23.36	18.55	22.54	44.34	24.04	31.98	29.31	50.62	39.71	34.59	21.86	0.09	47.55	31.07	16.82
	a	a	a	a	a	a	a	a	a	a	ab	b	c	a	ab	cb
Week 4		(94)	(75)	(91)		(54)	(72)	(66)		(78)	(68)	(43)		(52833)	(34522)	(18689)
	4.34	23.46	16.61	20.71	59.11	49.82	26.43	22.04	42.14	40.45	31.07	24.75	6.68	20.82	33.96	16.50
	b	a	a	a	a	a	b	b	a	a	a	a	b	ab	a	ab
Week 5		(541)	(383)	(477)		(84)	(45)	(37)		(96)	(74)	(59)		(312)	(508)	(247)
	14.77	26.05	18.77	24.31	44.55	48.30	29.12	16.91	50.80	51.18	17.34	26.14	15.14	41.02	17.57	6.18
	b	ab	a	a	a	a	ab	b	a	a	a	a	a	a	a	a
Week 6		(176)	(127)	(165)		(108)	(66)	(36)		(101)	(34)	(51)		(271)	(116)	(41)
Wheat growth (mm·day^{-1})	6.45	4.47	6.57	7.25	6.04	5.86	7.09	6.61	5.27	8.11	6.32	5.71	5.38	8.97	7.20	7.81
	a	b	a	a	a	a	a	a	b	a	ab	b	b	a	ab	ab
Week 2		(69)	(102)	(112)		(97)	(117)	(109)		(154)	(120)	(108)		(167)	(134)	(145)
	7.07	9.04	9.19	6.95	5.51	7.16	7.88	8.77	7.09	3.83	8.20	0.17	0.81	0.98	0.26	0.58
	a	a	a	a	b	ab	ab	a	a	b	a	c	a	a	a	a
Week 3		(128)	(130)	(98)		(130)	(143)	(160)		(54)	(116)	(2)		(121)	(32)	(72)
	20.98	23.96	22.12	21.76	20.86	18.60	20.06	16.58	15.14	19.82	12.60	15.36	0.49	7.13	9.62	3.23
	b	a	ab	ab	a	a	a	a	a	a	a	a	c	ab	a	bc
Week 4		(114)	(105)	(104)		(89)	(96)	(80)		(131)	(83)	(101)		(14455)	(1963)	(659)
	8.64	10.32	8.23	9.96	12.12	13.69	9.46	12.79	12.07	9.74	18.52	10.36	7.62	12.57	10.01	7.94
	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
Week 5		(119)	(95)	(115)		(113)	(78)	(106)		(81)	(153)	(86)		(165)	(131)	(104)

[1]Expressed as percent incident irradiance shaded. Mean daily maximum unshaded irradiance = 1600 $\mu Em^{-2}aec^{-1}$ PAR

[2]Values in rows under each shade level with the same letter are not significantly different at the 95% level.

Table 10. Mean effects of 4 UV-B irradiances and 4 shade levels on wheat biomass accumulation after 6 weeks exposure.[1] Data in parenthesis expressed as percent of mylar control.

	Shade[2]							
	% = 0				% = 33			
UV-B seu	0	½	1	2	0	½	1	2
Leaf area (cm^2)	233.46 ab[3]	206.38 b (88.40)	283.88 a (121.60)	232.44 ab (99.56)	151.06 b	230.13 c (152.34)	227.2 a (150.40)	238.16 a (157.66)
Total leaves	45.3 a	37.8 b (83.66)	45.1 a (99.56)	37.2 b (82.12)	23.7 c	27.1 b (114.35)	30.8 a (129.96)	28.2 b (118.99)
Root dry wt (g)	1.25 a	0.72 b (57.60)	1.17 a (93.60)	0.65 b (52.00)	0.16 c	0.28 b (175.00)	0.52 a (325.00)	0.27 b (168.75)
Leaf dry wt (g)	2.81 ab	1.98 c (70.46)	3.01 a (107.12)	2.20 bc (78.29)	0.97 c	1.45 b (149.48)	1.85 a (190.72)	1.55 ab (159.79)
Inflorescence dry wt (g)	0.52 ab	0.25 b (48.08)	0.61 a (117.31)	0.39 ab (75.00)	0.08 b	0.18 b (225.00)	0.30 a (375.00)	0.18 b (225.00)
Total dry wt (g)	4.57 a	2.94 b (64.33)	4.78 a (104.60)	3.24 b (70.90)	1.22 c	1.91 b (156.56)	2.67 a (218.85)	2.00 b (163.93)
Specific leaf thickness ($g \cdot cm^{-2}$)	0.0113 a	0.0090 c (79.65)	0.0101 b (89.38)	0.0089 c (78.76)	0.0061 b	0.0062 b (101.64)	0.0078 a (127.87)	0.0063 b (103.28)
Root-shoot ratio	0.479 a	0.390 bc (81.42)	0.411 ab (85.80)	0.322 b (67.22)	0.193 b	0.208 b (107.77)	0.306 a (158.55)	0.192 b (99.48)
% yellow leaves	70.83 a	52.05 b (73.49)	70.54 a (99.59)	72.03 a (101.69)	39.68 b	58.49 a (147.40)	59.91 a (150.98)	58.01 a (146.19)
% inflorescence	6.98 a	4.78 a (68.48)	7.42 a (106.30)	7.42 a (106.30)	4.69 a	6.37 a (135.82)	7.35 a (156.72)	5.96 a (127.08)
% root	31.49 a	27.17 bc (86.31)	28.46 ab (90.41)	23.69 c (75.25)	15.76 b	16.81 b (106.66)	22.22 a (140.99)	15.71 b (99.68)
% leaf	61.54 c	68.05 a (110.58)	64.12 b (104.19)	68.89 a (111.94)	79.55 a	76.82 b (96.57)	70.43 c (88.54)	78.33 ab (98.47)

[1] Harvested after 43 days of exposure
[2] Expressed as percent incident radiation shaded. Mean daily unshaded maximum = 1600uEm^{-2}sec^{-1} PAR
[3] Values in rows under each level of shade followed by the same letter are not significantly different at the 95% level

Table 10. Mean effects of 4 UV-B irradiances and 4 shade levels on wheat biomass accumulation after 6 weeks exposure.[1] Data in parenthesis expressed as percent of mylar control.
cont.

	Shade[2]							
	% = 55				% = 88			
UV-B seu	0	½	1	2	0	½	1	2
Leaf area (cm^2)	195.46 a	157.68 b (80.67)	174.1 ab (89.07)	113.35 c (57.99)	54.52 c	105.23 a (193.01)	115.04 a (211.01)	77.52 b (142.19)
Total leaves	25.6 a	24.3 a (94.92)	25.0 a (97.66)	24.4 a (95.31)	18.2 b	18.9 ab (103.85)	21.9 a (120.33)	17.78 b (97.69)
Root dry wt (g)	0.22 a	0.18 bc (81.82)	.36 a (163.64)	.13 c (59.09)	0.08 b	0.11 a (137.50)	0.11 a (137.50)	.07 b (87.50)
Leaf dry wt (g)	1.17 ab	0.97 b (82.91)	1.31 a (111.97)	0.71 c (60.68)	0.27 b	0.52 a (192.59)	0.55 a (203.70)	.33 b (122.22)
Inflorescence dry wt (g)	0.11 b	0.08 bc (72.73)	.20 a (181.82)	.02 c (18.19)	0 c	0 a --	0 a --	0 a --
Total dry wt (g)	1.50 b	1.23 b (82.00)	1.87 a (124.67)	0.86 c (57.33)	0.36 b	.622 a (172.78)	0.66 a (183.33)	.40 b (111.11)
Specific leaf thickness ($g \cdot cm^{-2}$)	0.0059 b	0.0059 b (100.00)	0.0070 a (118.64)	0.0061 b (103.39)	0.0055 a	0.0048 b (87.27)	0.0048 b (87.27)	0.0042 c (76.36)
Root-shoot ratio	0.204 b	0.220 b (107.84)	0.292 a (143.14)	0.222 b (108.82)	0.366 ab	0.266 b (72.68)	0.216 b (59.02)	0.504 a (137.70)
% yellow leaves	40.84 b	43.29 b (106.00)	41.51 b (101.64)	68.33 a (167.31)	67.67 a	34.61 b (51.15)	41.96 b (62.01)	41.82 b (61.80)
% inflorescense	4.79 a	4.30 a (89.77)	6.43 a (134.24)	1.70 b (35.49)	0 a --	0 a --	0 a --	0 a --
% root	16.56 b	17.38 b (104.95)	22.00 a (132.85)	17.53 b (105.86)	25.70 a	20.30 b (78.99)	17.40 b (67.70)	26.20 a (101.95)
% leaf	78.65 b	78.31 b (99.57)	71.57 c (91.00)	80.77 a (102.70)	74.30 b	79.70 a (107.27)	82.60 a (111.17)	73.80 b (99.33)

[1]Harvested after 43 days of exposure
[2]Expressed as percent incident radiation shaded. Mean daily unshaded maximum = 16$\mu Em^{-2}sec^{-1}$ PAR
[3]Values in rows under each level of shade followed by the same letter are not significantly different at the 95% level

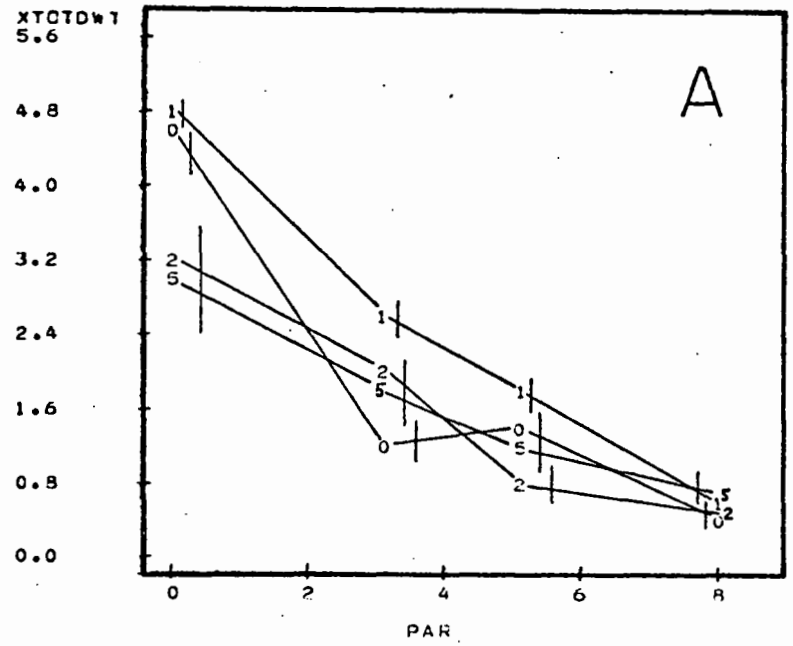
(mylar) nearly all the biomass reduction occurred between the unshaded and 33% shade treatments. Biomass remained constant in PAR levels below 33% shade. However, in wheat exposed to UV-B, dry weight reduction was nearly linear with decreases in PAR. Similar trends were noted for dry weight accumulation into leaves, roots and inflorescences (Figures 19B, C and D).

The difference in dry weight accumulation between UV-B treatments was reflected in the total leaf number and, to a lesser extent, the total leaf area (Figures 20A and B). Where significant, both total number of leaves and leaf area were greatest when plants were exposed to 1 $UV\text{-}B_{seu}$. In these plants, the proportion of total biomass allocated to leaves increased as the PAR level incident during growth was reduced (Figure 21A). When wheat was unshaded and grown under 1 $UV\text{-}B_{seu}$, leaves accounted for 62% of the total dry weight. However, when grown in 88% shade, 82% of the total biomass was allocated to leaves. Wheat exposed to 1/2 $UV\text{-}B_{seu}$ also increased allocation to leaves as PAR was reduced, however, at a lower rate. Wheat grown both under the mylar and 2 $UV\text{-}B_{seu}$ resulted in maximum biomass allocation to leaves in intermediate PAR levels. Under 88% shade, percent leaves declined under these UV-B conditions.

Wheat exposed to 1 $UV\text{-}B_{seu}$ and PAR levels between unshaded and 55% shade resulted in a significant ($P < 0.05$) reduction in the percent total biomass allocated to leaves compared with the mylar control and the other UV-B treatments. However, at PAR levels below this, these plants maintained a larger portion of biomass in leaves.

Dry weight accumulation into roots was very different from that of leaves (Figure 21B). More dry weight was partitioned into roots at high and very low PAR regimes when plants were exposed to 1/2 and 2 $UV\text{-}B_{seu}$ or when grown under mylar. Under these conditions, roots accounted for 20 to

Figure 19. Effects of four UV-B irradiances and four PAR levels on total plant dry weight (XTOTDWT), leaf dry weight (XDWLF), root dry weight (XDWROOT), and inflorescence dry weight (XDWFL) in wheat after six weeks. Means expressed in grams are plotted for each variable against level of shade (PAR) in which plants were grown. 0=unshaded, 3=33% shade, 5=55% shade, and 8=88% shade. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 9 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level.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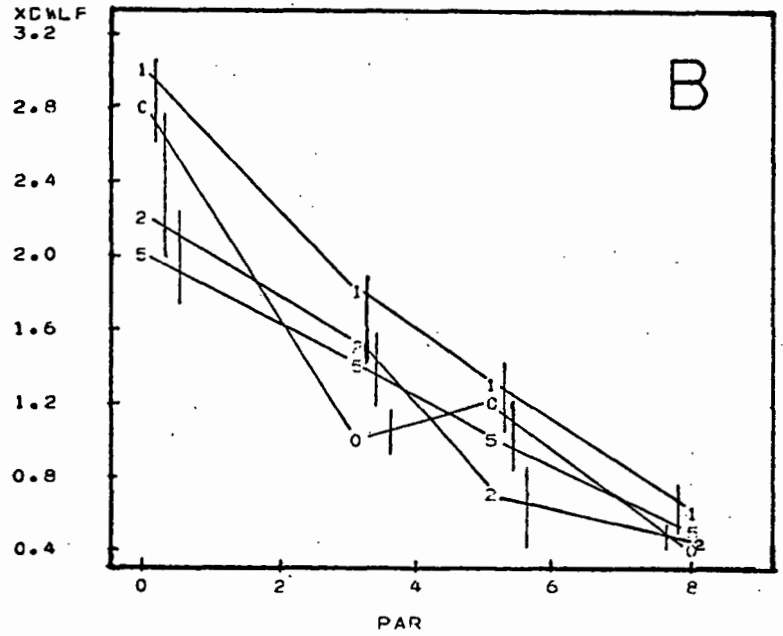
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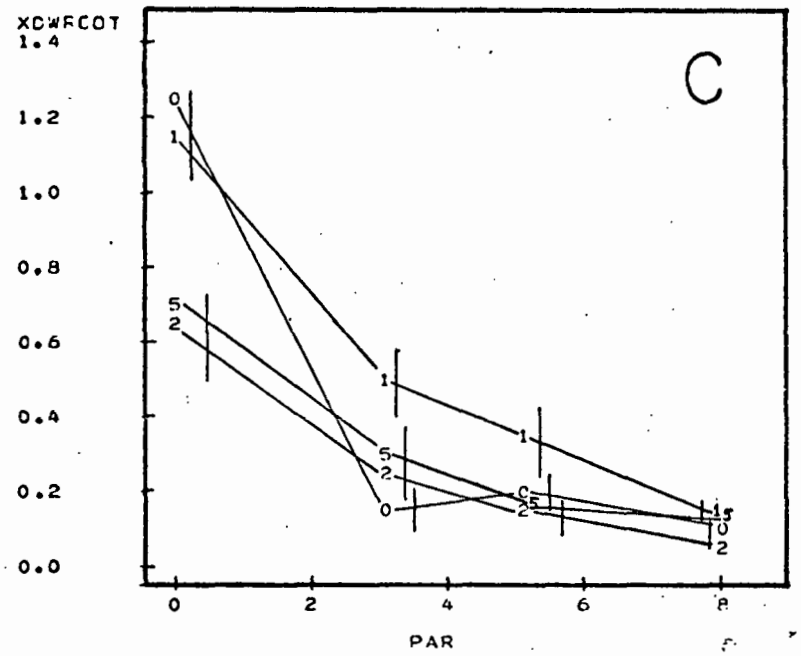
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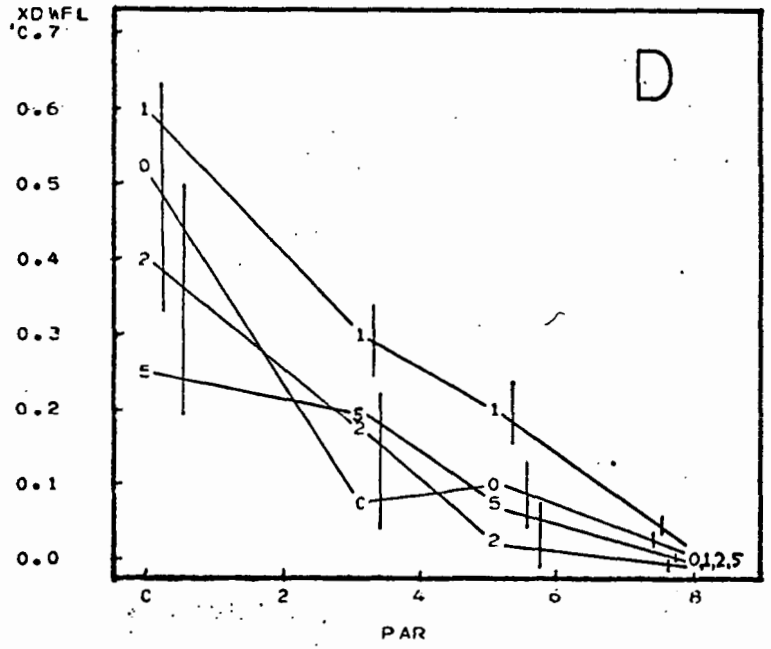
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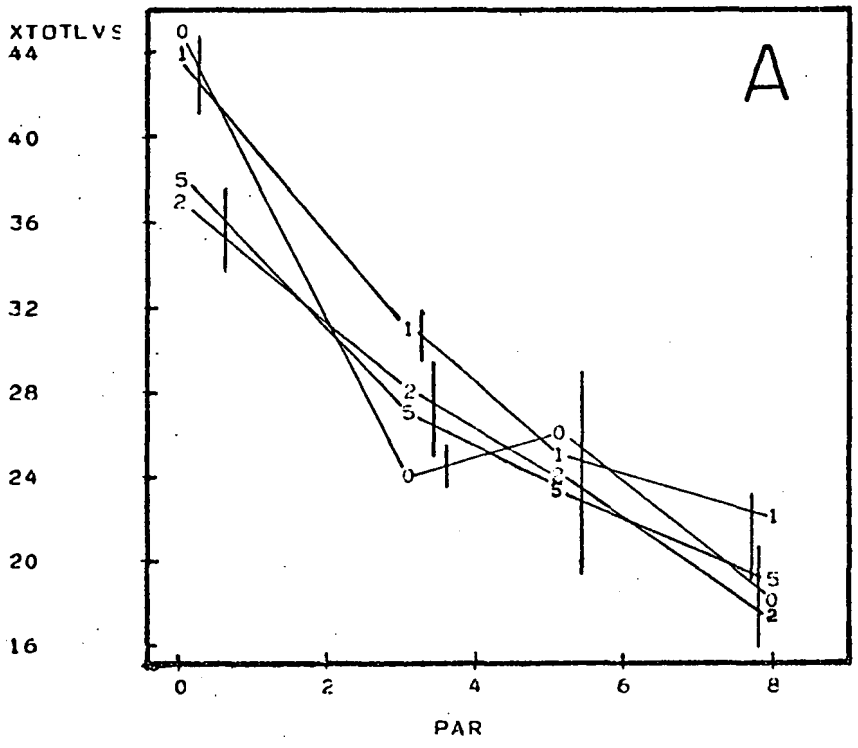
6
8

Figure 20. Effects of four UV-B irradiances and four PAR levels on total leaf production or number (XTOTLVS) and total leaf area (XLFAREA) in wheat after six weeks. Leaf areas are expressed in cm^2. Means for each variable are plotted against level of shade (PAR) in which plants were grown. 0=unshaded, 3=33% shade, 5=55% shade, and 8=88% shade. Average maximum daily unshaded irradiance=1600 uE $m^{-2}sec^{-1}$ PAR. Each mean is based on 9 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level.


XTOTLVS
44
40
36
32
28
24
20
16
A
0
1
5
2
0
1
2
5
0
1
2
5
1
5
0
2
0
2
4
6
8
PAR

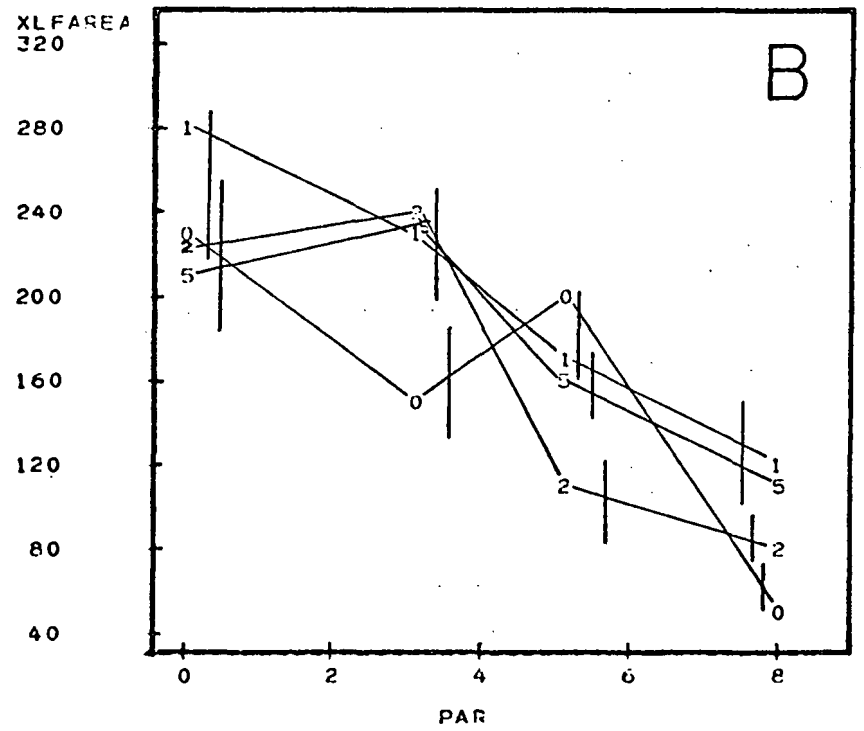
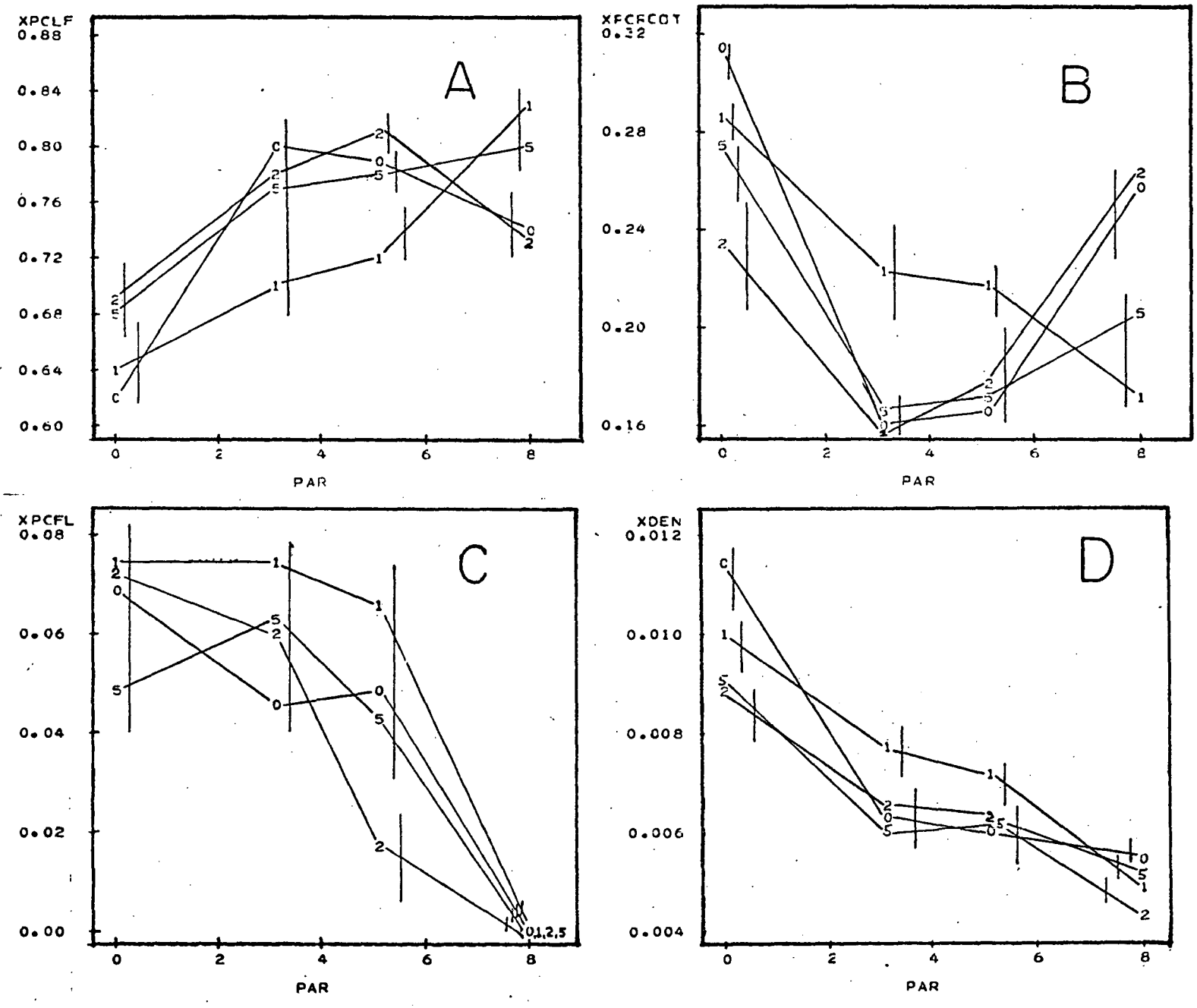

XLFAREA
320
280
240
200
160
120
80
40
B
1
0
2
5
3
1
0
1
5
2
1
5
2
0
0
2
4
6
8
PAR

Figure 21. Effects of four UV-B irradiances and four PAR levels on % leaves (XPCLF), % roots (XPCROOT), % inflorescences (XPCFL), and specific leaf thickness (XDEN) in wheat after six weeks. Specific leaf thickness is expressed in $g \cdot cm^{-2}$. Means for each variable are plotted against level of shade (PAR) in which plants were grown. 0=unshaded, 3=33% shade, 5=55% shade, and 8=88% shade. Average maximum daily unshaded irradiance=1600 $uE\ m^{-2}sec^{-1}$ PAR. Each mean is based on 9 observations. Numbers in each curve represent UV-B irradiances. 0=mylar control, 5=½ $UV\text{-}B_{seu}$, 1=1 $UV\text{-}B_{seu}$, 2=2 $UV\text{-}B_{seu}$. Vertical bars connect curves that are not significantly different at the 95% level.


A
XPCLF
0.88
0.84
0.80
0.76
0.72
0.68
0.64
0.60
0 2 4 6 8
PAR
B
XFCRCOT
0.32
0.28
0.24
0.20
0.16
0 2 4 6 8
PAR
C
XPCFL
0.08
0.06
0.04
0.02
0.00
0,1,2,5
0 2 4 6 8
PAR
D
XDEN
0.012
0.010
0.008
0.006
0.004
0 2 4 6 8
PAR

30% of the total dry weight. However, under intermediate PAR levels, only about 16% of the total dry weight was found in roots. Wheat plants exposed to 1 $UV\text{-}B_{seu}$ again resulted in very different responses. In these plants, percent roots declined linearly with decreasing PAR.

Percent flowers (or reproductive effort) varied inversely with PAR level and was light limited in 88% shade (Figure 21C). The percent total dry weight allocated to flowers was greatest in wheat plants exposed to 1 $UV\text{-}B_{seu}$ irradiance at all PAR levels, although not significantly so. At low PAR levels, wheat grown under 2 $UV\text{-}B_{seu}$ resulted in a significantly ($P < 0.05$) reduced reproductive effort.

Specific leaf thickness was significantly ($P < 0.05$) greater for control wheat leaves compared to leaves exposed to UV-B radiation when grown under unshaded conditions (Figure 21D). In shade levels greater than 33% shade, leaf thickness in control plants were unaffected by further PAR reductions. Specific leaf thickness was greater in wheat plants exposed to 1 $UV\text{-}B_{seu}$ compared to 1/2 and 2 $UV\text{-}B_{seu}$ exposures throughout the PAR range employed.

The effects of UV-B on wheat growth are presented on Table 9. Unlike soybean, there were no consistent UV-B associated effects on wheat growth rates among or between PAR levels.

Discussion

Gas Exchange Data

The growth of 'Hardee' soybeans in a combination of 4 flux levels of UV-B radiation and 4 PAR flux levels demonstrated the importance of plant interactions as related to UV-B and to longer wavelength radiation. When soybeans were exposed to UV-B and grown under unshaded (high PAR) levels,

there was no UV-B associated reduction in NCE. However, as the PAR level was reduced, increasing UV-B enhancements did result in significant NCE reductions. In shaded conditions, NCE varied inversely with UV-B flux.

This reduction in NCE was primarily due to increased non-stomatal resistances, $R_{CO_2}^{liquid}$, particularly at reduced PAR levels. Therefore the effect of UV-B must act on some other component of the photosynthetic apparatus, besides resistances to stomatal diffusion. Previous evidence indicates that UV radiation exposure results in an inhibition of photosystem II (PSII) and to a lesser extent photosystem I (PSI) (Brandle et al., 1977; Okada et al., 1976; Mantai et al., 1970; and Zill and Tolbert, 1958). This may be associated with UV-B induced disruption of the structural integrity of the lamellar membrane systems in the chloroplasts (Brandle et al., 1977; Campbell, 1975; Mantai et al., 1970). In the present study, total leaf protein was not affected by UV-B treatment. However, total chlorophyll and chlorophyll a/b ratios were generally greater in soybean plants exposed to 1 $UV\text{-}B_{seu}$.

Both proteins and nucleic acids are major chromatophores for UV-B induced damage in biological systems. The most important biological effect of UV-B to DNA is the formation of the pyrimidine dimer. UV-B induced dimerization can be reversed by a mechanism called photoreactivation. This repair mechanism restores normal cellular functions and is dependant upon the action of photoreactivating enzymes and radiation of longer wavelength (315-550 nm). Evidence indicates that a large number of other physiological manifestations, including UV-B associated reductions in NCE, are also photorepairable (Sisson and Caldwell, 1976; Van et al., 1976; Cline et al., 1969; Tanada and Hendricks, 1953). The data presented here tended to support this hypothesis. Under high PAR levels, photorepair of NCE was nearly complete for the range of UV-B fluxes tested. However, as light became more limiting both to NCE

and photorepair, the effectiveness of this repair mechanism diminished. This resulted in a decrease in NCE at reduced PAR levels by UV-B fluxes which were ineffective at higher PAR levels.

These findings were somewhat different from those reported by Sisson and Caldwell (1976) where Rumex patientia was grown under ambient PAR levels in the field (maximum PAR was 2100 $\mu E\ m^{-2}\ sec^{-1}$) and 800 and 400 $\mu E\ m^{-2}\ sec^{-1}$ in controlled environmental chambers. Large differences in NCE were noted in all three of these PAR regimes when compared with controls. However, in that particular study, the UV-B enhancement corresponded to an ozone depletion of 38%. The equivalent ozone depletion used in this study ranged between 6 and 25%. Therefore under low PAR growth conditions, the deleterious effects of UV-B radiation were magnified by the decreasing effectiveness of photorepair, possibly photoreactivation. After exposure to more intense UV-B fluxes, photorepair mechanisms were insufficient to prevent damage.

Sisson and Caldwell (1977) extrapolating from their Rumex-based model, reported that even small UV-B fluxes result in NCE reductions over time due to reciprocity. In the present study during the first few weeks of exposure of soybeans to 1/2 $UV\text{-}B_{seu}$ and high PAR levels, NCE rates were enhanced compared with controls. This increase was primarily associated with reduced stomatal resistances, $R_{CO_2}^{stomata}$. The nature of this response is not well understood, and disappeared by the 6th week of exposure. However, it seemed to suggest that very low UV-B background fluxes may be beneficial during the early stages of development, possibly while the plant is still not totally independent from cotyledonary reserves. Additionally, it illustrated that low UV-B fluxes affected stomatal as well as non-stomatal resistances.

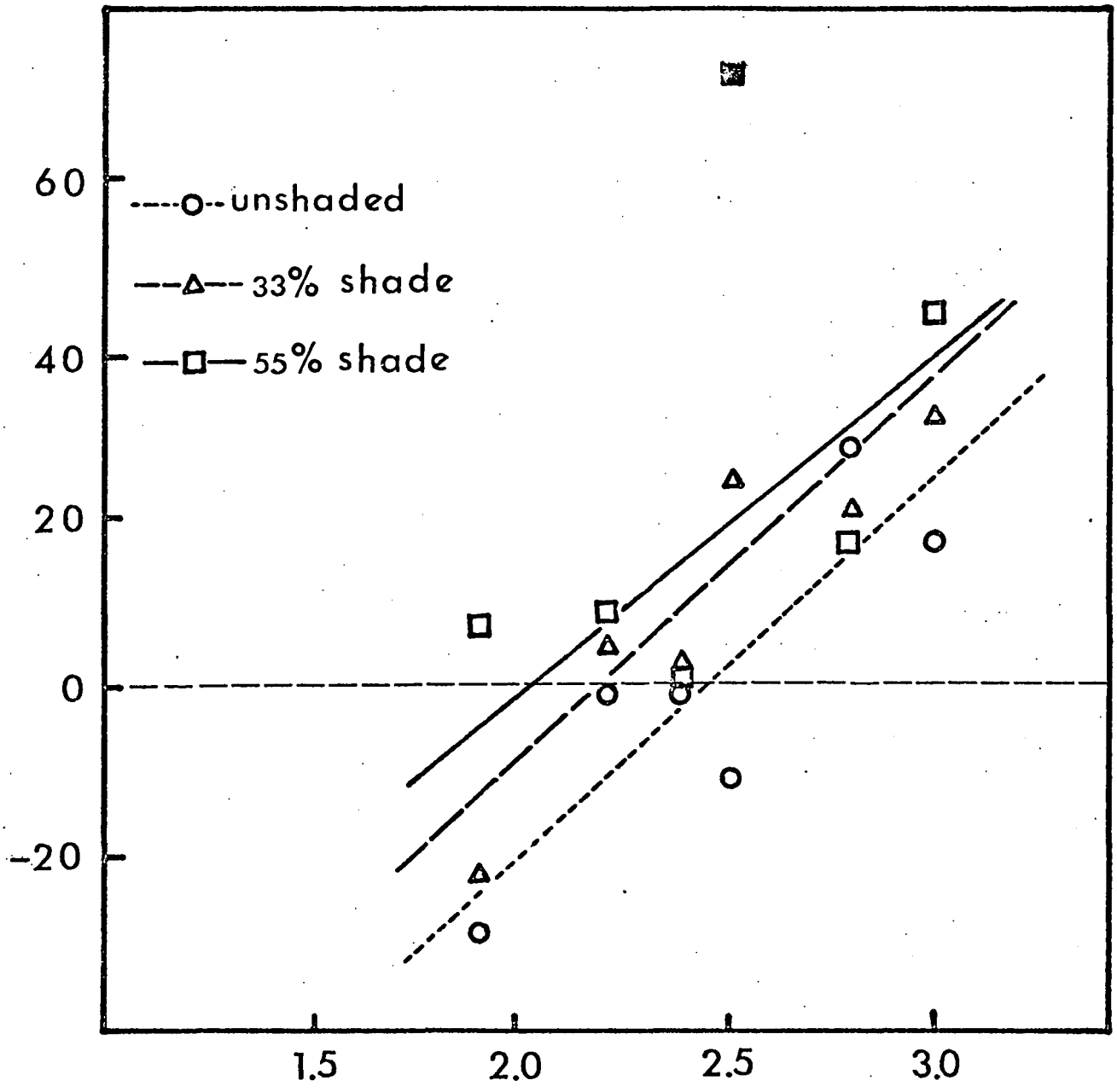
The concepts of threshold effects and reciprocity (Sisson and Caldwell, 1977) were supported by comparisons of the gas exchange data after two and six

weeks. Significant interactions between UV-B radiation and PAR were observed in NCE, transpiration, and the associated diffusive resistances after two weeks of treatment. However, after six weeks of UV-B radiation exposure, nearly all these interactions disappeared, indicating that soybean response to the combination of UV-B and simultaneous PAR treatment had been altered. This indicated that soybeans became more responsive to UV-B radiation after a threshold accumulation. This was supported by comparisons of NCE rates expressed as a percent of control after two and six weeks of UV-B radiation exposure (Figure 22). In general, relative NCE reductions were greater after six weeks exposure. These reductions in NCE were primarily associated with increased non-stomatal resistances. The effects of leaf age were not tested, and may have contributed toward increased leaf resistance.

The data (Figure 22) further indicated that reciprocity occurred at a reduced rate under reduced PAR levels. Similar UV-B associated reductions in NCE required a greater UV-B accumulation in full sunlight than in 33 or 55% shade. This was thought to be attributed to photorepair at high PAR irradiances. In PAR fluxes below these threshold levels, UV-B exposure may enhance NCE.

Two indices, interveinal leaf wrinkling and leaf chlorosis, also suggested threshold effects. Up to 1/2 $UV\text{-}B_{seu}$ had no affect on the visual assessment of either symptom of UV-B radiation-related damage. However, exposure to 1 or 2 $UV\text{-}B_{seu}$ greatly affected both indices. Although the precise nature of these morphological responses might be quite complex, they were independent of PAR, suggesting that they were not photorepairable. Interveinal wrinkling and leaf chlorosis were observed only when leaves were exposed to UV-B radiation during early leaf expansion. Fully expanded leaves exposed to very large UV-B fluxes (up to 4 $UV\text{-}B_{seu}$) did not show either manifestation (unpublished data). This could indicate that interveinal wrinkling might be

Figure 22. Effects of UV-B accumulation on NCE (leaf dry weight basis) in soybeans exposed to three different shade levels. Log UV-B accumulation in Wm^{-2} are plotted along the ordinate against percent change in NCE from the control. Data includes measurements made after 2 weeks (Table 4) and 6 weeks (Table 5). Dashed horizontal line indicates no change from control. Values below line indicate NCE enhancements, above it NCE reductions.


60
40
20
0
-20
unshaded
33% shade
55% shade
1.5
2.0
2.5
3.0

the result of UV-B effects on cell division or expansion early in leaf development.

Campbell (1975) found that chloroplasts appeared to be the first organelle to show injury responses when soybean leaves were irradiated with UV-B radiation. He added that much of the UV-B associated injury was similar to that found in the final stages of leaf aging. Since leaf chlorosis only appeared in leaves which had expanded in the presence of a UV-B flux, and not in fully expanded mature leaves, these data indicated that UV-B might be interfering with normal proplastid differentiation, rather than an acceleration of leaf senescence.

Transpiration was also affected by the range of UV-B radiation exposures used. After two weeks exposure, transpiration rates reflected differences in stomatal resistances, with the highest rates measured in soybeans grown under 1/2 $UV\text{-}B_{seu}$ which also showed NCE enhancement at this time. Both 1 and 2 $UV\text{-}B_{seu}$ treatments resulted in decreased transpiration rates. After a 6 week exposure to UV-B, transpiration rates declined as UV-B fluxes increased.

As reported by others, dark respiration rates were unaffected by UV-B even after 6 weeks of exposure. It was not clear whether this was due to complete photorepair of dark respiration even at low PAR irradiances or if dark respiration was simply unaffected by the UV-B fluxes employed. Sisson and Caldwell (1976) did report increased respiration rates in Rumex after only a few days of exposure. However, that study incorporated a much higher UV-B flux (equivalent to a 38% ozone depletion) and relatively low PAR levels ($800\ \mu E\ m^{-2}\ sec^{-1}$).

Comparisons were made of the NCE data for leaves measured in 2 and 21% O_2 after 6 weeks of UV-B radiation accumulation. The relative rankings of NCE for plants exposed to contrasting UV-B fluxes differed in 2% O_2 from responses measured in the same leaves at 21% O_2. This suggests that photorespiration

might be affected by UV-B radiation. However, NCE measured in low O_2 concentrations as an estimate of photorespiration relies on many assumptions (see Ludlow and Jarvis, 1971) and therefore interpretations must be viewed with caution. Other studies are underway to further elucidate the response of photorespiration to UV-B.

Plant Growth Data

Plant responses to the combination of UV-B and PAR irradiances differed between soybean, a UV-B sensitive (Van et al., 1976; Biggs et al., 1975) and wheat, a UV-B resistant species (Hart et al., 1975). In soybeans, total plant dry weight was unaffected by UV-B irradiances up to 1 $UV\text{-}B_{seu}$. However, exposure to 2 $UV\text{-}B_{seu}$ greatly reduced dry weight accumulation. This finding was consistent with the gas exchange data. UV-B also resulted in shifts in the total plant biomass allocation pattern. The nature of the shifts was dependant upon the PAR level incident during growth. In general, exposure to UV-B radiation resulted in a greater proportion of biomass accumulated in leaves rather than stems and roots. Therefore, the primary inhibitory effects of UV-B radiation (vis. NCE reductions) were somewhat compensated by the relative increase in leaf surface area available for photosynthesis. This was demonstrated both in terms of the total plant biomass accumulation and total leaf area production. Under 88% shade, biomass and total leaf area of soybeans in both the 2 $UV\text{-}B_{seu}$ regime and the mylar control were less than those in the 1/2 and 1 $UV\text{-}B_{seu}$ treatments.

Reduction of NCE by 2 $UV\text{-}B_{seu}$ was partially compensated by increased leaf area, thereby resulting in a total plant biomass accumulation similar to that of control soybeans. The increased leaf area in the soybeans exposed to 1/2 and 1 $UV\text{-}B_{seu}$ "over-compensated" for the reduction in NCE, and

therefore resulted in a greater dry weight accumulation compared to controls.

Under full sunlight, UV-B exposure resulted in stem elongation, as reflected in increases in plant height. However, under shaded conditions stunting associated with UV-B flux was observed.

At low irradiances, wheat growth in terms of dry weight accumulation was nearly unaffected by UV-B exposure. However, as PAR was increased, UV-B radiation became an increasingly important factor to the overall plant response. After a six week exposure to 1 $UV\text{-}B_{seu}$, biomass accumulation was greater than that of the mylar control, particularly at intermediate PAR levels. One-half $UV\text{-}B_{seu}$ exposure became increasingly important at lower PAR levels. At the lowest PAR irradiance, both 1/2 and 1 $UV\text{-}B_{seu}$ resulted in a significant increase in biomass accumulation compared with wheat grown under mylar or 2 $UV\text{-}B_{seu}$. These data suggested that in conditions where growth was light-limited, the addition of ambient levels of UV-B radiation to the spectral flux might result in a stimulatory effect on wheat growth.

Under the conditions of this experiment, 1 $UV\text{-}B_{seu}$ resulted in a pattern of biomass allocations that was distinct from other UV-B treatments or from the mylar control. This was consistent over a wide range of PAR levels. Therefore, the effects of UV-B radiation on wheat were flux density-specific and resulted in large shifts in carbon allocation as measured by dry matter accumulation. One of the factors involved was increased tillering in wheat exposed to UV-B radiation. These data indicated that tillering was greatest in wheat grown under 1 $UV\text{-}B_{seu}$ and in high to moderate PAR levels. As PAR was further reduced, tillering became more pronounced in wheat grown under 1/2 $UV\text{-}B_{seu}$.

In conclusion we have shown that even low level UV-B enhancements (equivalent to only a 6% depletion in stratospheric ozone) had a direct

effect on NCE. NCE was enhanced by low UV-B fluxes when accumulated below a minimum or threshold level. Above this level, NCE reductions occurred. Larger UV-B fluxes were associated with greater reductions. Both stomatal and non-stomatal diffusive resistances were affected by UV-B radiation. Stomatal effects were also reflected in transpiration rates.

Photorepair of NCE was ineffective at low PAR levels, but played an important role in unshaded, ambient situations. In high PAR regimes, photorepair was nearly complete in soybeans exposed to fluxes up to 2 $UV\text{-}B_{seu}$. Additionally, our study revealed that the interactions between the flux densities of UV-B and PAR are complex, and that soybean response to increasing UV-B fluxes was altered by the flux density of incident radiation available for photorepair and other photoprotective mechanisms. These differences might be partly due to modifications within leaves in response to decreasing PAR levels. Bunce et al. (1977) found that soybean leaves were associated with large physiological and anatomical shifts during light acclimation. If these observations are generally applicable, then interpretations of growth chamber or greenhouse studies regarding the effectiveness of moderate UV-B enhancements in natural situations must be viewed with caution.

Of all the plant growth and gas exchange variables examined, only two, indices for interveinal wrinkling and leaf chlorosis were unaffected by PAR. Fluxes greater than 1 $UV\text{-}B_{seu}$ had a large affect on both indices, even in unshaded plants, suggesting that these responses were not photorepairable. Therefore, both were good indicators of UV-B accumulation, even under a wide range of PAR levels.

Finally, this study indicated that wheat responds differently from soybean when exposed to increasing UV-B fluxes. Soybeans underwent shifts in carbon allocation patterns when exposed to UV-B radiation. The magnitude

of these shifts was directly related to the UV-B flux density. Two $UV\text{-}B_{seu}$ resulted in increased allocation to leaves at the expense of all other plant organs. Wheat on the other hand, demonstrated unique biomass allocation patterns when exposed to 1 $UV\text{-}B_{seu}$, indicating more of a flux density-specific response. In shaded conditions, UV-B fluxes above or below this resulted in little change from control. However, in unshaded conditions, these fluxes resulted in biomass reductions.

The greatest biomass differences between UV-B fluxes occurred in moderately shaded conditions for soybeans and in full sunlight for wheat. Therefore, PAR levels incident in greenhouse or growth chambers would provide maximum sensitivity for soybeans, but minimum sensitivity for wheat. This could lead to spurious interpretations of the effects of UV-B radiation on wheat. This again underlines the importance of the interaction between UV-B and PAR in understanding plant responses.

Color photographs taken of the UV-B x PAR experiment are included in Appendix I. The experimental set-up illustrating the use of neutral density shading materials to obtain the desired PAR levels is shown in I-35. Mylar film separate treatments to minimize any UV-B scatter. I-37 shows the positioning of the experimental plant material beneath a light fixture containing 2 FS 40 sunlamps. Plastic films of either mylar or 3 mil cellulose acetate were used to filter the radiation to the desired spectral quality and flux.

Representative soybean plants from each treatment are shown in I-38 after 6 weeks UV-B exposure. Notice that controls (mylar) were shorter than plants exposed to UV-B in unshaded (100% full sun) conditions, but that they were tallest in reduced PAR levels. I-39 illustrates treatment effects on wheat. Under 45% full sun (55% shade) only plants which received 2 $UV\text{-}B_{seu}$ did not flower. Note in the two highest PAR levels, plants exposed to 1 $UV\text{-}B_{seu}$ had the greatest tillering. Under lower PAR levels, greater tillering was found in plants exposed to 1/2 $UV\text{-}B_{seu}$.

Color photographs illustrating leaf chlorosis are presented in I-35. The leaf labelled 100 mylar was given an index value of 0 (see Table 2 in text). 100% 0.5 showed some chlorotic patches and was rated 1. 100% 1 showed much more developed chlorosis (rated index value=5). 100% 2 illustrated a leaf which was entirely chlorotic and leaf margins had begun to curl (index values=8). Interveinal wrinkling is illustrated in I-36. Both 67% .5 and 45% 0.5 showed slight puckering and were rated index value=1. 45% 1 showed definite puckering and was rated as 4. 67% 1.0 illustrated pronounced wrinkling and leaf curl (index value=9) along with leaf chlorosis. 67% 2 showed bronzing on the leaf surface, which usually was associated with leaf chlorosis.

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EFFECT OF ULTRAVIOLET-B ENHANCEMENT ON CUTICLE AND EPIDERMAL CELL DEVELOPMENT

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Materials and Methods

Plant Material

Plants were grown under a high UV light source with mylar, 3 mil or 5 mil cellulose acetate film filters. Tomato and pepper plants were grown from seed and blueberry leaves were taken from new shoots grown under the filtered light sources. One set of tomato and pepper plants were grown under the light conditions from July 28 through August 29 or 32 days. Another group of tomato and pepper plants were grown from September 13 through November 7.

Electron microscopy. For transmission electron microscopy (TEM), small sections of young unfolded, newly expanded and mature blueberry, tomato, and pepper leaves were removed with a sharp razor blade in 3% glutaraldehyde in 0.2 M potassium phosphate buffer. These were placed in fresh 2% glutaraldehyde in phosphate buffer for 1 hr at room temp (2, 6). The samples were then washed in buffer and post-fixed in 1% OSO_4 in 0.2 M potassium phosphate buffer for 1 hr at room temp or in $K_2 MnO_4$ for 15 to 30 min (2, 6). Dehydration was done in an acetone series or an ethanol/acetone series (6, 7). The samples were embedded in Spurr's plastic (5).

Silver to gold sections were made with a diamond knife on an LKB-Huxley microtome, stained with aqueous 0.5% uranyl acetate for 15 min (3), followed by aqueous 0.25% lead citrate for 5 min (4), and viewed on a Phillips 201 electron microscope at 60 KV.

For scanning electron microscopy (SEM), sections (3 x 3 mm) of mature leaves of tomato and pepper were fixed in glutaraldehyde and osmium (2, 6), dehydrated and critical point dried (1), mounted on stubs and sputter coated with gold-palladium, and then veiwed on a JEOL

JMS-35 microscope. Alternatively leaf sections were air dried before mounting and coating to preserve the surface wax structure.

Wax analysis. Leaves from the first set of tomato and pepper plants were selected in 2 groups for each treatment and treated as follows: 1) The 1st primary leaves after the cotyledons of pepper plants were used (120 leaves per group) and the oldest 5 leaflet unit of the tomato plants were selected (65 leaves per group). 2) The total leaf area of each group was measured with a Lambda Li-Cor area meter with traveling belt. 3) Each sample was extracted in 2 aliquots (300 ml each) of 60°C $CHCl_3$ for 1 and 1/2 min, respectively. 4) The dissolved wax for each sample was combined, filtered, dried, and weighed. 5) The waxes were spotted on 250 µm TLC plates of silica gel at the rate of 5 µl of a 10 mg wax/g $CHCl_3$ solution. The plates were developed with benzene:acetic acid (99:1) and Rodamine 6G (.005% aqueous) was used as an indicator spray.

Cuticle extractions. Cuticles were excised with $ZnCl_2$:HCl (1:1.7, w:w) using 5 ml per 1 cm diameter leaf disk. An attempt was made to separate these cuticles from the remaining cell debris and leaf vascular system so that cuticle weights and included wax content could be determined.

Results and Discussion

The higher UV light quality provided by the 3 mil cellulose acetate film filter did not appear to alter the upper leaf epidermis of the 3 plant species studied (Fig. 1). Cell confirmation, chloroplast location, wall thickness, and cytoplasmic densities as observed by TEM were similar for mature leaves of plants grown under mylar filtered light (Fig. 1 A, C, E) and 3 mil cellulose acetate filtered

light (Fig. 1 B, D, F). The younger stages of leaf development also did not demonstrate differences between treatments. Closer examination of the surface wax, cuticle, wall structure, and cytoplasm of the mature leaves of plants grown under mylar filtered light (Fig. 2 A, C, E) and 3 mil cellulose acetate filtered light (Fig. 2 B, D, F) also did not reveal any obvious differences in upper epidermal structure.

SEM observation of upper leaf surfaces of tomato and pepper plants did reveal greater numbers of small pebbles of wax or other material on the mature leaves of plants grown under the 3 mil cellulose acetate film filters (higher UV light) (Fig. 3 B, D and Fig. 4 B, D) than on the leaves of plants grown under mylar film filters (Fig. 3 A, C and Fig. 4 A, C). This material was widely spaced and would not be easy to detect from 0.1 μm thick TEM sections and probably would not affect light penetration into the leaves.

Measurement of the total surface wax (Table 1) did not reveal any difference due to treatment on the concentration of surface leaf wax. There was more variation between the 2 replicates of a given treatment than between treatments in most cases. Any trend that might exist would appear to favor more wax on the mylar treatments.

The same situation was true for the amount of each individual chemical group of waxes for the tomato (Fig. 5) and pepper (Fig. 6) samples. The tomato wax extracts consistently contained 3 more groups of waxes than the pepper wax extracts (Fig. 5). These were at RF's .03, .06, and .78.

The 3 mil cellulose acetate treatment extracts for tomato leaves (Fig. 5) and the mylar treatment extracts for the pepper leaves (Fig. 6) show the variation within treatments.

The cuticles of both tomato and pepper leaves were too fragile to clean up after digestion of the underlying tissues, and data on cuticle/unit area and included waxes could not be obtained.

Conclusions

Except for the SEM evidence of some widely spaced droplets on the surface of leaves of plants from cellulose acetate film filter treatments, no differences were observed between the treatments. These droplets may not have been plant material if somehow the film was shedding these droplets. This might be checked by SEM observation of new and used cellulose acetate film. On the other hand, the lack of response from treatments may have been the result of other stresses, water and heat, masking the UV effect on the 1st set of plants. The second set which was not as extensively examined had a greater difference in total growth and necrosis between treatments.

Fig. 1. Adaxial epidermal cell appearance of mature leaves of blueberry (A, B), tomato (C, D), and pepper (E, F) from plants grown under a high UV light source with mylar (A, C, E) or 3 mil cellulose acetate (B, D, F) film filters--low magnification.

Fig. 2. Adaxial cuticle appearance of mature leaves of blueberry (A, B), tomato (C, D), and pepper (E, F) from plants grown under a high UV light source with mylar (A, C, E) or 3 mil cellulose acetate (B, D, F) film filters--high magnifications.

Literature Cited

1. Anderson, T. F. 1966. Electron microscopy of microorganisms. Pages 319-388 in A. W. Pollister, ed. Physical techniques in biological research: vol. III, part A, 2nd ed. Academic Press, New York.
2. Hallam, N. D. 1970. Leaf wax fine structure and ontogeny in Eucalyptus demonstrated by means of a specialized fixation technique. J. Microsc. 92:137-144.
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4. Reynolds, E. S. 1963. The use of lead citrate at high pH as an electron opaque stain in electron microscopy. J. Cell Biol. 17: 208- .
5. Spurr, A. R. 1969. A low-viscosity epoxy resin embedding medium for electron microscopy. J. Ultrastruct. Res. 26:31-43.
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7. _____, L. N. Lewis, and C. W. Coggins. 1967. The reversion of chromoplasts to chloroplasts in Valencia oranges. Cytologia 32:117-124.

Table 1. Surface wax on tomato and pepper leaves of plants grown under high UV light with various film filters.

Filter for UV light	Surface wax	
	Tomato	Pepper
	$\mu g/cm^2$	$\mu g/cm^2$
Mylar	4.0, 7.7	7.8, 16.6
5 mil cellulose acetate	3.9, 4.3	5.5, 6.5
3 mil cellulose acetate	2.2, 7.0	5.0, 5.7

Fig. 1

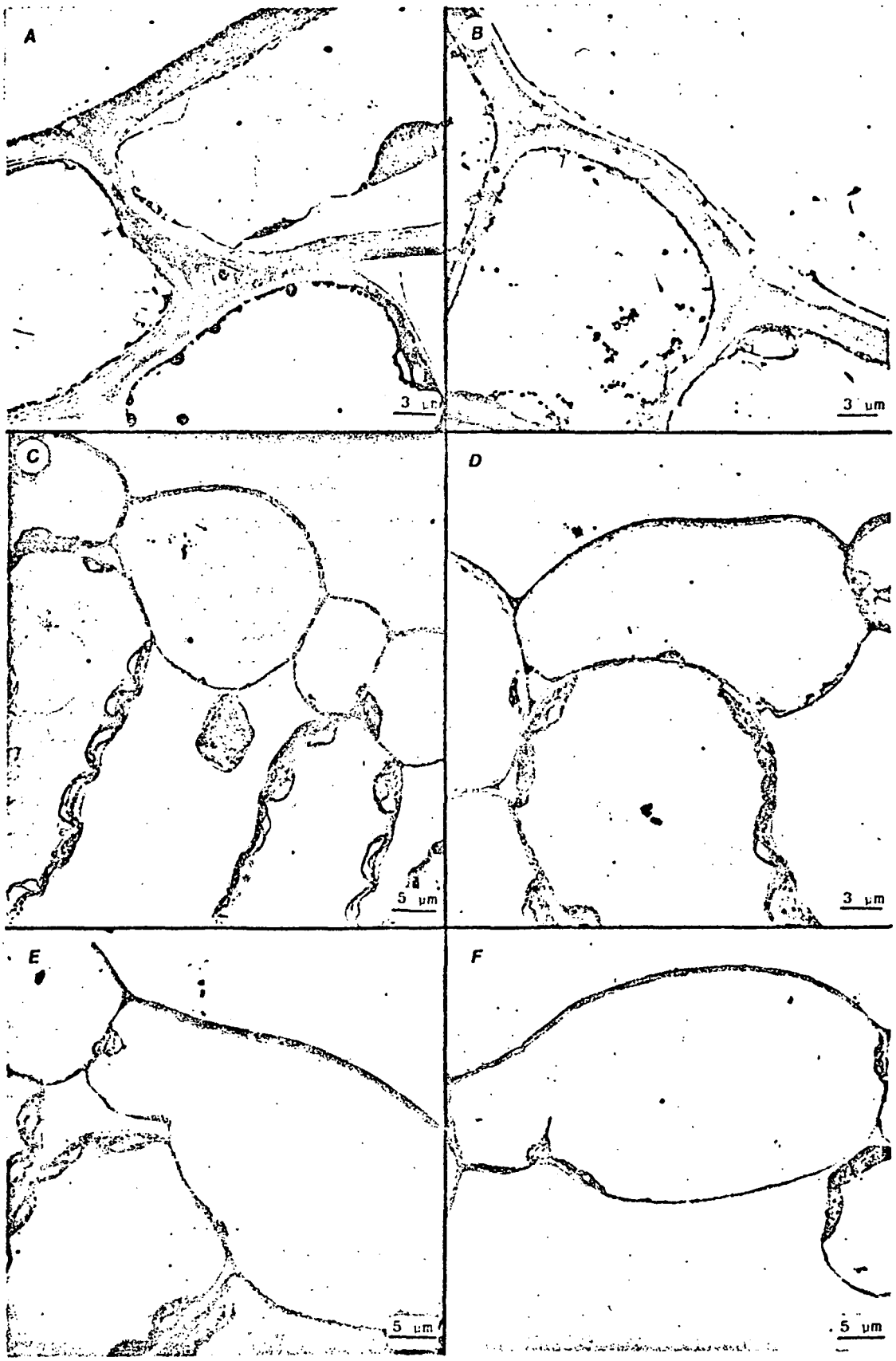
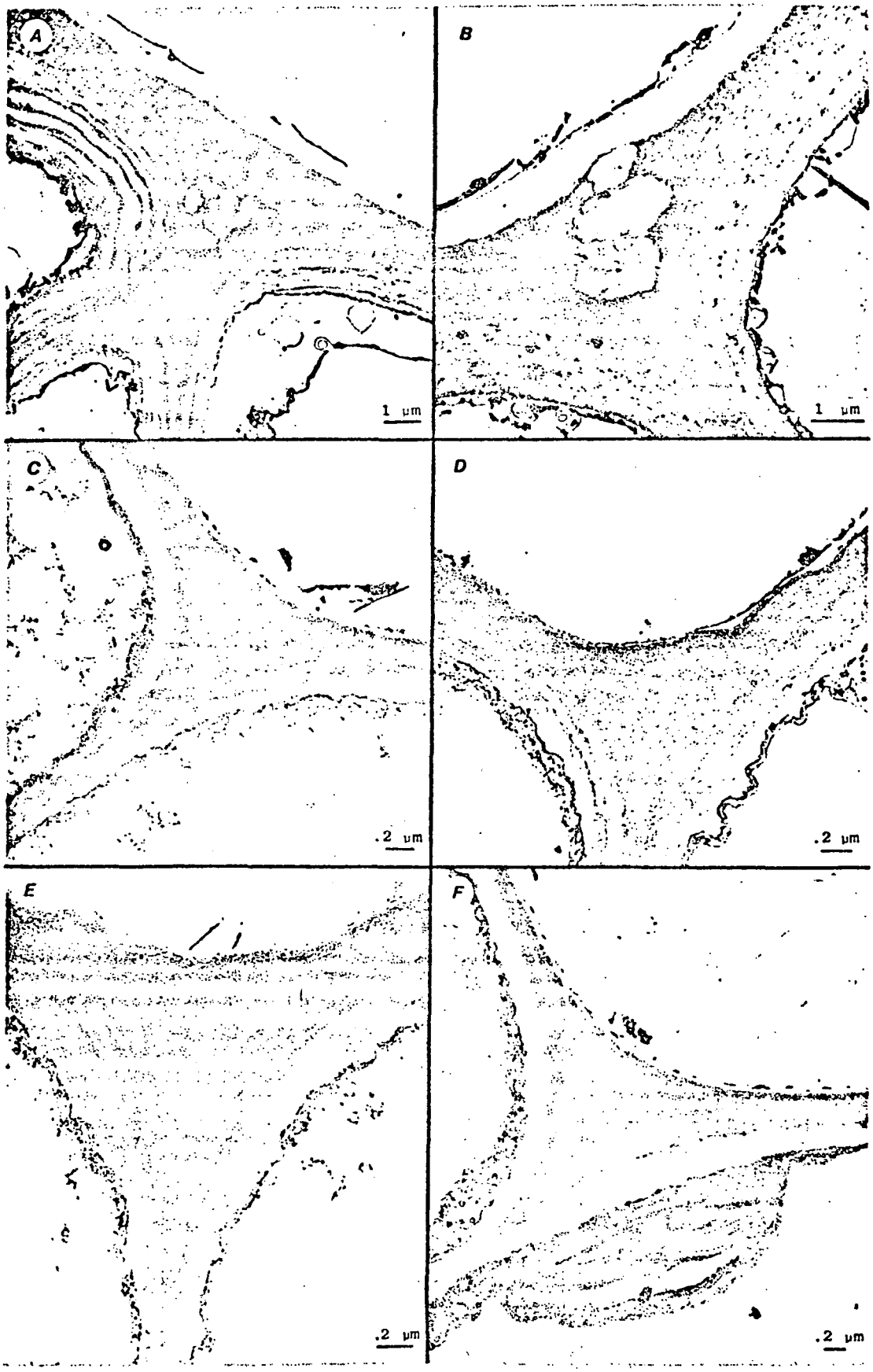


Fig. 2



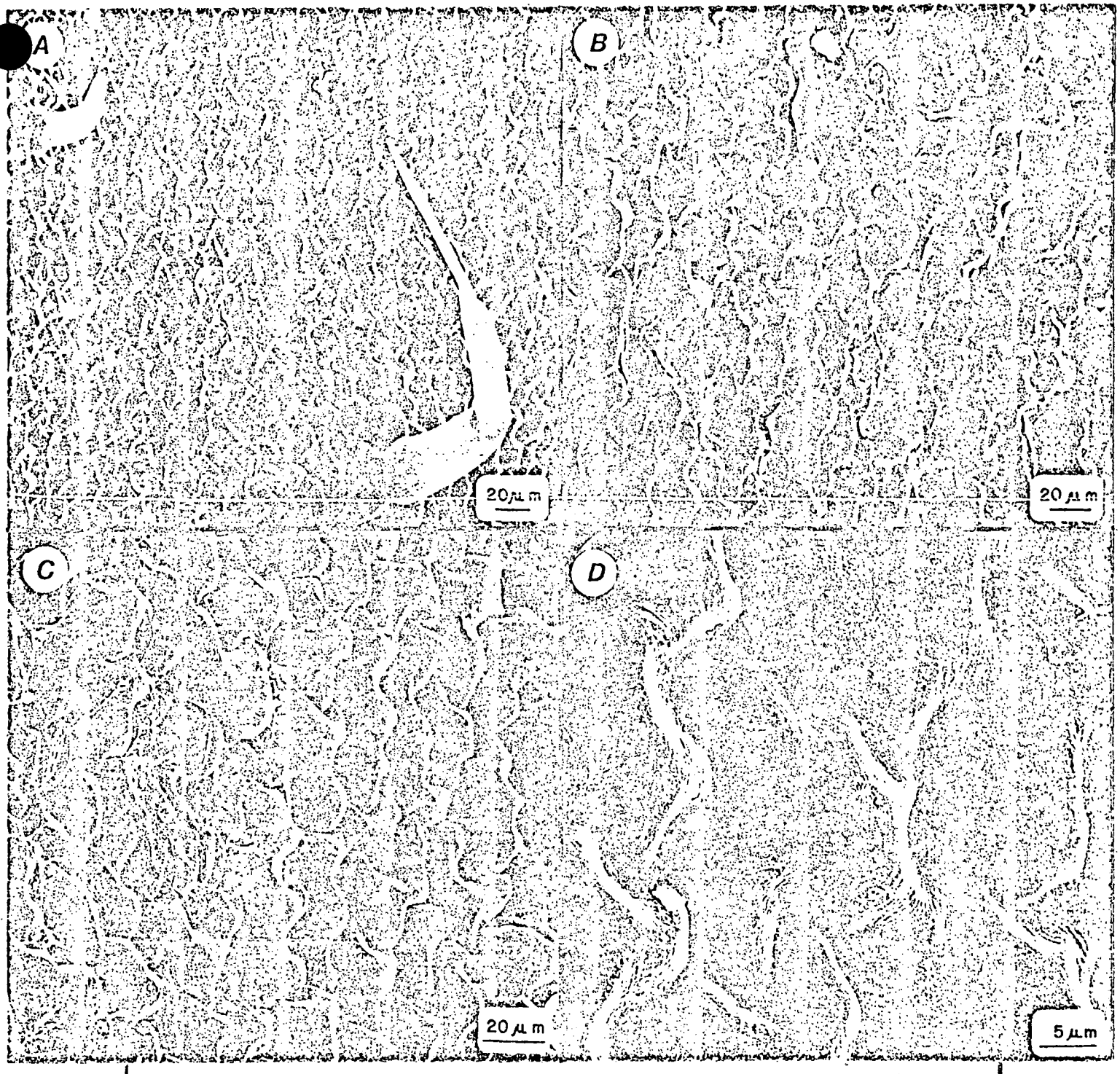


Fig. 3. Adaxial surfaces of tomato (A, B) and pepper (C, D) leaves from plants grown under a high UV light source with mylar (A, C) and 3 mil cellulose acetate (B, D) film filters--low magnifications.

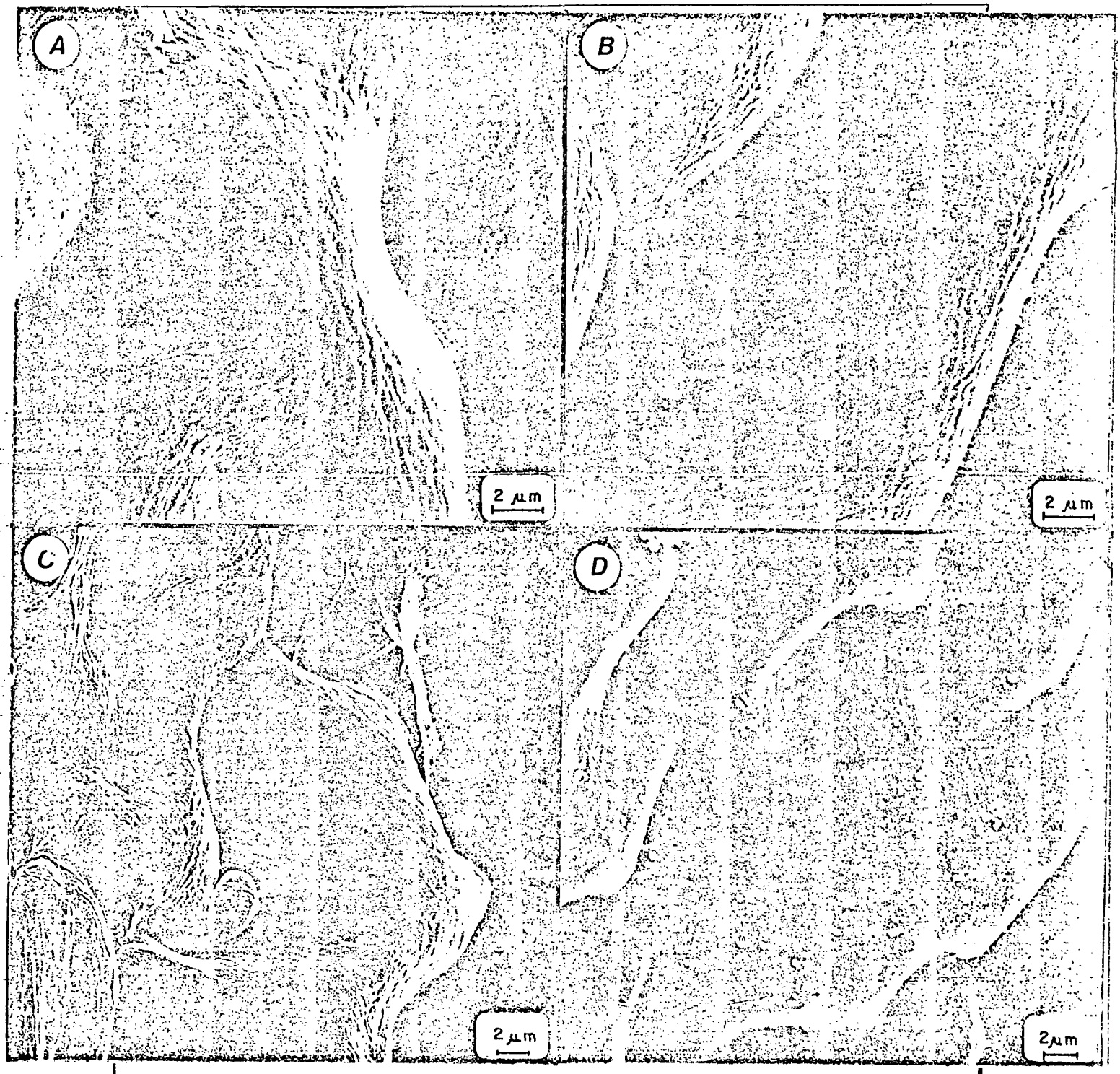
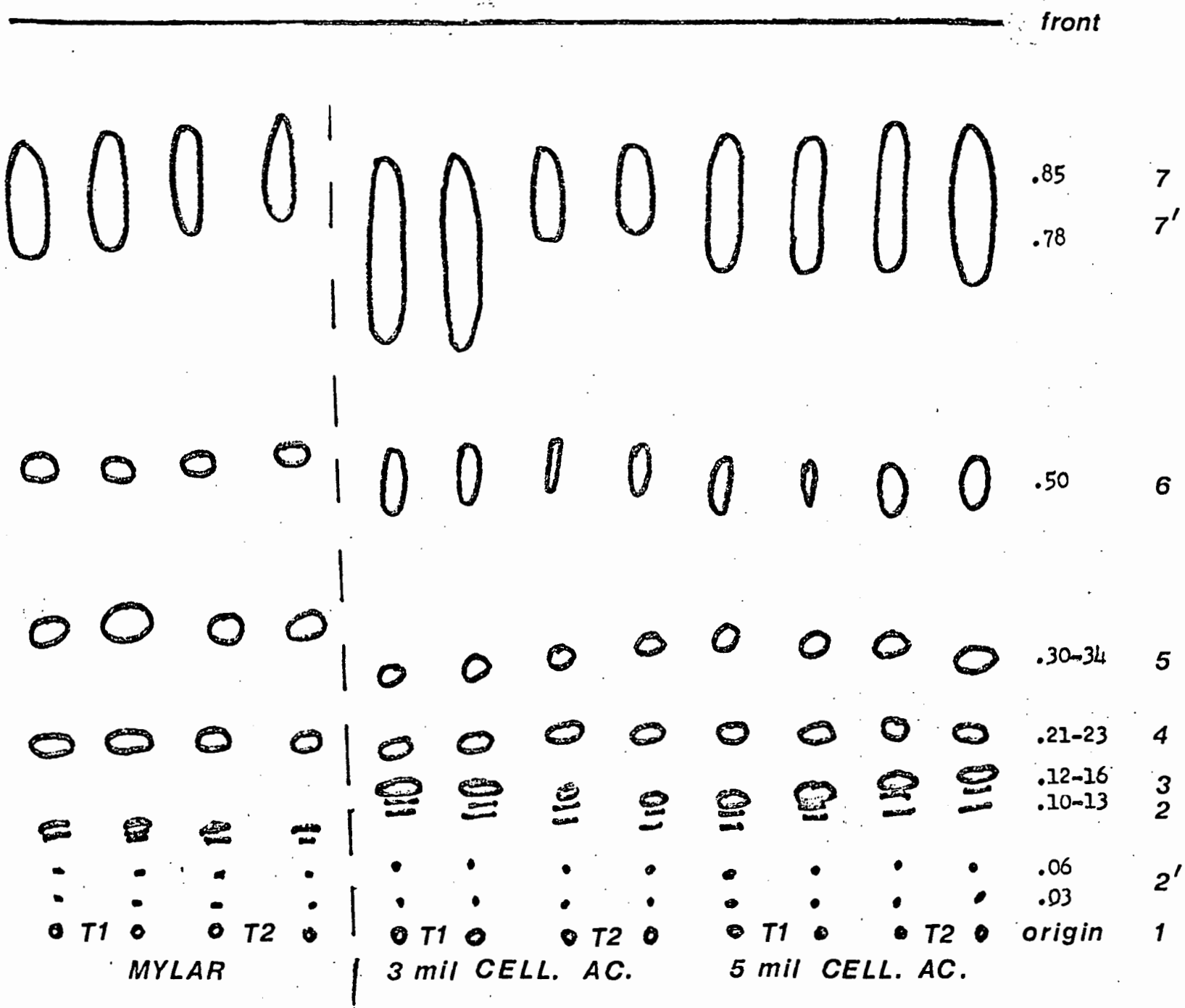
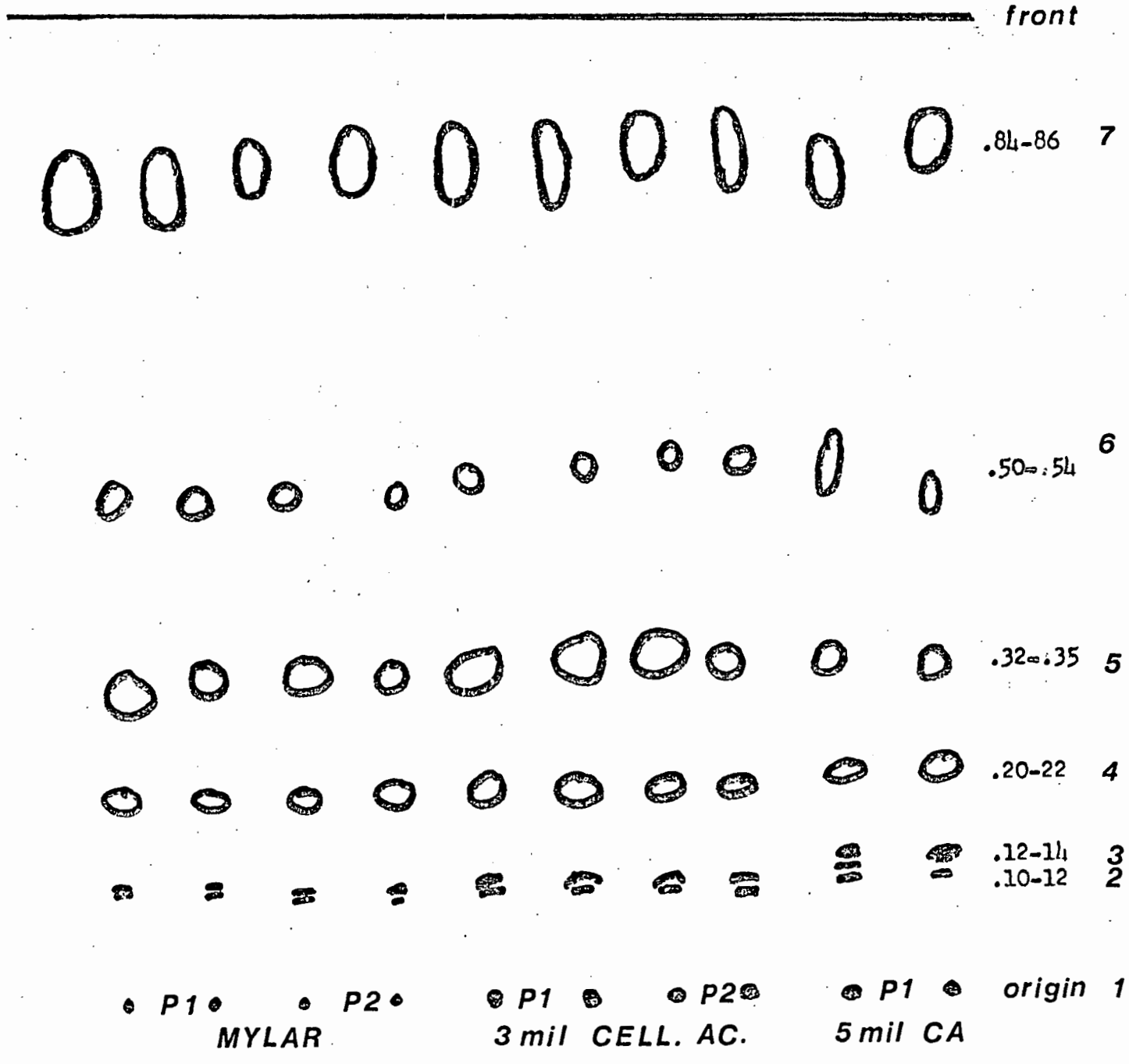


Fig. 4. Adaxial surfaces of tomato (A, B) and pepper (C, D) leaves from plants grown under a high UV light source with mylar (A, C) and 3 mil cellulose acetate (B, D) film filters--high magnifications.

Fig. 5. Wax fractions by chemical groups in the surface waxes of tomato leaves from plants grown under a high UV light source with mylar or 3 mil or 5 mil cellulose acetate film filters. Each sample was spotted using 5 µl of a 10 mg total wax/g $CHCl_3$ (1%) solution per spot and separated with Benzene:acetic acid (99:1) tentative spot identification follows according to the numbers to right of spots: 1--acids, 2'-triterpenoids or fatty acids, 2--fatty acids, 3--fatty acids, 4--primary alcohols, 5--unknown, 6--ketone or aldehydes, 7--alkene or alkyl ester, 7--paraffins.

Fig. 6. Wax fractions by chemical groups in the surface waxes of pepper leaves from plants grown under a high UV light source with mylar or 3 mil or 5 mil cellulose acetate film filters. Each sample was spotted using 5 µl of a 10 mg total wax/g $CHCl_3$ (1%) solution per spot and separated with benzene:acetic acid (99:1). Tentative spot identification follows according to the numbers to right of spots: 1--acids, 2--fatty acids, 3--fatty acids, 4--primary alcohols, 5--unknown, 6--ketones or aldehydes, 7--paraffins.


front
.85
7
.78
7′
.50
6
.30-34
5
.21-23
4
.12-16
3
.10-13
2
.06
2′
.03
origin
1
T1
T2
T1
T2
T1
T2
MYLAR
3 mil CELL. AC.
5 mil CELL. AC.


front
.84-86
7
.50-.54
6
.32-.35
5
.20-22
4
.12-14
3
.10-12
2
P1
P2
P1
P2
P1
origin
1
MYLAR
3 mil CELL. AC.
5 mil CA

EFFECTS OF ULTRAVIOLET-B RADIATION ENHANCEMENT ON INDUCTION OF PHENYLALANINE AMMONIA LYASE AND ETHYLENE PRODUCTION

Abstract

Only preliminary assays showed phenylalanine ammonia lyase activity to increase with increase UV-B radiation. These results need corroboration. Ethylene production showed a consistent decreasing trend with UV-B radiation, apparently being inhibited by UV-B treatment.

Introduction

Under inductive conditions the limiting factor in flavanoid synthesis may be the enzyme phenylalanine ammonia lyase which is responsible for the one step deamination of phenylalanine to cinnamic acid, a precursor in flavanoid biosynthesis. The present study was undertaken to determine if higher levels of PAL could be detected in tomato peel tissue after exposure to UV-B radiation.

'Walter' tomato plants of the same seed lot as was used in the Duke University Phytotron and in the field study were grown and tomatoes of the "mature green" stage (3-6cm) harvested for experimental purposes. Tomatoes were placed in a pan with the stem and stylar axis parallel to the FS-40 sun lamps and height on each tomato was adjusted so the upper surfaces of all tomatoes in a pan were even (Appendix I-41). Also, the height of each pan was adjusted to give 0, 4, 2, and 1 $UV\text{-}B_{seu}$ in pans covered with Mylar, 3, 5 and 10 mil cellulose acetate, respectively. The tomatoes were irradiated for 12 of 24 hours for 3 days and then analysed for PAL activity.

Analytical Procedure

Internal Ethylene Concentration:

Eight tomatoes per treatment were used and an internal gas samples was taken from each at the end of the UV-B radiation enhancement period prior to the PAL analyses. Ethylene was determined in the gas samples by the use of a Hewlett-Packard M-400 gas chromatograph equipped with a hydrogen flame ionization detector. Separation was accomplished on an activated alumina column at 60°C with N_2 as the carrier gas. The system can be used to detect down to 10 ppb with a - 10 % error.

Phenylalanine Ammonia-Lyase Determinations:

A modified method of Rahe et al. (1970) and Aoki et al. (1971) was used to extract PAL. Tomato peel tissue was cut into small pieces and blended with

cold ethyl ether (-20°C). The homogenate was filtered on a Buchner funnel by suction and the residue washed several times with cold ethyl ether and dried in a vacumm desiccator at 0°C. For the preparation of enzyme solution 1g of ethyl ether powder was suspended in 40 ml of 0.05 M sodium borate buffer (pH8.8) at approximately 3°C for 1 hr and the suspension cleared by centrifugation at 7000xg for 10 min at 0°C. The supernatant was used as the crude enzyme preparation.

PAL activity was assayed spectrophotometrically by measuring trans-cinnamic acid formed according to the method of Koukol and Conn. The reaction mixture consisted of 1 ml of 10^{-2}M L-phenylalanine, with 2 ml of 0.05 M sodium borate buffer (pH8.8) and 1 ml of enzyme solution. Distilled water was added to the blank. The mixture was incubated for 3 hours at 30°C. The reaction was stopped by adding 0.1 ml of 6N hydrochloric acid. The acidified mixture was extracted once with 5 ml of peroxide-free ethyl ether, that was removed and evaporated to dryness at room temperature under an air stream by a fan. The residue was dissolved in 4 ml of 0.05 M sodium hydroxide and the optical density determined at 268 nm. Enzyme activity was expressed in mμ moles of trans-cinnamic acid formed per g of fresh weight of tissue per 3 hours under the conditions described above.

In the initial assays, PAL activity appeared to be higher in tomatoes receiving the higher UV-B enhancement levels, however, subsequent runs did not corroborate the earlier assays. This work is being repeated with some modifications in procedure.

Concentrations of ethylene in the internal air spaces of the fruit immediately after treatment demonstrated a decreasing pattern with increasing UV-B radiation enhancement levels. This is consistent with the findings on bean petioles (see section IX) where high doses of UV-B radiation (greater than 1.5 UVB_{seu}) inhibited ethylene production.

Literature Cited

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2. Aoki, S., C. Araki, K. Kaneko and O. Katayama. 1971. Occurrence of L-phenylalanine ammonia-lyase activity in peach fruit during growth. Agr. Biol. Chem. 35: 784-787.

Table 1. Ethylene production by UV-B treated tomatoes.

$UV\text{-}B_{seu}$ Enhancement[1]	Ethylene Conc. (ppm)[2]
0	6.40
1.8	4.80
2.1	2.80
4.1	0.76

[1] Length of exposure was 36 hrs in a 72 hr period of 12 hrs radiation: 12 hrs dark.

[2] Analyzed in a 1 ml of gas sample from the internal gases of the fruit. EThylene measurement was performed with a Hewlett:packard M-400 gas chromatograph equipped with a H_2 flame ionization detector and a 0.6 x .003 in. activated alumina column.

EFFECTS OF ULTRAVIOLET-B RADIATION ENHANCEMENT ON CHLOROPHYLL a, b AND TOTAL OF AVOCADO LEAVES

Abstract

Short term decreases in total, a and b chlorophyll were observed after 8 minutes exposure to UV-B at 295nm, 3.36 joules. This was followed by increases and then a leveling off in content consistent with dark degradation. Induction of flavanoids in the avocado leaf system was most effective at 295nm.

Introduction

Exposure of plants to UV-B radiation in controlled environment chambers caused a significant decrease in chlorophyll content (see Section V), particularly in certain areas of leaves. Photosynthesis has been demonstrated to be affected by UV-B radiation (see references in section V). The objective of these preliminary experiments was to study rapid changes in chlorophyll - a prominent visual pigment system of higher plants that are the primary pigments of the photosynthetic apparatus of the cell. An analysis of stability or non-stability, and if the latter, as related to rates of changes and photon fluence,could indicate the destruction of

chlorophyll, inhibition of synthesis or loss of functional position in the photosynthetic apparatus. This work was undertaken to describe quantitative and qualitative changes in total as well as chlorophyll a, b and their ratios after exposure to 7nm ban widths of UV-B radiation.

Materials and Methods

Mature, healthy avocado leaves are long-lived when detached from the plant and kept in a high humidity chamber. Avocado leaves 15-20cm long were exposed for various lengths of time to UV-B with a 7nm bandpass centering on either 290, 295, 200, 305, 310 or 315nm. The tissue area exposed at any one time was 1 cm^2. A xenon lamp (Appendix I-40) served as the UV-B irradiance source. There were 3 to 13 exposure replicates made for each observation. After exposure the leaves were placed between moistened paper toweling and kept in the dark for the designated length of incubation.

One cm^2 leaf sections were ground in cold 80% acetone saturated with magnesium carbonate. Each sample was centrifuged for 10 min, filtered and the pellet re-extracted. Combined extracts were made to a standard volume and absorbance at 663 and 645nm were determined using a Beckman DB-G grating spectrophotometer. Chlorophyll a, b and total were calculated according to Arnon (1949) as follows:

$$\text{Total chlorophyll, mg/l} = 20.2\ (OD_{645}) + 8.02\ (OD_{663})$$

$$\text{Chlorophyll a , mg/l} = 12.7\ (OD_{663}) - 2.69\ (OD_{645})$$

$$\text{Chlorophyll b , mg/l} = 22.9\ (OD_{645}) - 4.68\ (OD_{663})$$

Results and Discussion

As can be seen from Table 1, there is an indication that irradiances of 290 and 295nm lowered chlorophyll b content. However, the data is not conclusive enough to obtain an action spectrum for a change in chlorophyll. It does indicate that the shorter wavelengths are interacting with chlorophyll to lower content. That there is an after-effect on chlorophyll quantities of avocado leaves after exposure to UV-B radiation can be seen by the data of Fig. 1 and Table 2. Exposure of leaves to 8 minutes of UV-B irradiance of 3.36 Joules cm^{-2} and then incubating the leaves in the dark resulted in transient changes in both chlorophyll a and b. Both decrease immediately after the UV-B treatment and then increase. This was followed by another decrease with chlorophyll b affected the most. Dose vs rate changes are still under study but at the present it does seem that UV-B radiation is having an immediate effect on chlorophyll metabolism.

Induction of flavenoids in this avocado leaf test system is also being investigated. Appendix I-40 shows that UV-B at 295nm is the most effective wavelength. At least 2 or more days incubation time is required for the pigments to be seen visually and this is dependent upon the length and amount of exposure.

Literature Cited

Arnon, D.I. 1949. Pl. Physiol., Lancaster 24: 1-15.

Table 1. Chlorophyll content of avocado leaves exposed to 7nm bandpass UV-B radiation for 8 and 16 minutes.

	% of Control								
	Chl. a		Chl. b		Total		Mean	UV-B Joules	
nm	8"	16"	8"	16"	8"	16"	a/b ratio	8"	16"
290	105	92	106	59	197	165	2.74	1.92	3.84
295	102	100	116	87	202	203	2.38	3.36	6.72
300	102	96	101	97	198	198	2.31	4.80	9.60
305	92	110	75	76	202	151	3.21	5.76	11.52
310	100	112	100	103	212	203	2.55	5.76	11.52
315	101	108	101	103	209	204	2.35	4.32	8.64

Figure 1. Chlorophyll content of avocado leaves exposed to a 7 nm bandpass of UV-B at 295nm giving 3.36 Joules cm^{-2} over an eight minute exposure period.

Fig. 1

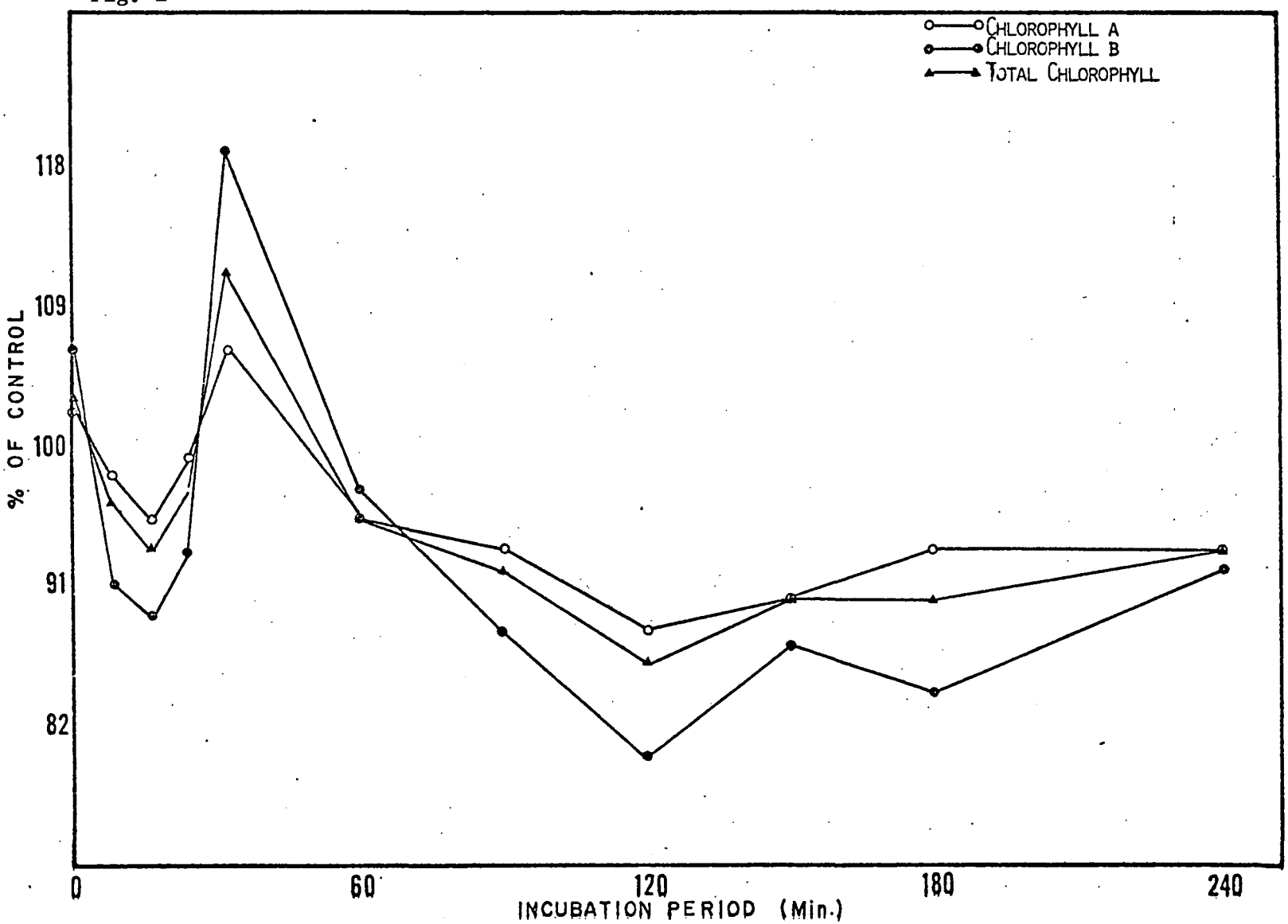

CHLOROPHYLL A
CHLOROPHYLL B
TOTAL CHLOROPHYLL
% OF CONTROL
118
109
100
91
82
0
60
120
180
240
INCUBATION PERIOD (Min.)

Table 2. Chlorophyll content and a:b ratio of 1 cm^2 avocado leaves exposed to a 7 nm bandpass UV-B at 295nm giving 3.36 Joules cm^{-2} over an 8 minute exposure period.

Incubation Period(min)	% of Control			Mean a:b ratio
	Chl. a	Chl. b	Total Chl.	
0	102	106	103	2.52
8	98	91	96	2.78
16	95	89	93	2.72
24	99	93	97	2.73
32	106	119	111	2.50
60	95	97	95	2.78
90	93	88	92	3.09
120	88	80	86	3.23
150	90	87	90	3.05
180	93	84	90	3.30
240	93	92	93	3.13

EFFECT OF ULTRAVIOLET-B RADIATION ENHANCEMENT ON ABSCISSION, ETHYLENE PRODUCTION, ABSCISIC ACID AND SEVERAL ENZYMES OF LEGUMES

Abstract

Intermediate levels of UV-B radiation (1 UV-B_{seu}) hastened the abscission processes of bean explants but higher levels (2 and 4 UV-B_{seu}) inhibited abscission. However, intermediate levels of UV-B had no measurable effect on ethylene production but the higher level (4.2 UV-B_{seu}) stimulated it. Bean plants exposed to levels of 1.2 and 2.1 UV-B_{seu} enhancements had greater amounts of abscisic acid in the stem exudates, presumably xylem fluid. RuDP-carboxylase in leaves was not altered by 1.2 and 2.6 UV-B_{seu} levels of enhancement. Two cellulase isozymes were inhibited by UV-B radiation.

Introduction

Abscission of plant organs plays a prominent role in survival of higher plants to environemntal stress factors. Intimately associated with the mechanism of positive shedding of organs are growth regulators (see references in Kozlowski, ed., 1973) such as abscisic acid (Carns, 1966) ethylene (see references in Abeles, 1973) and auxin (Biggs and Leopold, 1958) and certain enzymes. A prominent enzyme complex associated with the separation processes

are cellulases (see references,Kossuth and Biggs, 1977). Other enzymes not directly involved with separation but which are indicative of associated sequencing of natural processes are changes in pigments, proteins and other nitrogen metabolic processes, translocation phenomena etc. (Addicott, 1968). Since the abscission process is so closely related to stress factors, is a correlative phenomena, is most prominent on organs exposed to light, and has a biological endpoint that is not death of the entire organism, it was chosen as a pivotal process for studying UV-B radiation on beans. Certain legumes which includes beans, are excellent test organisms for several reasons. They have evolved a complex system for autotropy of intermediate oxides and reduced forms of nitrogen, yields of seeds are strongly related to photosynthesis, the cultivated plants in this family play a major role in supplying world food demands and much information is available on the response of this family of plants to environmental stress factors.

Materials and Methods

Plant Material

Glycine max (L.) Merr. var. 'Hardee' and Phaseolus vulgaris L. var. 'Tennessee flat' beans were used as the test plants. Both test plants were grown in the greenhouse using the same UV-B irradiators as discussed in section I. The level of UV-B enhancement varied with different tests and will be described with each. In the case of the beans, plants were sometimes decapitated or explants made of leaf parts to include abscission zones. These will be described with the test systems. All plants were grown in pots of Redi-earth, a commercial potting mix of peat and vermiculite and grown without disease and with all other factors, except UV-B treat-

ments, being as uniform as possible.

Bean Abscission Bioassay

The primary leaves of three-week-old seedlings of Phaseolus vulgaris L. var. 'Tennessee flat' were used as the source of the explant. The explant was made to include 5mm of petiole and 5mm of the leaf pulvinus up to the base of the leaf blade. Ten explants were inserted with the petiole portion to a 3mm depth in 3% agar in small containers and each treatment had 3 containers of explants. The explants were kept at 25°C and examined every 24 hours for numbers that abscised the pulvinus tissue (Appendix I-41).

Ethylene Analysis

Gas samples to be analyzed for ethylene were injected, 1 or 0.5 ml, on the column for analysis. A Hewlett Packard M-400 gas chromatograph equipped with a hydrogen flame ionization detector, a 0.5 x .003 M activated alumina column, operated at an injection port oven temperature of 60° and detector temperature of 215° and N_2 flow of 60 ml/min. was used.

Abscisic Acid Analysis

Stem exudates from bean plants were separated using a DuPont model 860 high pressure liquid chromatography system equipped with a microporasil column and a UV-detection system at 254nm. Abscisic acid has a strong absorbance at the 254nm wavelength. Separation was on the microporasil column using 15% (v/v) acetonitrile in chloroform acidified with 0.2 N formic acid at a programmed linear flow rate of 2 ml/min. This system is similar to the one used by Ciha, Brenner and Brun (1977).

A 'Hairy Peruvian' alfalfa seed bioassay was used to test fractions separated from the exudates for inhibitory action. The test consisted of placing 50 seeds on 2.0cm filter paper discs moistened with water and test substances in special flat bottom, small beakers and allowed to germinate 24 hours (Biggs, 1971). Each test fraction was replicated 4 times.

RuDP-Carboxylase Assay

Approximately 500 mg of fresh leaf with midrib removed were ground in a glass homogenizer with 10.0 ml of a solution that was 50.0 mM Tris (pH 8.0), 10.0 mM $MgCl_2$, 1.0 mM EDTA, 5.0 mM D-isoascorbate, and 5.0 mM DTT. The extracts were centrifuged at 30,000 g for 15 min and then assayed immediately for RuDP-carboxylase activity.

The activity of the enzyme was assayed by measuring the rate of ^{14}C-labeled CO_2 incorporation into acid-stable products. The reaction vessels contained 1.0 ml of a solution that was 50.0 mM Tris at pH 8.0, 10.0mM $MgCl_2$, 1.0mM EDTA, 5.0 mM DTT, 0.4mM ribulose-1,5 diP, and 20.0 mM $NaH^{14}CO_3$ (2.0 uCi). The reaction was initiated by addition of leaf extract and terminated after 5 min by addition of 0.1 ml of 6.0N HCl. Gaseous $^{14}CO_2$ was removed from the reaction vessels by a stream of compressed air. The radioactivity of the samples was determined by scintillation counting. Chlorophyll content was determined by suspending 50ul of leaf extract in 20 ml of 80% acetone. The absorbance at 652nm (1cm light path) was determined and then the value was m ltiplied by a factor of 100/9 to approximate the chlorophyll content of the suspension in ug/ul.

Cellulases

Cellulases were extracted from bean abscission zones using 0.2M phosphate buffer: 1M NaCl (pH-7) media. The tissue was ground in the extraction media, centrifuged at 12,000 g to remove cellular debris, supernatant decanted, filtered through an Amicon molecular sieve to pass solution plus solutes greater than 30,000 MW. The residue on the surface of the sieve was resuspended in an ampholine plus gel matrix and applied to an agarose: ampholine flat-bed gel for pH focusing for 16 hours at 8 watts. A model 2116 LKB Multiphor and 2103 power supply was used for the ionophoresis.

After separation the gels were subdivided into 30 equal sections, each section was ground and eluted with buffer through special filter tubes supplied by LKB, and the eluted fractions tested for cellulase activity by viscometric analysis using carboxymethyl cellulose as the substrate.

Results and Discussion

Intermediate levels of UV-B radiation (1.2 $UV\text{-}B_{seu}$) accelerated the abscission processes of bean petioles but higher levels (2.6 and 4.2 $UV\text{-}B_{seu}$) inhibited the processes in relation to control explants (Table 1). The promotion of abscission is in agreement with a previous report (Carns, et al., 1975); but the inhibition was not evident on cotton explants. This could indicate that the bean petiole abscission zones are more responsive to UV-B radiation. There was a marked difference in the response of cotton and bean to UV-B with the beans being much more sensitive in the Phytotron screening tests.

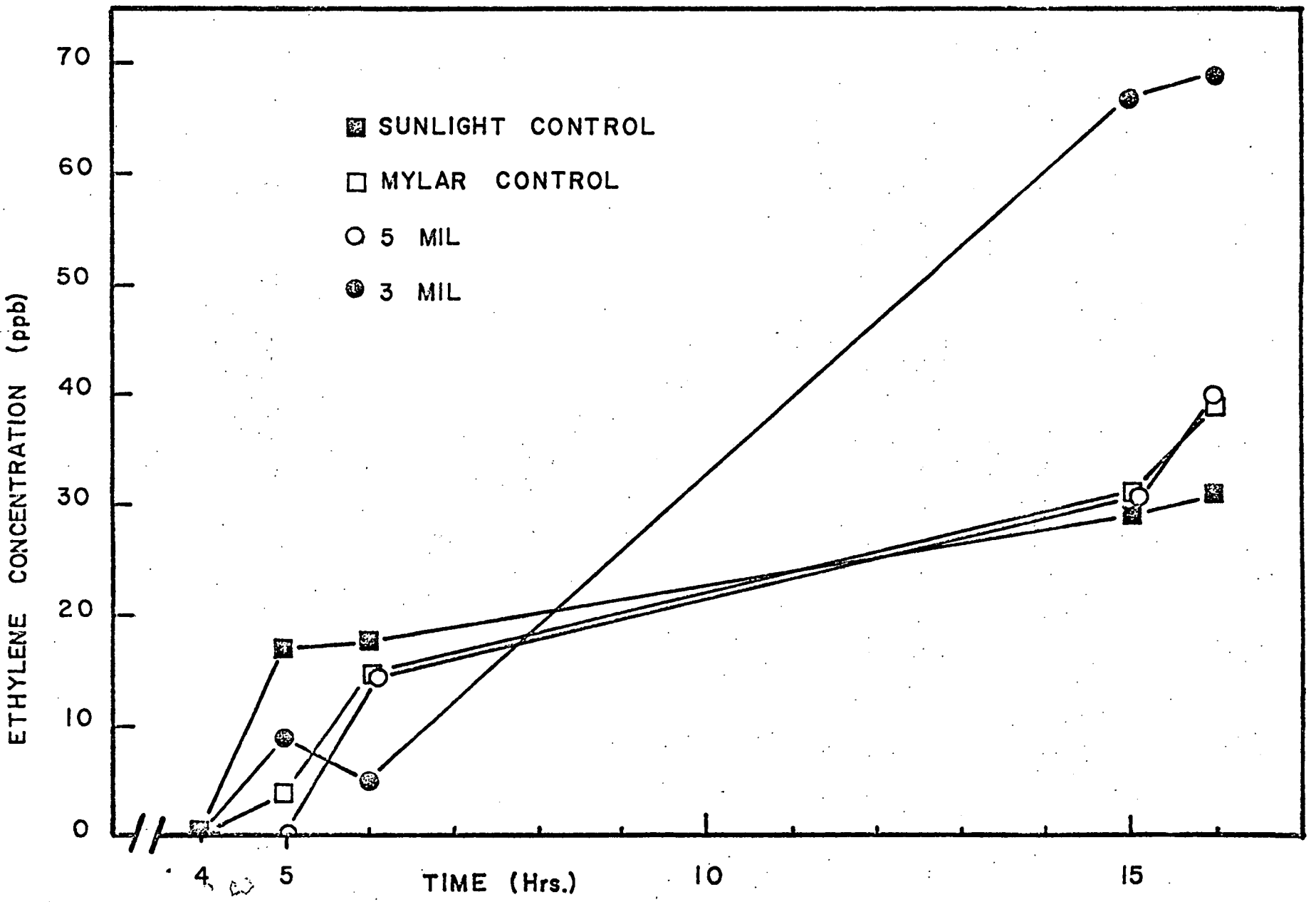
Table 1. Effect of UV-B radiation enhancement on the time required for 50% abscission of bean explants.[1]

Treatment[2]	Hrs. to 50% Abscission
Control (Mylar)	128
1.2 $UV\text{-}B_{seu}$	72
2.6 $UV\text{-}B_{seu}$	137
4.2 $UV\text{-}B_{seu}$	160

[1]Three-week-old beans were decapitated 1 cm above the primary leaf blade and the decapitated plant exposed to UV-B (see Appendix I-40). Subsequent to UV-B exposure, explants were made of the petiole and pulvinus to include the abscission zone (see Materials and Methods).

[2]UV-B irradiance enhancement was for 6 hours for 3 days from 0900 to 1800 hours in the greenhouse.

Fig. 7


70
60
50
40
30
20
10
0
ETHYLENE CONCENTRATION (ppb)
SUNLIGHT CONTROL
MYLAR CONTROL
5 MIL
3 MIL
4
5
TIME (Hrs.)
10
15

Ethylene

Increases in doses of UV-B radiation beyond a threshold amount seemed to stimulate ethylene production (Fig.1). The control explants were from beans exposed to natural sunlight in the greenhouse. Ethylene production from beans exposed to mylar filtered FS-40 irradiance plus sunlight and 5 mil cellulose acetate filtered FS-40 lamp irradiance was approximately the same. FS-40 lamp and 3 mil filter combinations, resulting in 2.6 $UV\text{-}B_{seu}$ enhancement stimulated ethylene production. The increase in ethylene production reinforces the concept that UV-B radiation hastens senescence of organs of some plants.

Abscisic Acid

Abscisic acid in the exudates from stems were higher in beans exposed to UV-B irradiances. As shown in Table 2, a 1.2 $UV\text{-}B_{seu}$ enhancement level resulted in a doubling of the concentration in the exudates and plants exposed to 2.1 $UV\text{-}B_{seu}$ had 2.4 times as much abscisic increase as a result of ultraviolet radiation stress. Abscisic acid may play a role in photoprotection of the plants. The interesting feature of these tests is that UV-B must be affecting the entire plant, including the root system, for presumably the increase in abscisic acid is produced in the roots and is being transported to the shoots in the xylem. Root biomass was affected by UV-B in other tests and part of this affect may be through chemical regulators.

Table 2. Abscisic acid content of stem exudates[1] from beans grown under UV-B irradiance enhancement.[2]

Treatment	mgABA/Plant[3]	% alfalfa seed inhibition[4]
Control (Mylar)	190.1	94
1.2 $UV\text{-}B_{seu}$	380.5	33
2.1 $UV\text{-}B_{seu}$	454.7	22

[1]Three week-old beans were decapitated at the cotyledonary node and 200ul of exudate collected from each of 40 plants.

[2]Irradiance determined as outlined in section I.

[3]Calculation based on high pressure liquid chromatography analysis.

[4]Separated fraction from high pressure liquid chromatography and tested in alfalfa seed bioassay.

RuDP-Carboxylase

We tested bean leaves for the possible effect of UV-B radiation on the primary carboxylating enzyme, RuDP-caroxylase. The data of Table 3 indicates that there was no reduction in the level of this enzymes under these test conditions.

Cellulases

Bean seedlings 3-weeks from emergence were decapitated just above the two primary leaves and exposed to 2 $UV\text{-}B_{seu}$ for 3 days for 6 hours per day from 0900 to 1500 hours in the greenhouse(see Appendix I-41 for an example of the type of bean plant treated). After exposure, 50 bean explants 2mm in length were cut from the pulvini:petiole area at the base of the primary leaves. The abscission zone was at mid-point of the explant. All 50 explants were ground and cellulases extracted.

Molecular sieving and an LKB ionophoresis unit was used to investigate the isozymes in the bean petioles. Ionophoretograms of molecular sizes greater than 30K in the pH range of 2.2 to 9.2 have shown that at least 6 different isozymes are present in non-treated abscission zone tissue (Fig. 2). From the UV-B radiation treatment (2 $UV\text{-}B_{seu}$), cellulases extracted from abscission zone tissue were in lesser amounts and fewer in number than the controls. This is in agreement with the observations in the previous section that a 2 $UV\text{-}B_{seu}$ level of enhancement inhibited abscission even though ethylene production was stimulated.

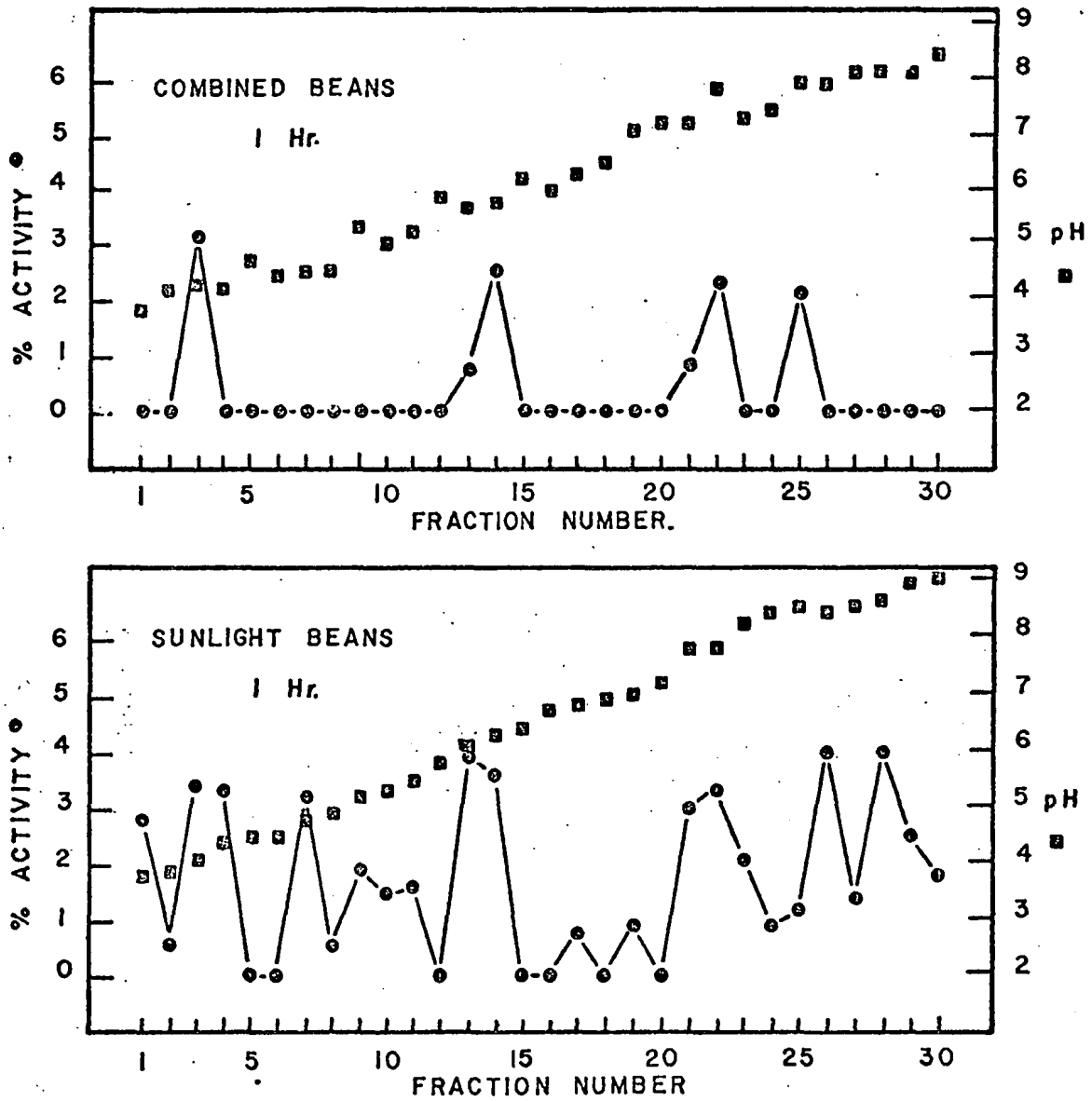
Table 3. Ribulose-1,5-diphosphate carboxylase activity of soybean leaves grown under control (mylar), 1.1 and 2.3 $UV\text{-}B_{seu}$ enhancement regimes.[1]

Treatment	RuDP-carboxylase activity (umoles CO_2 mg^{-1} chl. h^{+1}
Control (Mylar)	240[2]
1.2 $UV\text{-}B_{seu}$	221
2.6 $UV\text{-}B_{seu}$	218

[1] Soybean leaves exposed to UV-B radiation for 14 days for 6 hours per day from 0900 to 1500 hrs. in the greenhouse. $UV\text{-}B_{seu}$ enhancement determined as outlined in section I.

[2] Average of 4 determinations. The means were not significantly different from each other at $p = 0.05$.

Fig. 2


COMBINED BEANS
1 Hr.
% ACTIVITY
pH
FRACTION NUMBER.
SUNLIGHT BEANS
1 Hr.
% ACTIVITY
pH
FRACTION NUMBER

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EFFECTS OF ULTRAVIOLET-B RADIATION ENHANCEMENT ON REPRODUCTION AND VEGETATIVE GROWTH OF BLUEBERRY

Abstract

Berry weight was reduced by 50% on fruits from plants grown under 2 UV-B_{seu} and 1 UV-B_{seu} enhancement levels. Mylar control plants had more shoots and larger leaves than UV-B treated plants.

Introduction

The vegetative and reproductive capacity of blueberries (*Vaccinium ashei* cv. 'Woodard') under UV-B enhancement regimes was studied. Observations on annual crops have shown that yields and vegetative biomass may be reduced. No such studies have been conducted with perennial crops, especially tree crops which are past juvenility stages.

Materials and Methods

Rooted cuttings of the cultivated blueberry variety 'Woodard' which had been in cold storage since October were potted on May 10,1977 in Redi-Earth soil mix and allowed to grow under normal greenhouse conditions until May 18 when the UV-B enhancement regimes were begun

in the greenhouse (Appendix I-1). Seven to 10 plants were placed under Mylar, 3 mil, 5 mil and 10 mil cellulose acetate (CA) which was changed every 3 or 4 days. The 3 mil CA filtered plants were set for 2 UV-B_{seu} and the other fixtures raised to the same distance from plant height as the 3 mil plants. The blueberry plants were irradiated for 6 hours per day in the center of the natural photoperiod for almost 4 months until berry harvest.

Initial data taken on the plants included number of vegetative and inflorescence shoots and number of leaves per shoot. Each plant was thinned to a maximum of 2 inflorescences and then to 2 well developed flowers per inflorescence, which were hand pollinated at anthesis. On September 9, 1977 each plant and all fruit were harvested. Data was taken on the number of fruits, weight of fruit, number of shoots, number of leaves per shoot and leaf area per plant.

Results and Discussion

Blueberries from the control plants had larger berries and higher percentages of berries matured than 1 and 2 UV-B_{seu} treated plants. The blueberry from the 10 mil treatments weighed the same as the mean of the 5 control blueberries. These blueberries were twice as heavy as the 1 and 2 UV-B_{seu} treated berries (Table 1).

Large differences were also observed in vegetative growth with the control plants showing an increase in the number of shoots per plant from 0.9 to 8.3 vs 1.57 to 5.71 for the 1 UV-B_{seu} treated blueberries (Table 1). However, the number of leaves per plant was lower on the control than on the UV-B treated plants. Leaf area on a per leaf basis was about the same

Table 1. Vegetative and reproductive development of rooted 'Woodard' blueberry cuttings exposed to UV-B enhancement.[1]

Parameter[1]	2UV-B_{seu}	1UV-B_{seu}	0.5UV-B_{seu}	Mylar Control
1. # plants	7	7	7	8
2. # flowers pollinated	2.29	2.00	2.00	1.80
3. absolute berry #	3.00	4.00	1.00	5.00
4. # berries matures	0.43	0.57	0.25	0.50
5. % berries matured	0.19	0.28	0.13	0.29
6. berry weight (g)	0.54	0.43	0.99	0.99
7. # shoots (May)	1.29	1.57	1.25	0.90
8. # shoots (Sept.)	5.00	5.71	5.29	8.30
9. # leaves (May)	9.14	8.14	9.88	6.80
10. # leaves (Sept.)	48.43	57.29	58.14	49.80
11. leaf area, cm^2 (Sept.)	249	290	303	278
12. leaf area/leaf (Sept.) cm^2	5.13	5.06	5.20	5.59

[1] Parameters are expressed as mean values per plant for the designated UV-B_{seu} treatment.

for all levels of UV-B enhancement ranging from 5.06 to 5.2 cm^2. The control was slightly higher with 5.59 cm^2 (Table 1).

It was apparent that vegetative growth on the control plants was different from treated in that controls had more shoots but fewer leaves that were larger whereas the UV-B treated plants had a larger number of smaller leaves on fewer shoots. The expected reduction in individual leaf area often observed under enhanced UV-B treatment was observed but the larger number of shoots on the control plants was not. The limited sample size and variation in cutting size, establishment and initial outgrowth after removal from the long cold storage period may account for some of the variability.

EFFECTS OF ULTRAVIOLET-B RADIATION ENHANCEMENT ON REPRODUCTION AND VEGETATIVE GROWTH OF CITRUS

Citrus irradiators were constructed in the field (Appendix I-1) in March, 1977 and placed .7 meters from 'Washington' navel trees in full bloom. A .7 m x 1.3 m area was flagged on each tree for the center of the UV-B treatment. Each flowering shoot was tagged, number of flowers determined, type of inflorescence scored and flowers pollinated. The same area was marked, flowers pollinated and data taken on control trees. The FS-40 lamps were filtered with 5 mil cellulose acetate which was changed twice weekly. Irradiation was for 6 hours per day in the center of the photoperiod.

'Washington' navel orange trees were very resistant to damage from UV-B radiation. There were no apparent differences between vegetative or reproductive growth on UV-B treated area and non-treated areas. However, in the fall and winter under increasing water and cold stress, premature leaf abscission was observed to occur. This observation will be used to test interactions of stress on abscission *per se* and on cold tolerance.

EXPERIMENTATION UNDERWAY

UV-B Radiation Activation of Plant Viruses

During the screening trials it was noted that the symptoms at intermediate levels of UV-B irradiance ($2UV\text{-}B_{seu}$) on several species in the Solanaceae and Leguminosae families resembled those observed on viral infected plants. Since seed-borne viruses are prevalent in these two families and cause many production problems in agriculture, a test was made for potato yellow virus on controls and UV-B treated plants of bell pepper, tomato, soybeans and beans. The virus was present in detectable quantities on a few plants in each treatment of bell pepper and beans to indicate some plants were infected. The titer of the virus was slightly higher in the pepper and bean in the 2 $UV\text{-}B_{seu}$ treatment than in the control (mylar) and 4 $UV\text{-}B_{seu}$ treatment. The number of plants infected was also greater for this treatment. On the basis of these observations, tests are underway to determine whether UV-B radiation could be activating latent viruses. The present investigations are underway on bell pepper, soybeans, bean, yellow lupine and citrus. The tests are of two types: 1) obtain seedlings from seed contaminated with the virus, and expose them to various UV-B radiation enhancement levels from emergence until testing for the presence of the virus in the seedling and the titer

of the viruses. 2) innoculate the plants with viruses and determine the rate of increase in the titer with and without exposure to UV-B radiation at different dose levels.

Effects of UV-B Radiation on Reproduction and Vegetative Development of Several Fruit Crops

Containerized flowering plants of peach, blueberry, citrus and apple are being tested in the greenhouse and field for possible effects of UV-B radiation on pollination, fertilization, and fruit-set. These tests were initiated as indicated under the grant and preliminary data are reported for blueberries and citrus. It still must be recognized that with perennial crops, long term studies must be made to be meaningful and these will require ongoing programs.

UV-B BIOLOGICAL AND CLIMATE EFFECTS RESEARCH

TERRESTRIAL FY 77

IMPACT OF SOLAR UV-B RADIATION ON CROP PRODUCTIVITY

FEBRUARY 28, 1978 APPENDIX I FINAL REPORT

BY

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Appendix I Color Photographs

1. Color indicators on the photographs emphasize the following:

   red = stunting, dwarfism

   yellow = chlorosis, tip burn

   blue = lateral bud breaking

   green = cupping of leaves (concave or convex)

   orange = reduction in vineness (twining)

   white = red pigments

2. UV-B enhancement: Mylar = control, no UV-B radiation.

   $UV\text{-}B_{seu}$: 0.5, 1.0, 1.5 and 2.0.

   For soybean: 1 = 0.5, 2 = 1.0, 3 = 1.5, and 4 = 2.0 $UV\text{-}B_{seu}$.

3. Pages 1-4: Field and greenhouse experiments.

4. Pages 5-22: Duke University Phytotron growth chamber screening study, 82 species, 5 UV-B enhancement regimes.

   Page 5: Growth chamber with experiment in progress.

   Page 6-11: Chenopodiaceae, Cruciferae, Compositae

   Page 12-13: Cucurbitaceae

   Page 14-16: Leguminosae

   Page 17-18: Gramineae

   Page 19-20: Pinaceae

   Page 21 : Solanaceae, Liliaceae

   Page 22 : Malvaceae, Leguminosae, Compositae - favored and resistant species.

5. Duke University Phytotron "C" environmental chamber variety testing:

   Page 23-26: Individual soybean varieties from each of the 5 UV-B enhancement regimes.

Page 27-31: Comparison of several soybeans from separate UV-B enhancement regimes and symptomology.

Page 32-33: Watermelon varieties.

6. Page 34: Field grown soybeans (Gainesville, Fl.) which may be UV stressed (1977).
7. Page 35-37: Duke University Phytotron greenhouse grown soybean leaves and set-up for the factorial UV-B/PAR study.
8. Page 38-39: Comparison of soybeans and wheat by PAR and UV-B level.
9. Page 40: Xenon lamp irradiator and avocado leaf exposed to different UV-B wavelengths for different times. Note pigmentation development.
10. Page 41: Tenn. Flat beans and tomatoes irradiated under laboratory conditions.

Appendix I Description of Color Photographs

Pictures are identified by position as top (T), middle (M), bottom (B), right (R) or left (L).

Page No.

1. Greenhouse and field irradiators: (TL) FS-40 sun lamps and filter arrangement in greenhouse; (TR) overview of UV-B field irradiator; (ML) citrus tree irradiator; (MR) via-flow watering system for field irradiator; (BL) radishes in the field irradiator; (BR) overview of of UV-B field irradiator.
2. UV-B field irradiator for 1977 crops: (TL) potatoes in bloom; (TR) silverqueen corn at maturity showing reduction in height; (BL) Walter tomatoes; (BR) Southern peas.
3. UV-B field irradiator for 1977 crops: (TL) Florunner peanuts; (TR) Star Bonnet rice; (BL) Florunner peanuts in bloom; (BR) yellow neck squash.
4. UV-B field irradiator for 1977 crops: (TL) marginal chlorosis on mustard; (TR) mustard; (BL) Star Bonnet rice; (BR) environmental measurement station adjacent to field irradiator.
5. Plants inside the Duke University Phytotron environmental "C" chamber. Note FS-40 sun lamps, filter arrangement and reflective walls. See table 1 for list of species in Phytotron screening study including the number of weeks each was grown before harvest and pictures were taken.
6. Phytotron screening study, 1977: (TL) artichoke; (TR) broccoli; (ML) brussel sprouts; (MR) cabbage; (BL) cauliflower; (BR) cauliflower.
7. Phytotron screening study, 1977: (TL) chard; (TR) collards; (ML) chard; (MR) collards; (B) chard.

8. Phytotron screening study, 1977: (TL) kale; (TR) kale; (ML) kohlrabi; (MR) kohlrabi; (BL) kohlrabi; (BR) lettuce.

9. Phytotron screening study, 1977: (TL) mustard; (TR) rubarb; (ML) mustard; (MR) rutabega; (B) rutabega.

10. Phytotron screening study, 1977: (T) radish; (M) mylar radish; (B) x 2.0 UV-B $_{seu}$ radish with cupped and chlorotic leaves.

11. Phytotron screening study, 1977 showing cupping and marginal chlorosis of Cruciferae seedlings: (TL) radish; (TR) brussel sprouts; (ML) kohlrabi; (MR) kale; (B) cabbage.

12. Phytotron screening study, 1977: (TL) cucumber; (TR) Hales best jumbo cantelope; (ML) honeydew melon; (MR) watermelon; (B) pumpkin.

13. Phytotron screening study, 1977: (TL) acorn squash; (TR) early summer squash; (BL) prolific squash; (BR) zucchini squash.

14. Phytotron screening study, 1977: (TL) garden bean; (TR) Jackson wonder lima bean; (ML) pinto beans; (MR) Tenn. Flat bean; (BL) White Dixie butterpea; (BR) White Dixie butterpea.

15. Phytotron screening study, 1977: (TL) Blackeye No. 5 cowpeas; (TR) blackeye peas; (BL) Jackson wonder lima bean; (BR) little marvel English peas.

16. Phytotron screening study, 1977: Hardd soybean: (TL) 4 UV-B_{seu} levels; (TR) x 2.0 UV-B_{seu}; (ML) release from apical dominance; (MR) bronzing; (BL) chlorosis; (BR) bronzing.

17. Phytotron screening study, 1977: (TL) Arivat barley; (TR) Silver-queen corn; (ML) chufas; (MR) oats; (BL) Lebonnet rice; (BR) brown top millet.

18. Phytotron screening study, 1977: (T) sorghum; (M) Jori wheat; (B) Crane wheat.

19. Phytotron screening study, 1977: (TL) loblolly pine; (TR) lodgepole pine; (BL) ponderosa pine; (BR) slash pine.

20. Phytotron screening study; 1977: (TL) noble fir; (TR) white fir; (BL) noble fir; (BR) Douglas-fir.

21. Phytotron screening study, 1977: (TL) bell pepper; (TR) eggplant; (BL) Walter tomato; (BR) onions.

22. Phytotron screening study, 1977: (TL) cotton; (TR) okra; (BL) Florunner peanut; (BR) sunflower.

23. Phytotron soybean variety testing, 1977: (TL) x 2.0 UV-B_{seu} "C" environmental chamber; (TR) Mylar control chamber; (ML) Acadian (MR) Altona, showing release from apical dominance; (B) Altona.

24. Phytotron soybean variety testing, 1977: (TL) Americana; (TR) Biloxi; (ML) Bossier; (MR) Centennial; (BL) Cobb; (R) Davis.

25. Phytotron soybean variety testing, 1977. (TL) Forrest; (TR) Hardee; (ML) Hood; (MR) Hutton; (BL) Jupiter; (BR) Mineira.

26. Phytotron soybean variety testing, 1977: (TL) Otootan; (TR) Roanoke; (M) Santa Maria; (B) Seminole.

27. Phytotron soybean variety testing, 1977, comparison among Acadian, Americana, Altona, Biloxi, Bossier, Centennial varieties (T) Mylar; (M) x 2.0 UV-B_{seu} (B) x 1.0 UV-B_{seu}.

28. Phytotron soybean variety testing, 1977, comparison among Cobb, Davis, Forrest, Hood, Hutton, and Jupiter varieties: (TL) Mylar; (TR) x 0.5 UV-B_{seu}; (ML) x 1.0 UV-B_{seu}; (MR) x 1.5 UV-B_{seu}; (B) x 2.0 UV-B_{seu}.

29. Phytotron soybean variety testing, 1977, comparison among Mineira, Hardee, and Santa Maria varieties: (TL) Mylar; (TR) x 0.5 UV-B_{seu}; (ML) x 1.0 UV-B_{seu}; (MR) x 1.5 UV-B_{seu}; (B) x 2.0 UV-B_{seu}.

30. Phytotron soybean variety testing, 1977, comparison among Mineira, Otootan, Pickett, Roanoke and Seminole varieties: (TL) Mylar; (ML) x 1.0 UV-B_{seu}; (MR) x 1.5 UV-B_{seu}; (B) x 2.0 UV-B_{seu}.

31. Phytotron soybean variety testing, 1977: Individual plant pictures showing reduction in leaf area, chlorosis and leaf cupping.

32. Phytotron Charleston Gray watermelon variety testing, 1977, comparison among Charleston Gray control, Charleston Gray Fl. 77-1 and 77-2: (T) Mylar; (M) x 1.0 UV-B_{seu}; (B) x 2.0 UV-B_{seu}.

33. Phytotron Charleston Gray watermelon variety testing, 1977: (TL) Mylar; (TR) Fl. 77-1; (BL) 77-2; (BR) Charleston Gray control.

34. Field grown soybeans at the University of Florida, Gainesville, Fl. showing symptoms similar to UV-B affected plants grown under greenhouse and Phytotron conditions.

35. PAR X UV-B study: (TL, TR) Phytotron greenhouse set-up with different shading and UV-B levels; (ML) leaf, 100% sun, mylar; (MR) leaf, 100% sun, 0.5 UV-B_{seu}; (BL) leaf, 100% sun, 1.0 UV-B_{seu}; (BR) leaf, 100% sun, 2.0 UV-B_{seu}.

36. PAR X UV-B study: (TL) leaf, 67% sun, 0.5 UV-B_{seu}; (TR) leaf 67% sun, 1.0 UV-B_{seu}; (ML) leaf, 67% sun, 2.0 UV-B_{seu}; (MR) leaf, 45% sun, 0.5 UV-B_{seu}; (B) leaf, 45% sun, 1 UV-B_{seu}.

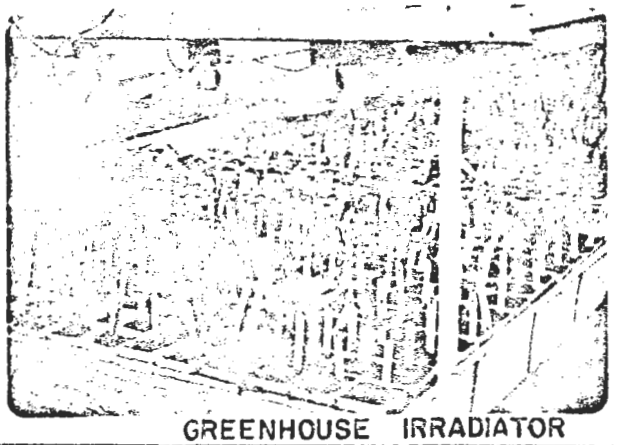
37. PAR X UV-B study: (T) Phytotron greenhouse set-up; (M) leaf, 12% sun, 1.0 UV-B_{seu}; (B) leaf, 12% sun, 2.0 UV-B_{seu}.

38. PAR x UV-B study: Comparison whole plant response of Hardee soybean under mylar, 0.5, 1.0 and 2.0 UV-B_{seu}. (TL) 100% sun; (TR) 67% sun; (BL) 45% sun; (BR) 12% sun.

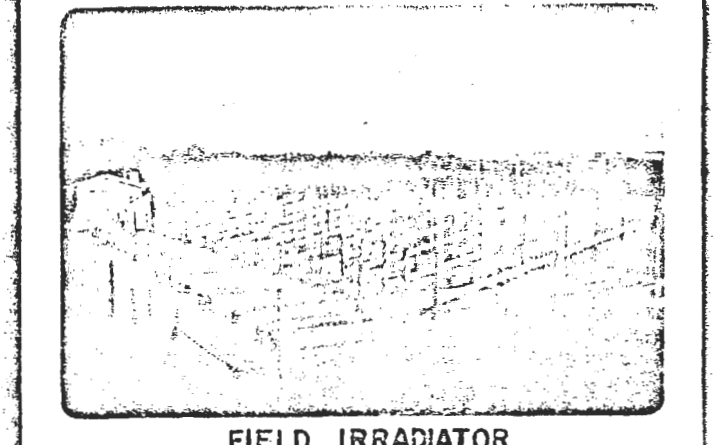
39. PAR X UV-B study: Comparison whole plant response of Jori wheat under mylar, 0.5, 1.0 and 2.0 UV-B_{seu}. (TL) 100% sun; (TR) 67% sun; (BL) 45% sun; (BR) 12% sun.

40. (T) Pigment development in avocado leaf after various time exposures to 7nm bandwidth UV-B radiation supplied by (B) xenon lamp source.

41. Tennessee flat bean and tomato irradiated in the laboratory under FS-40 lamps: (T) whole plant abscission study; (ML) bronzing on bean leaf; (MR) Laboratory set-up for irradiating beans and tomatoes; (B) irradiation of tomatoes in the lab for PAL study.



GREENHOUSE IRRADIATOR



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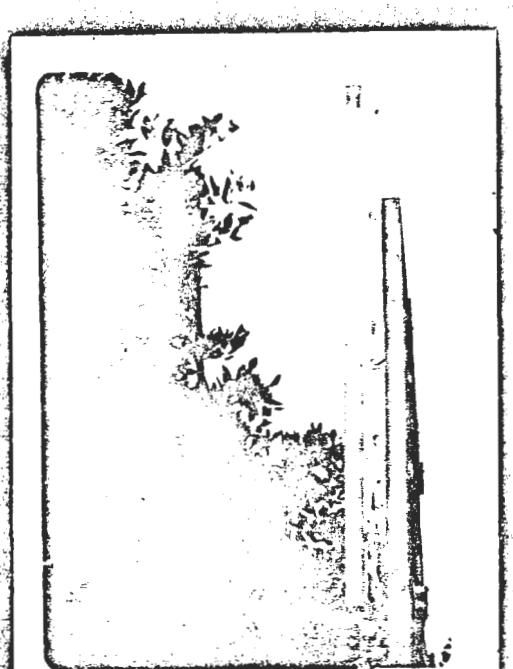

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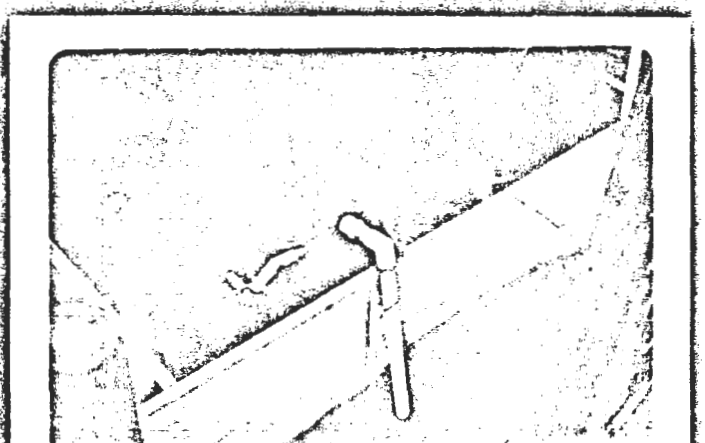

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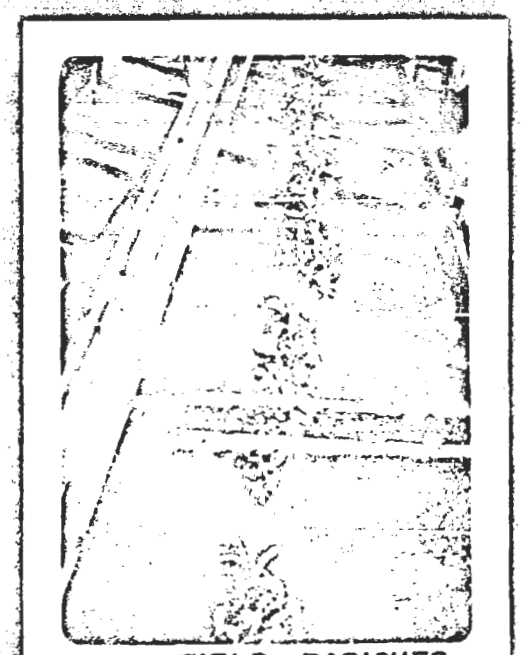

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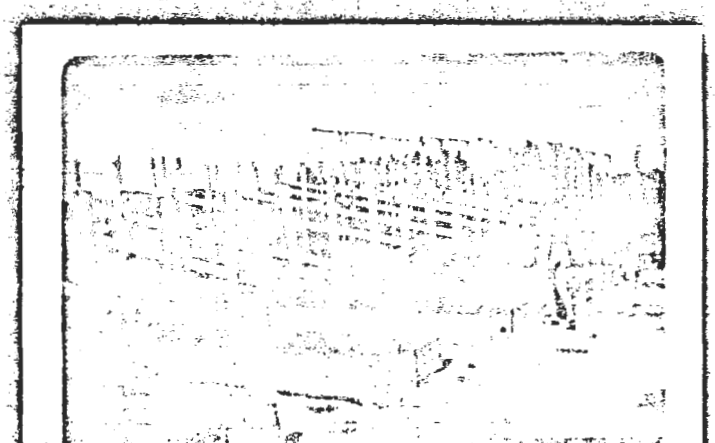

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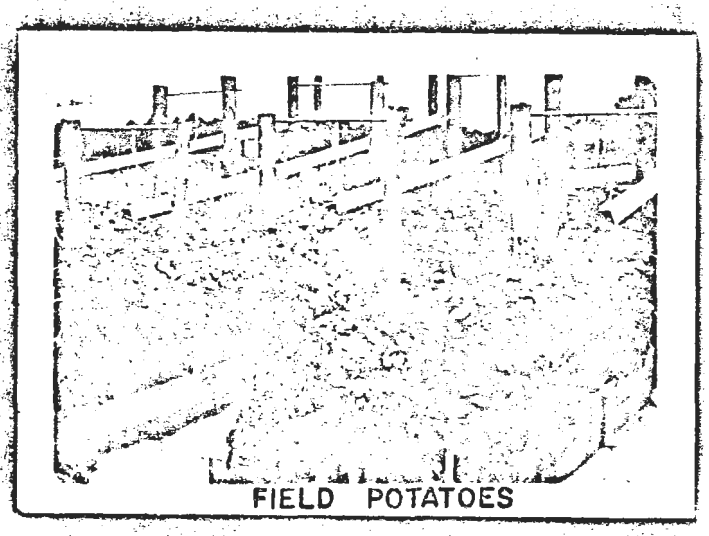

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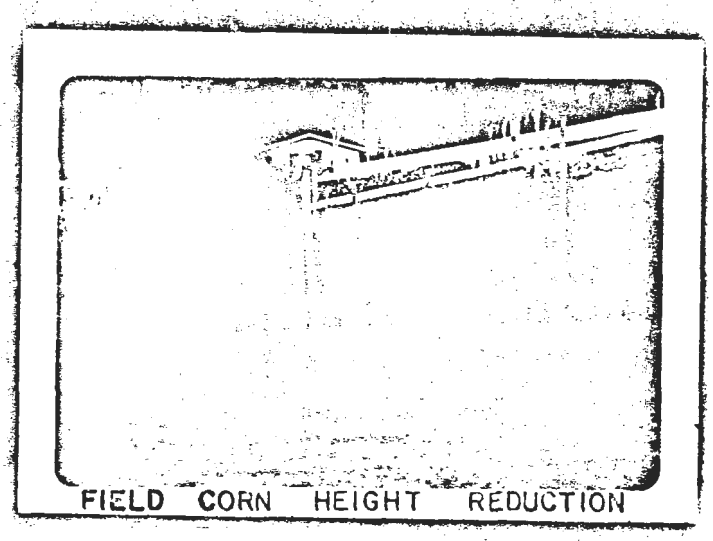

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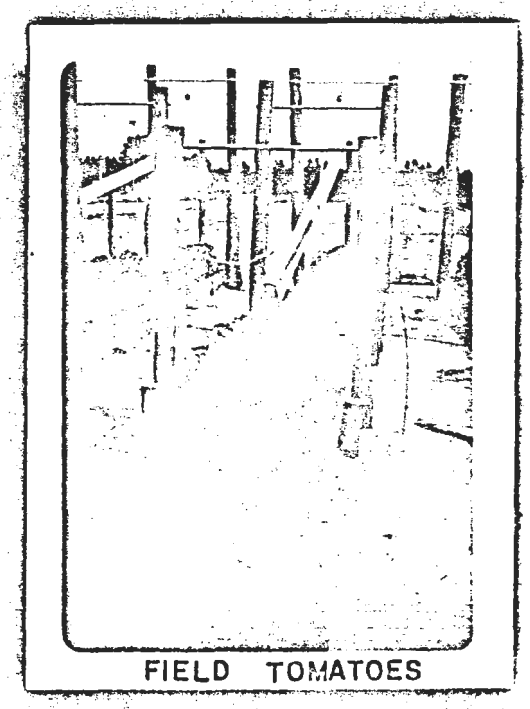

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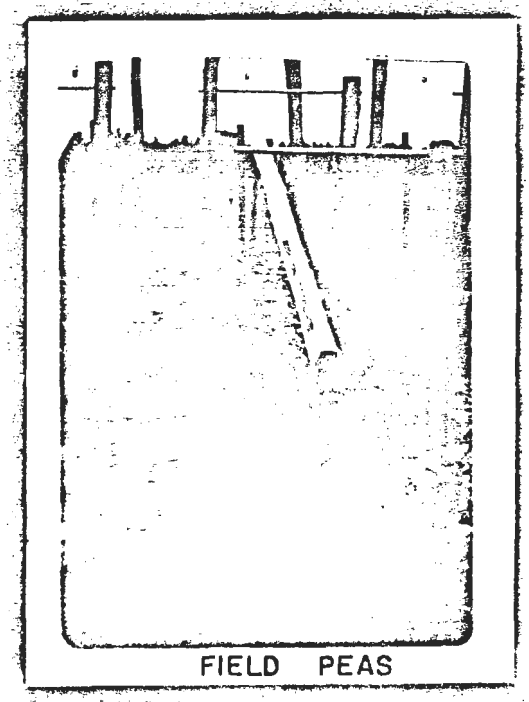

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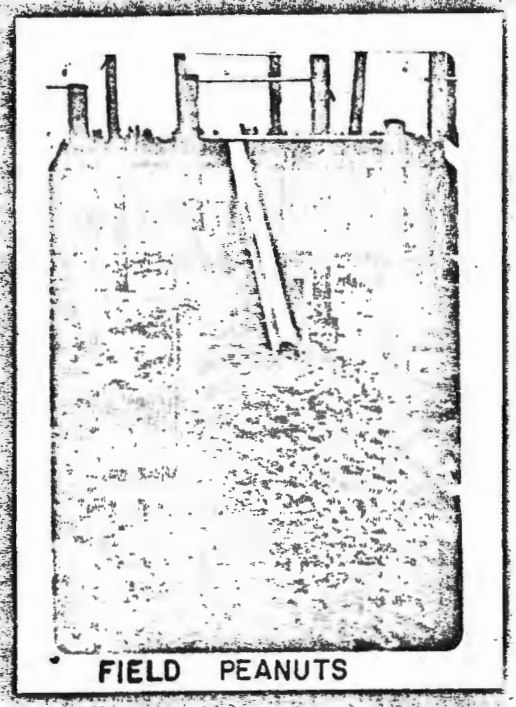

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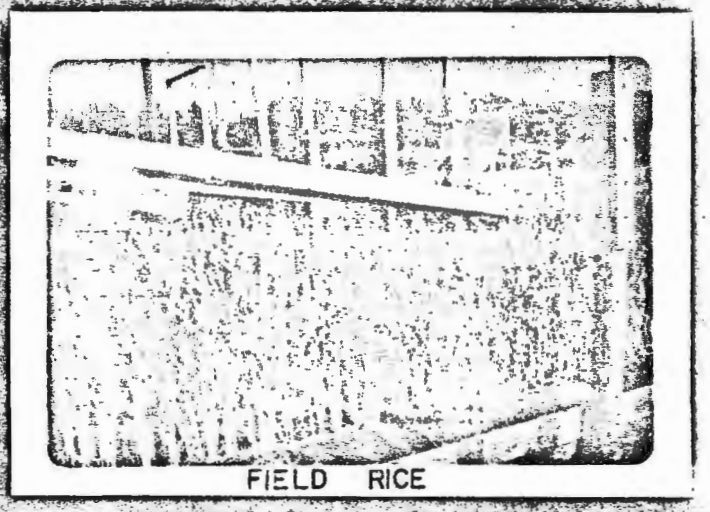

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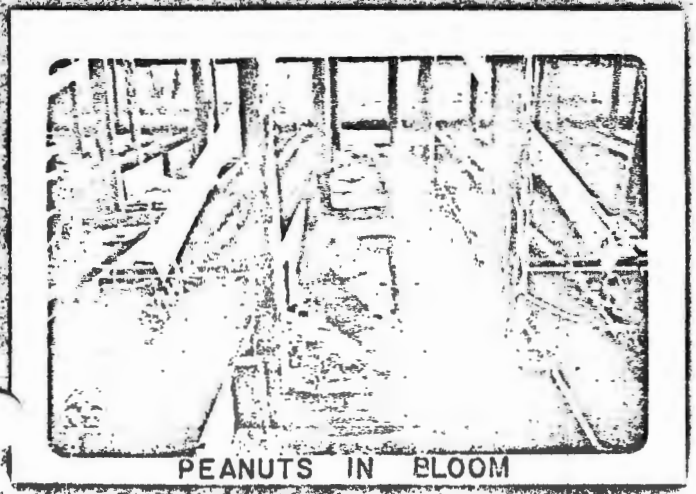

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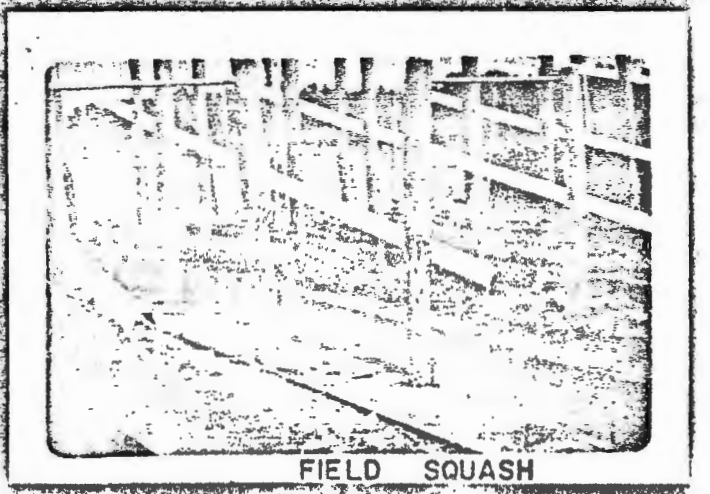

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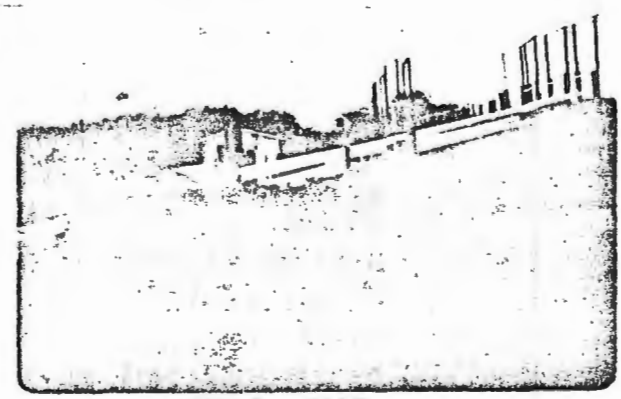
FEILD MUSTARD MARGINAL CHLOROSIS

FIELD MUSTARD



FIELD RICE

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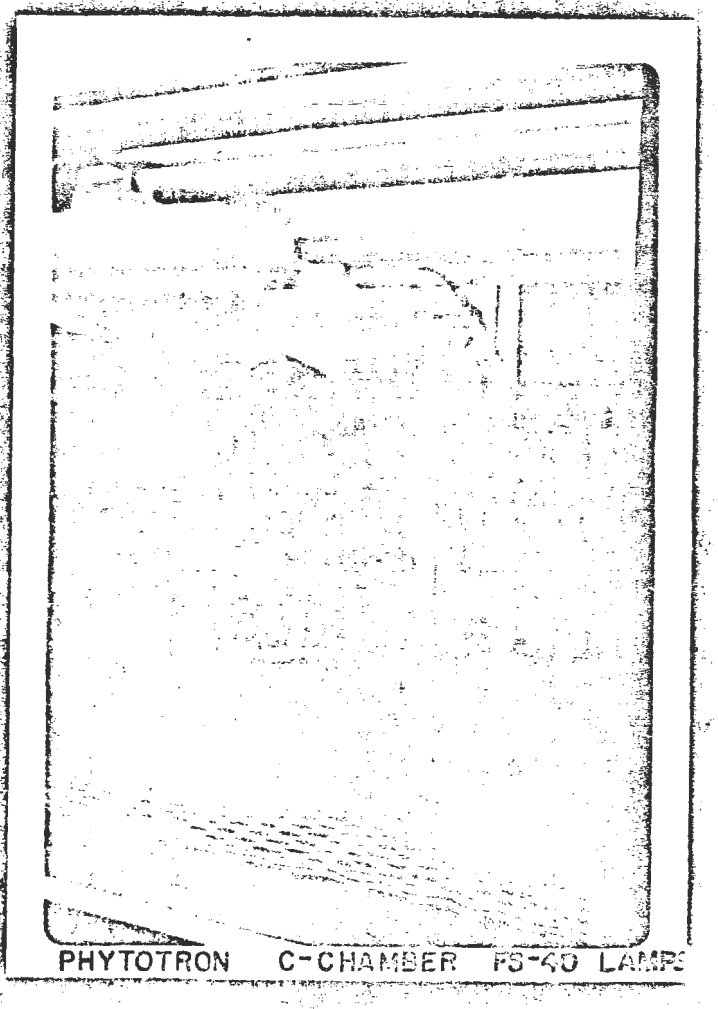

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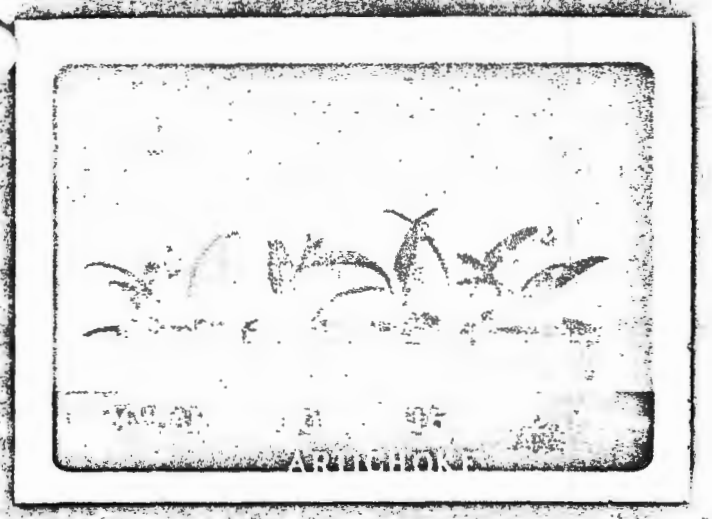
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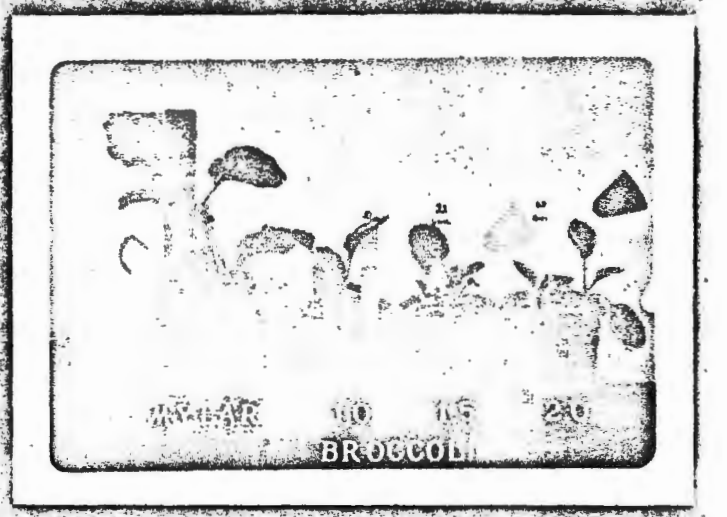
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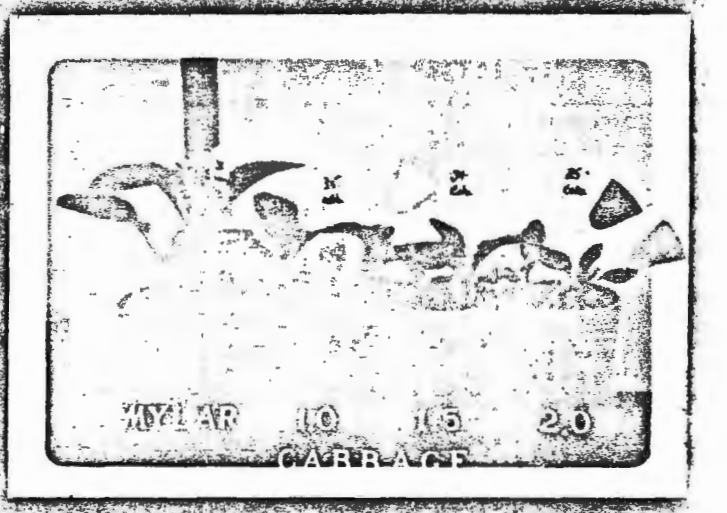
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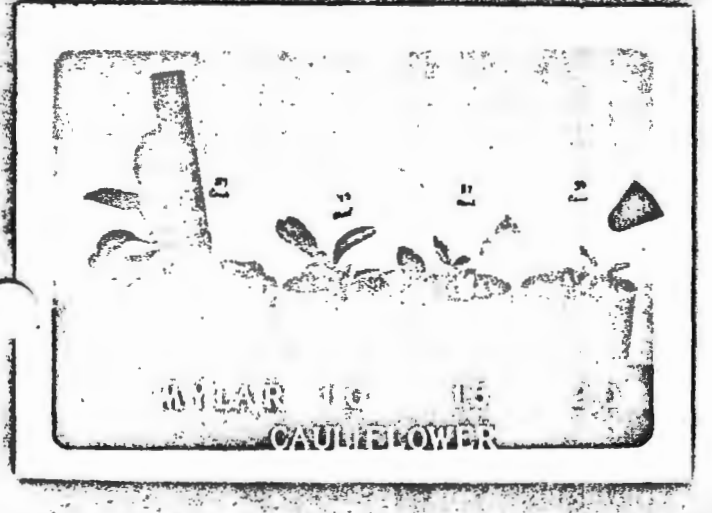
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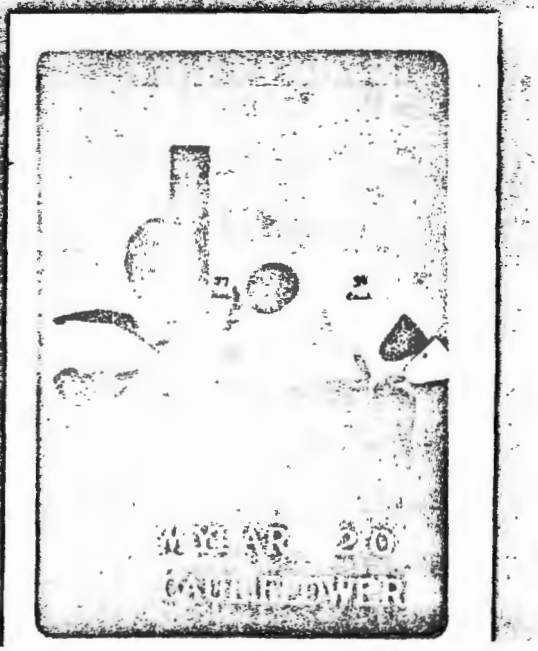
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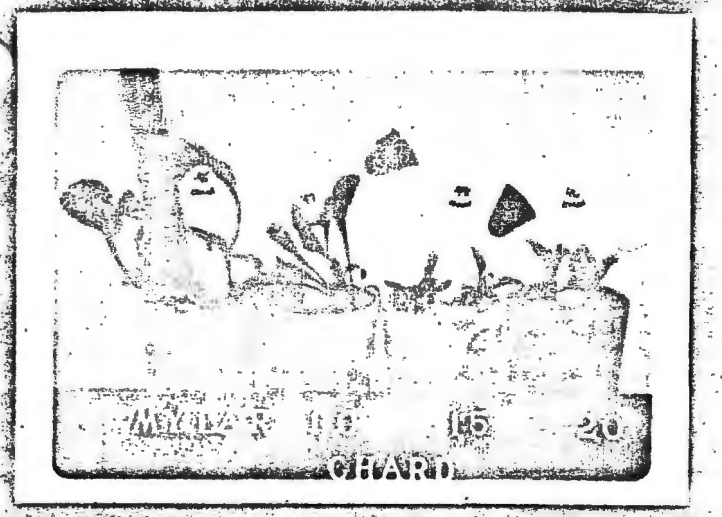
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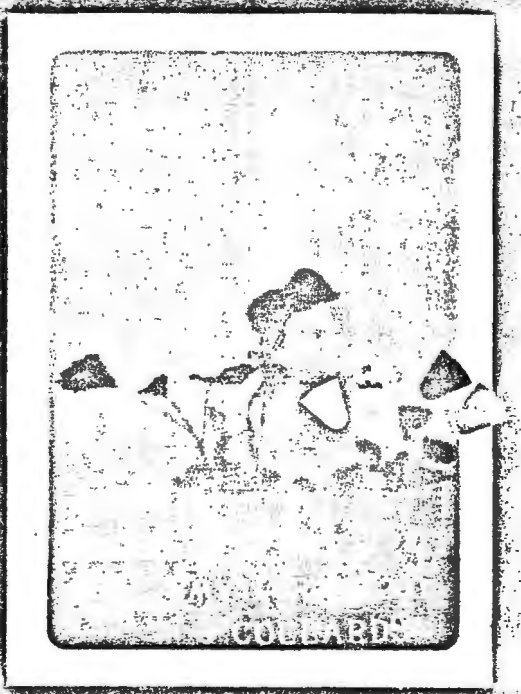

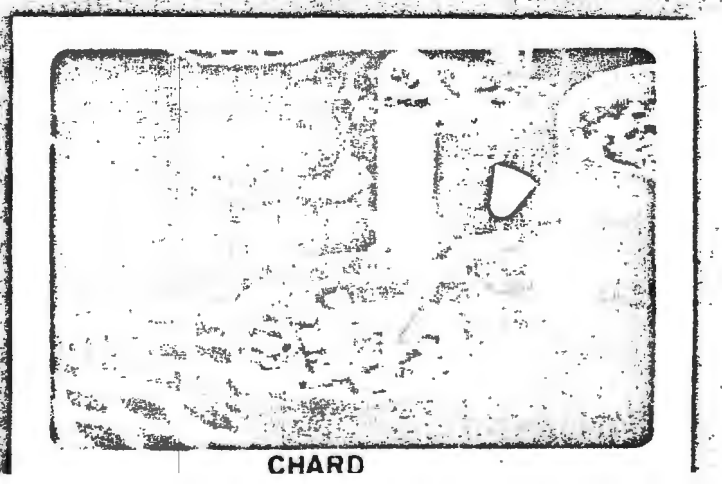
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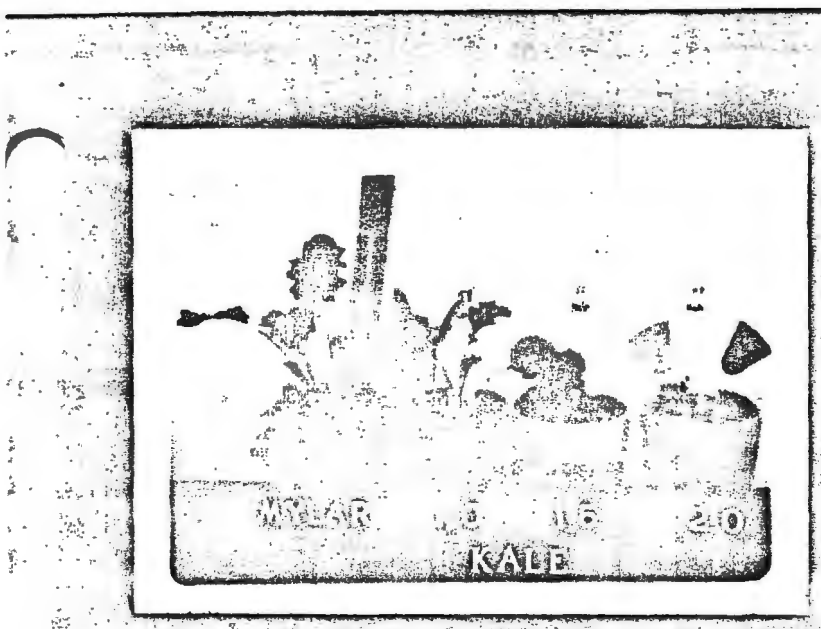
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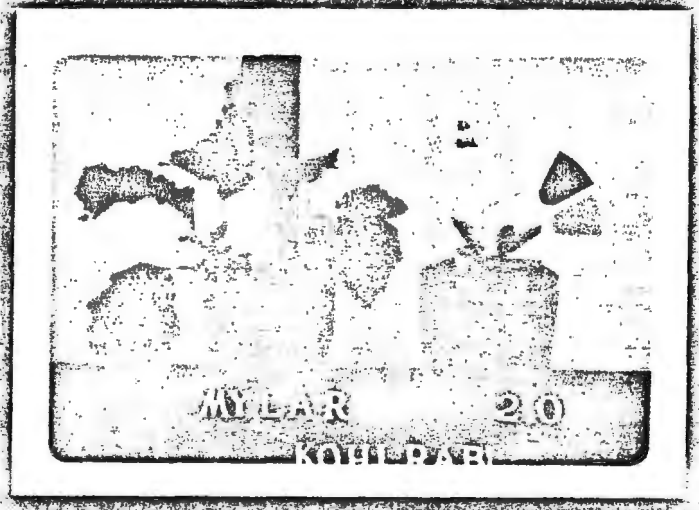
KALE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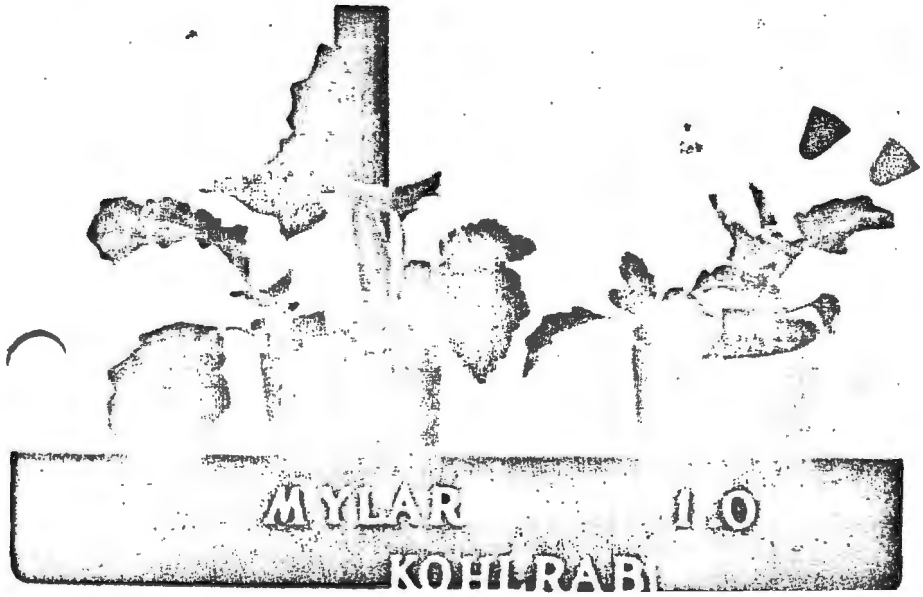
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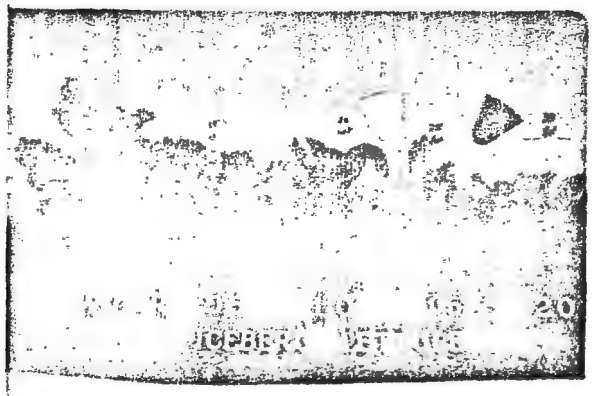

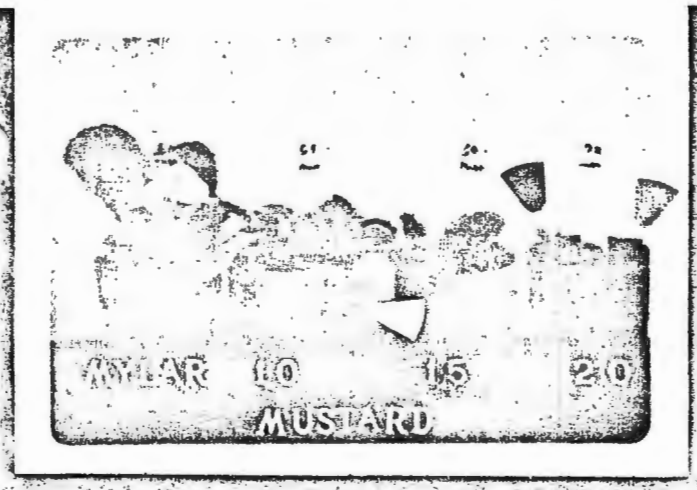
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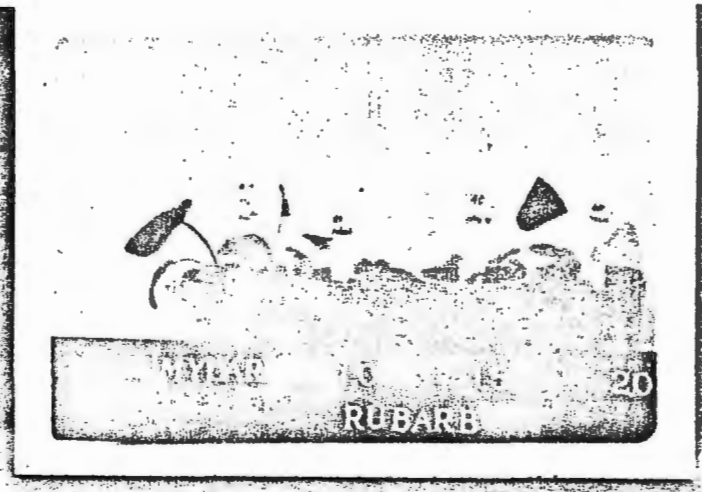
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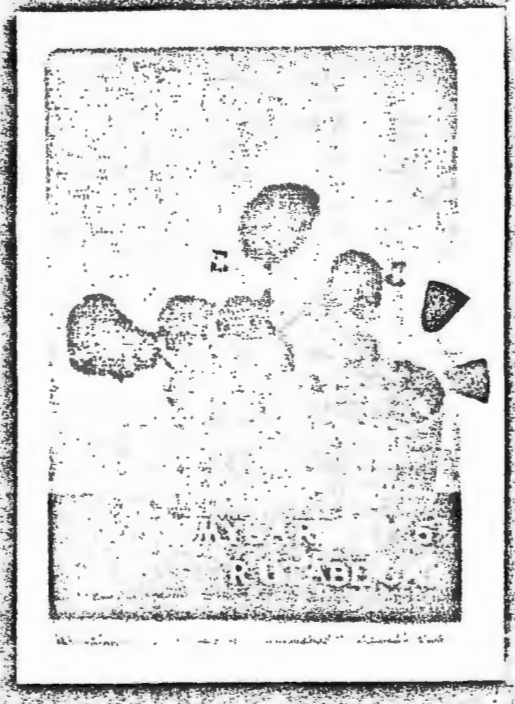

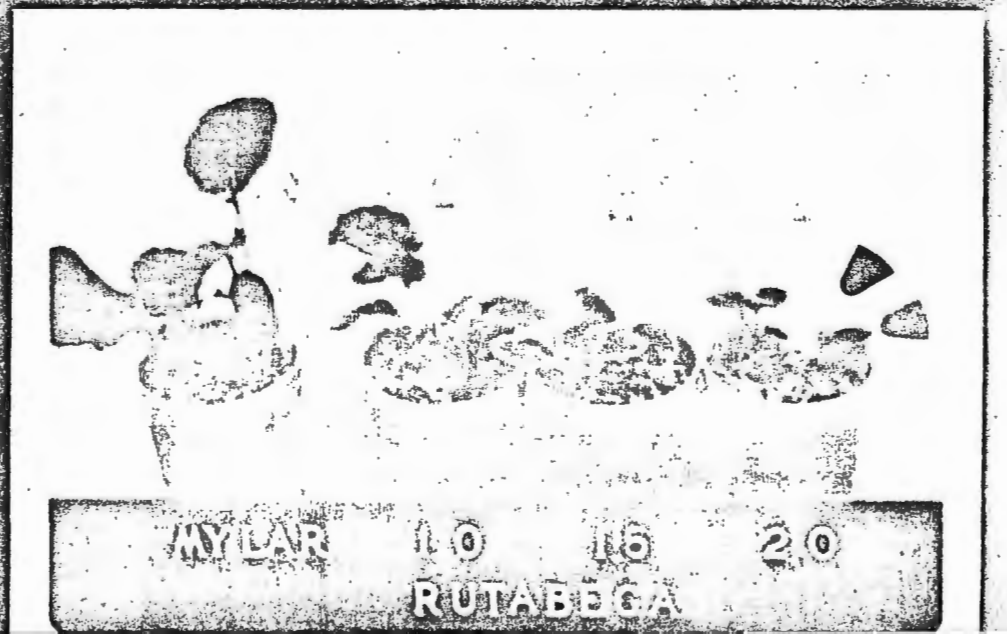
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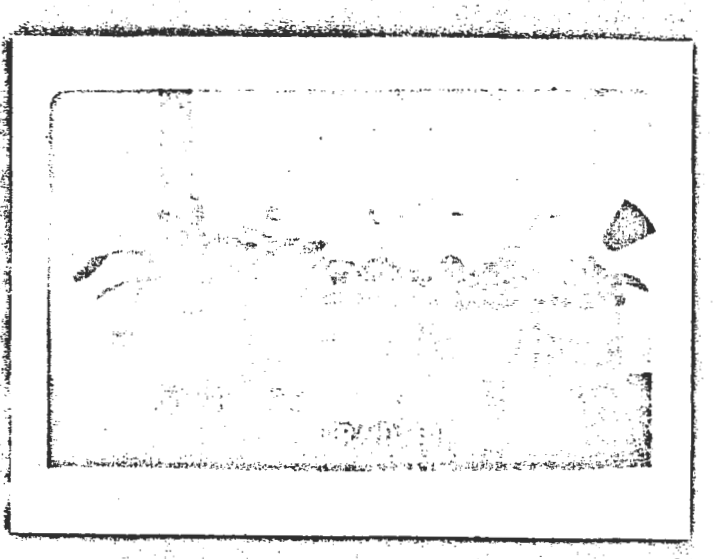

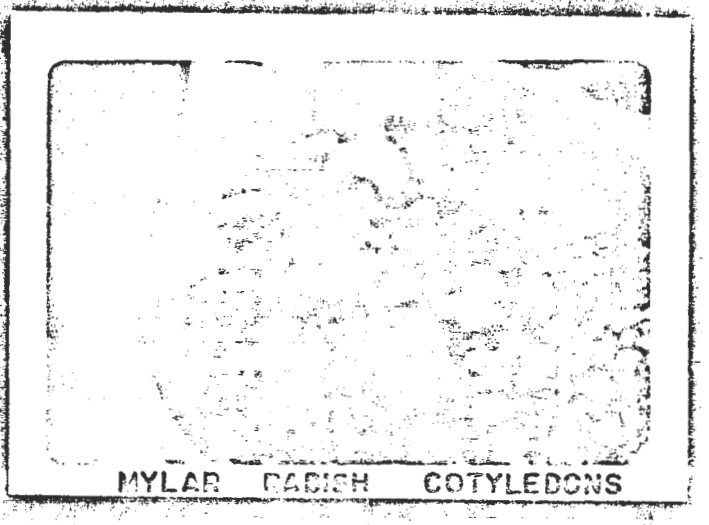
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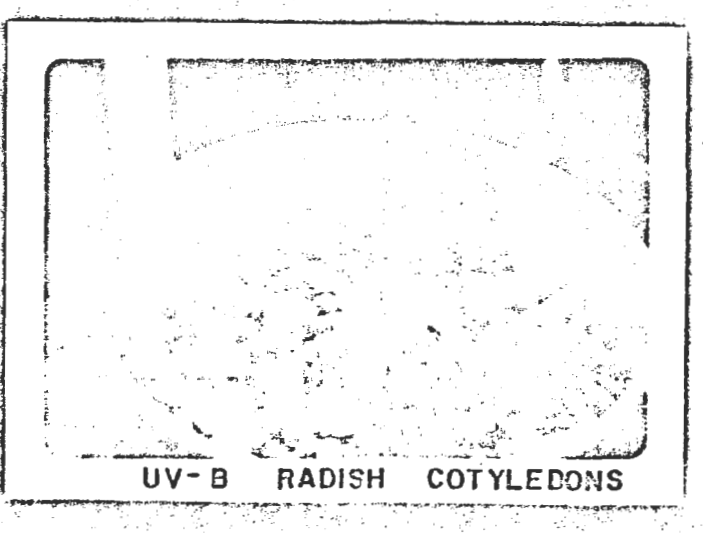
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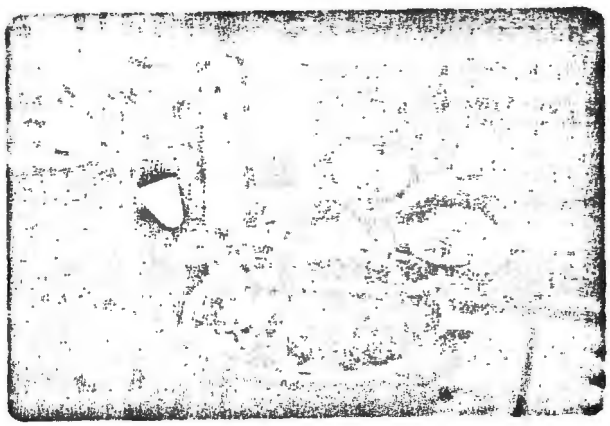

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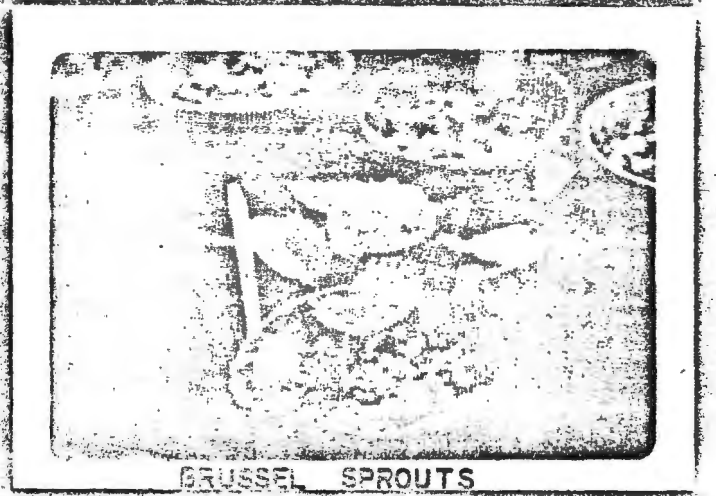

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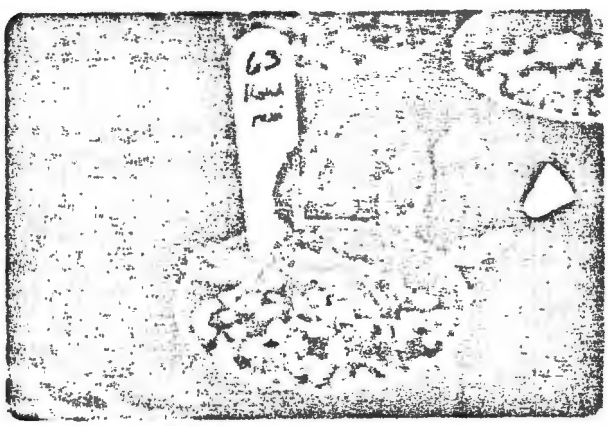

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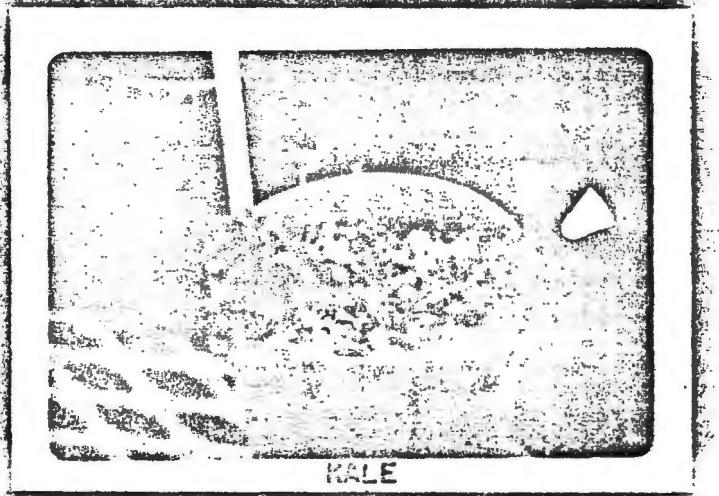

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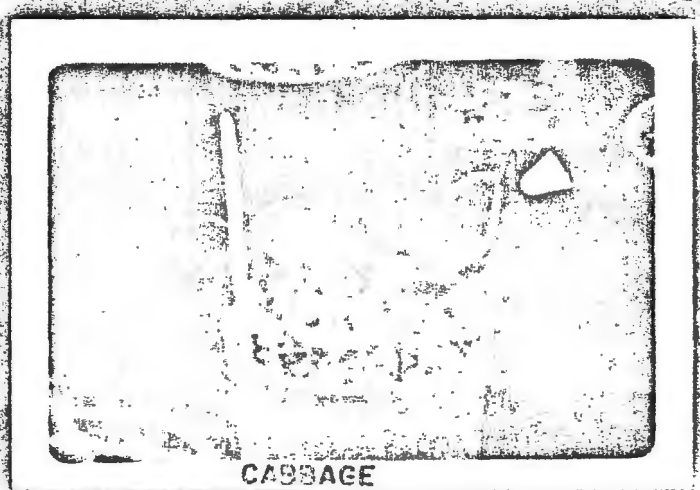

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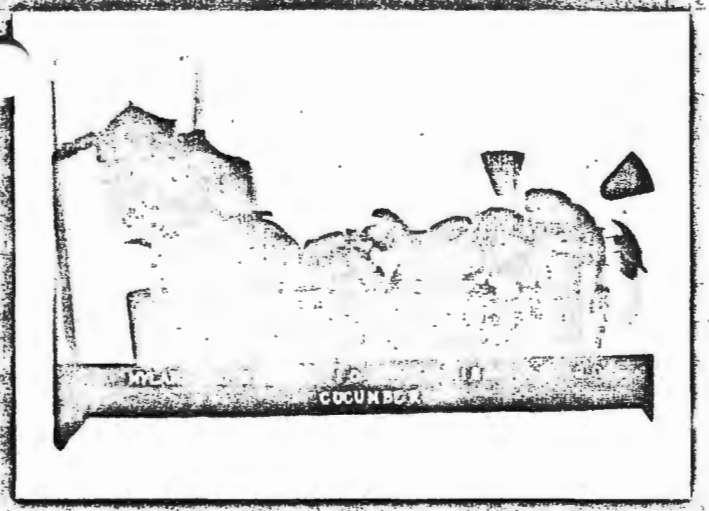
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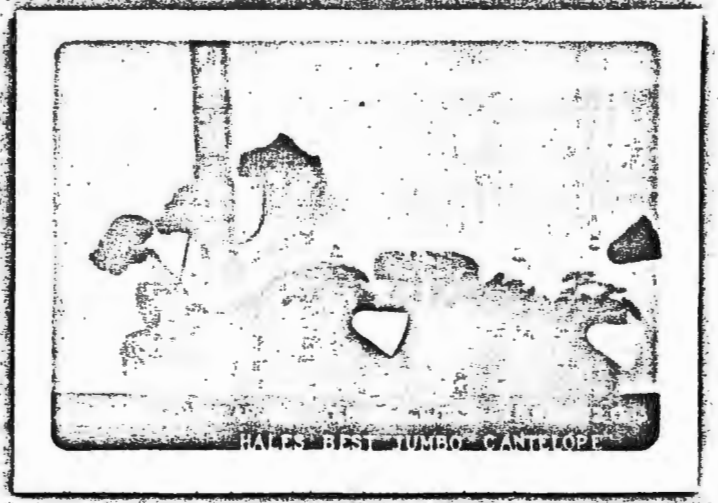
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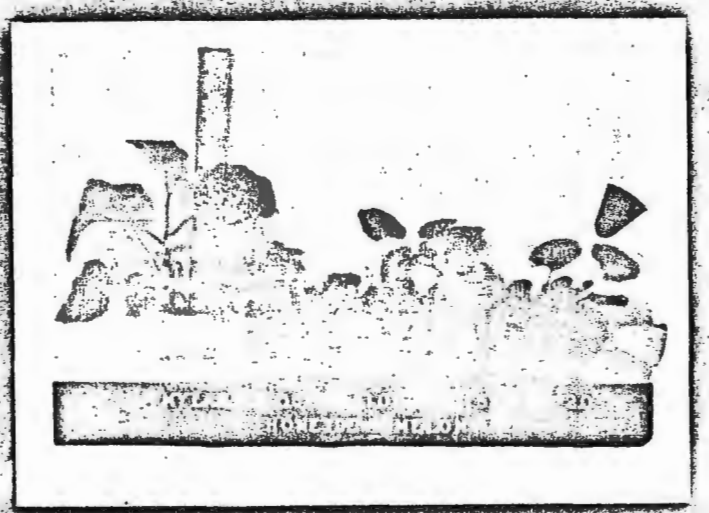

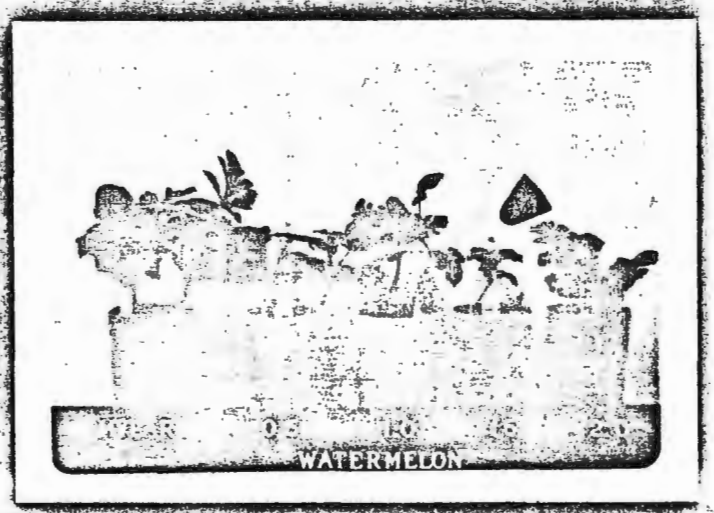
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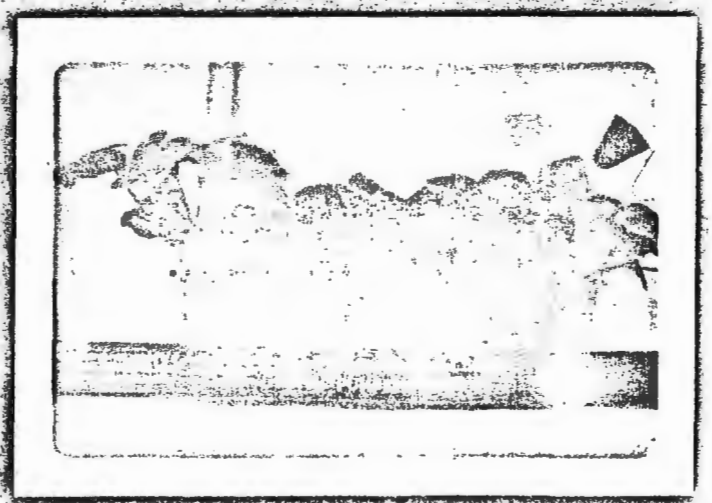

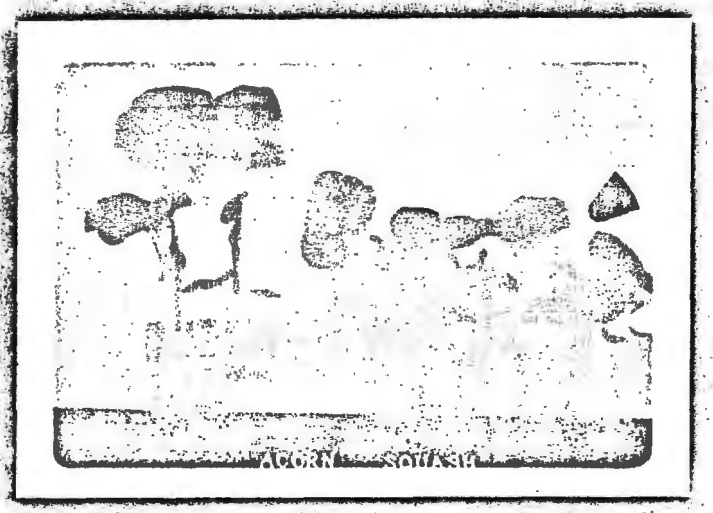

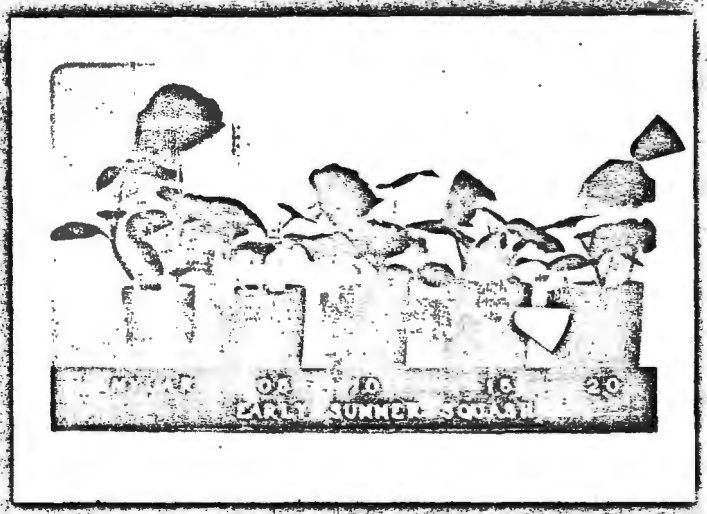

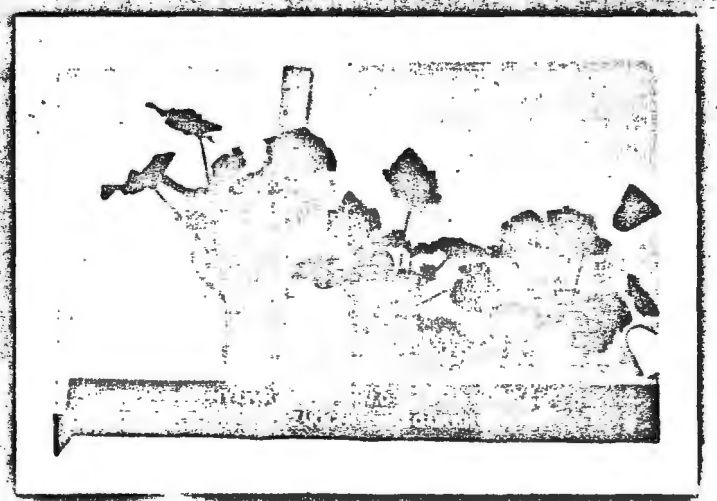

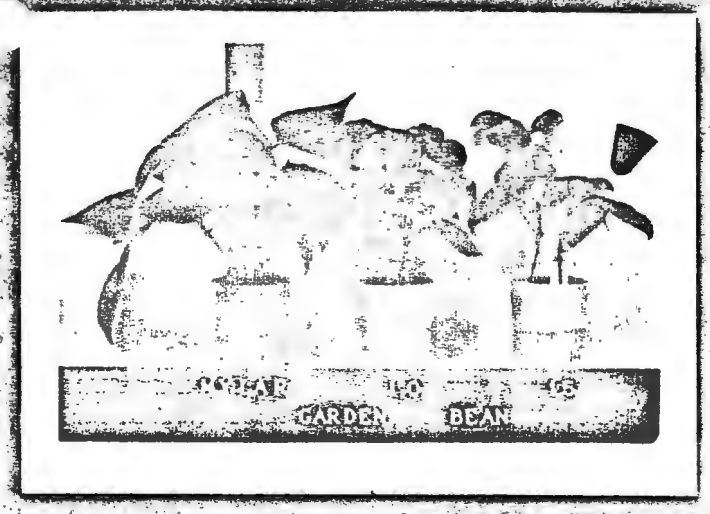
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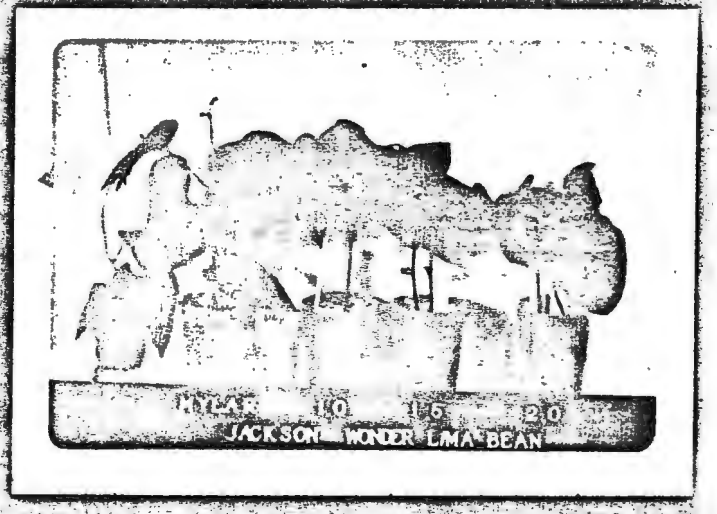
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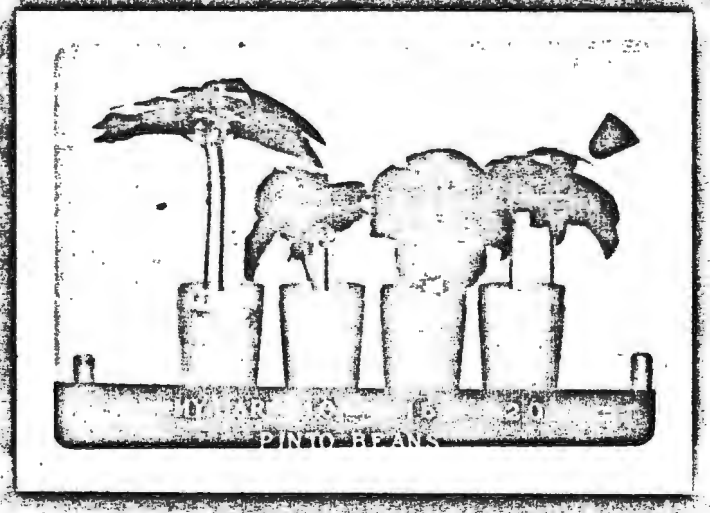
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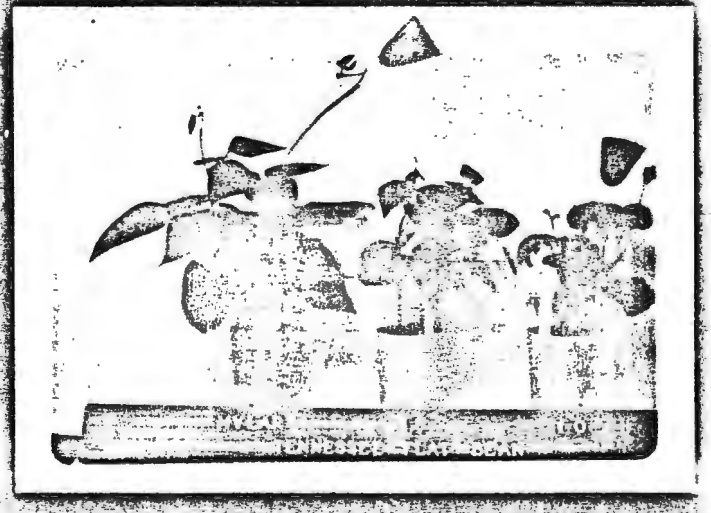

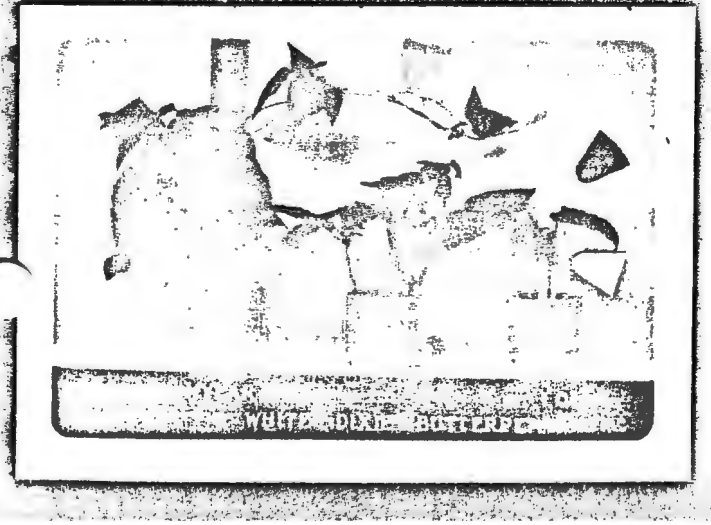

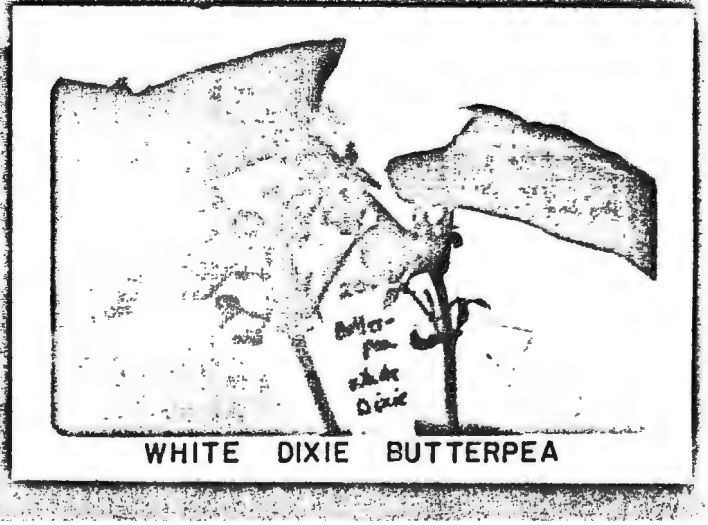
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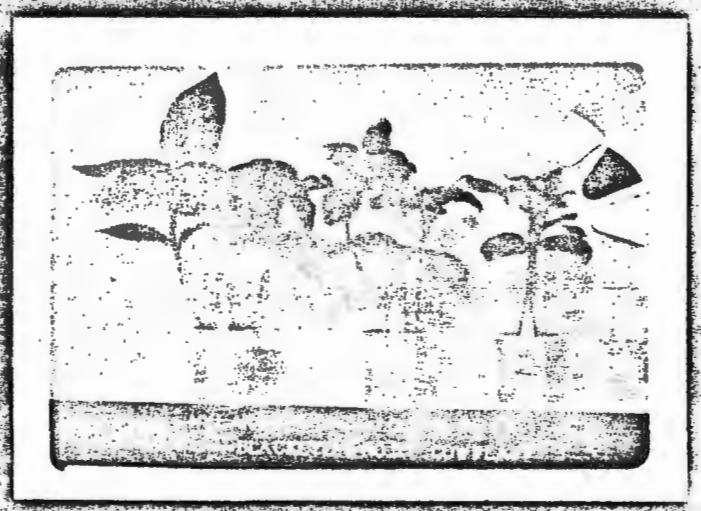

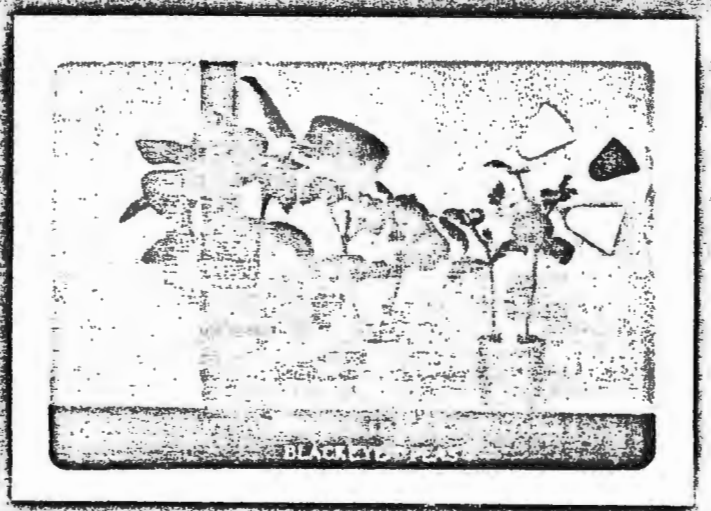

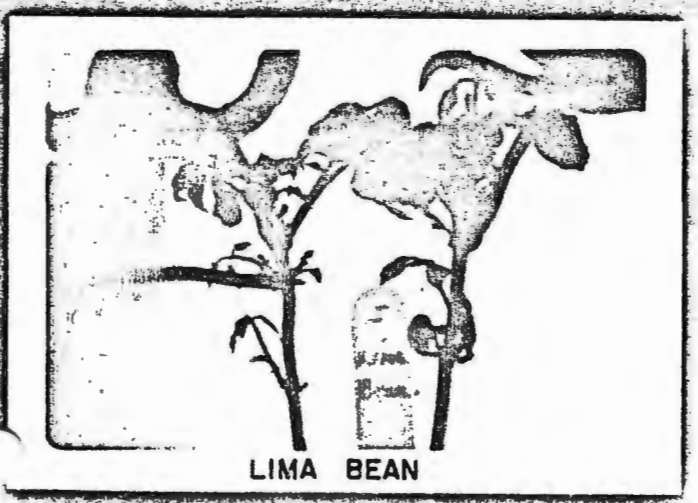
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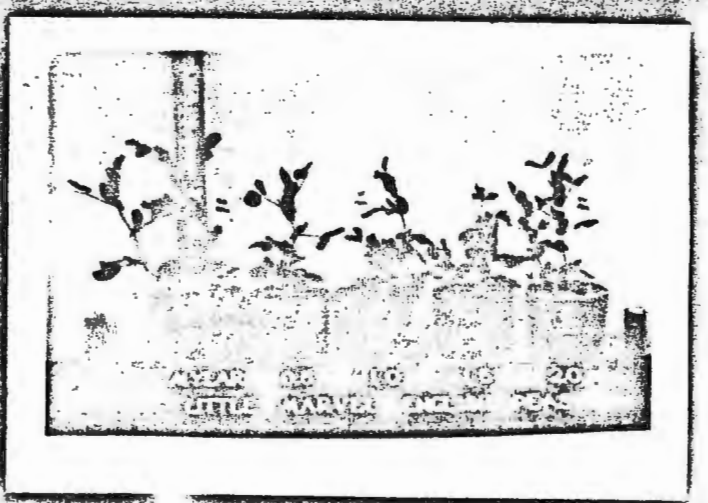

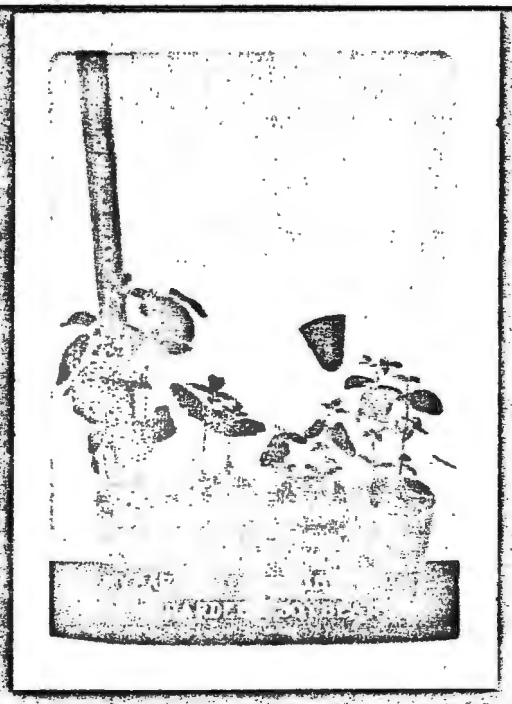

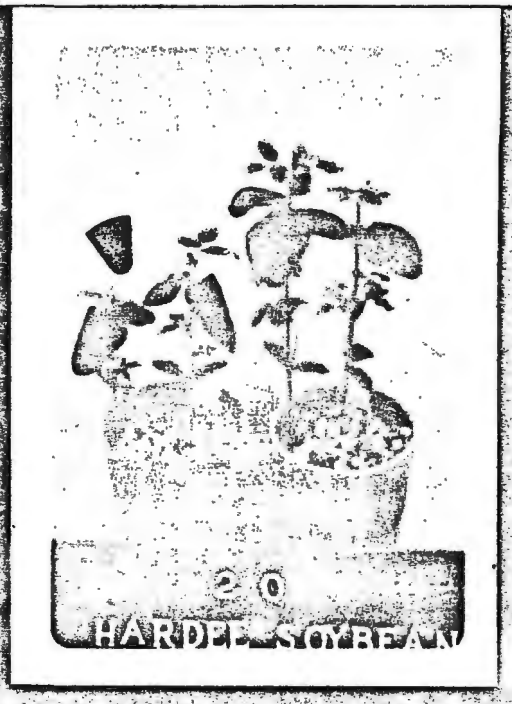
HARDEE SOYBEAN


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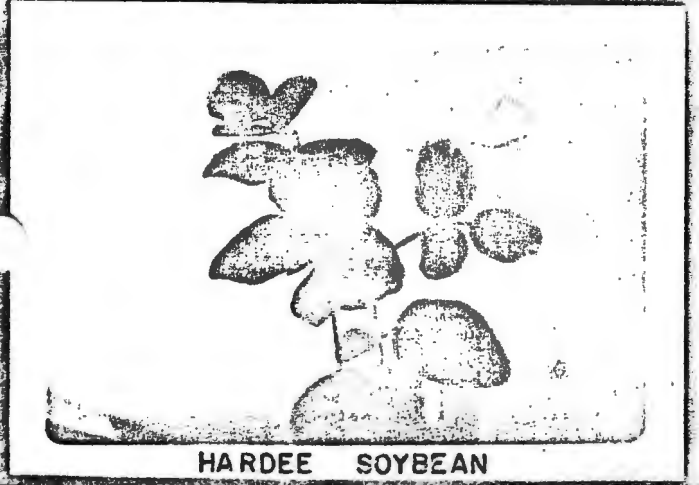
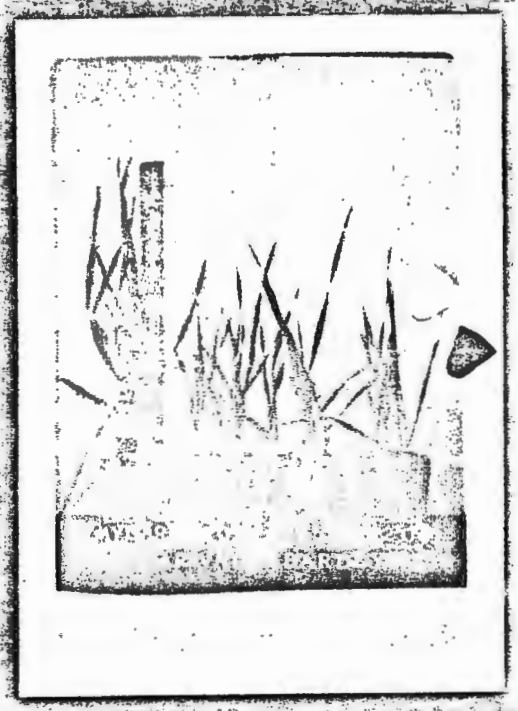
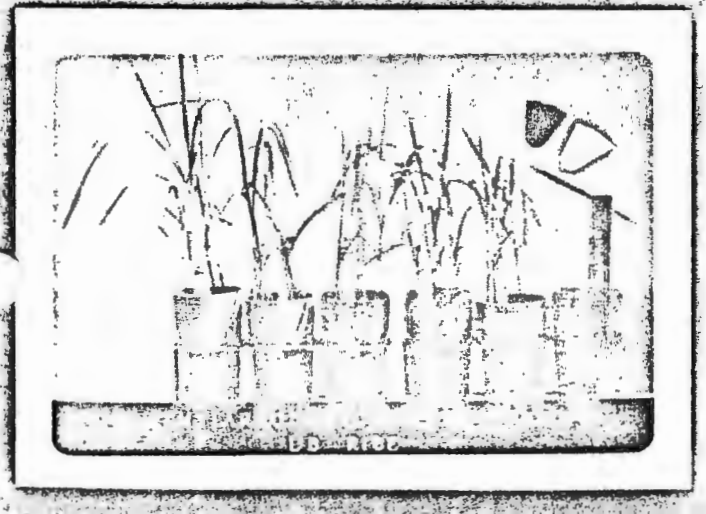
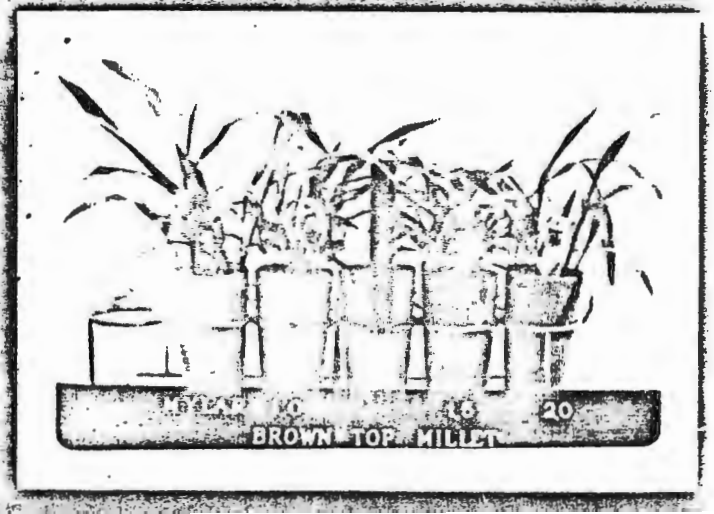

HARDEE SOYBEAN


HARDEE SOYBEAN




SILVERQUEEN CORN

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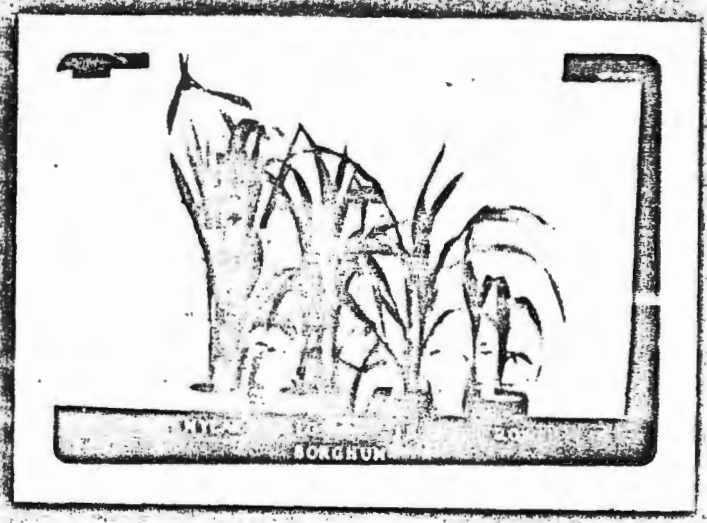
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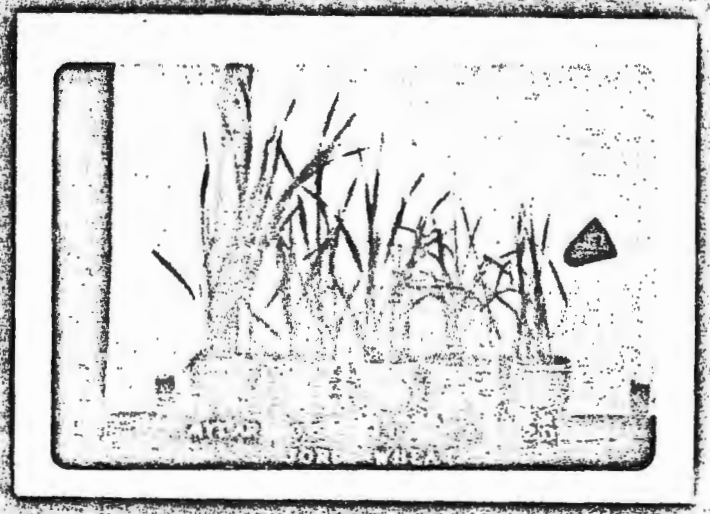
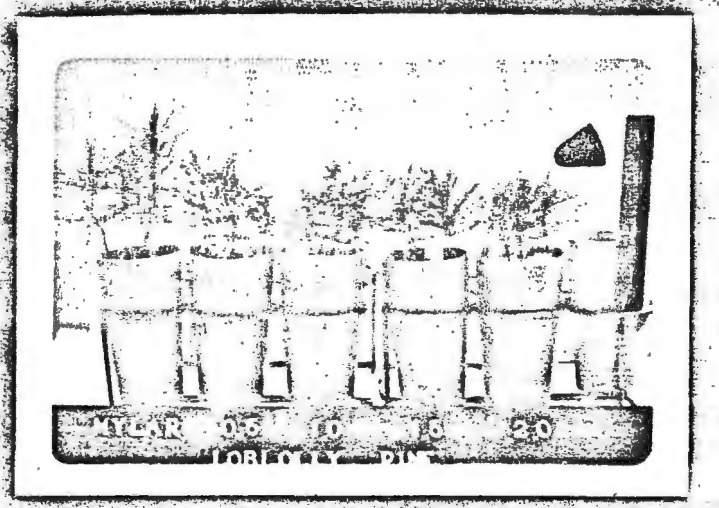
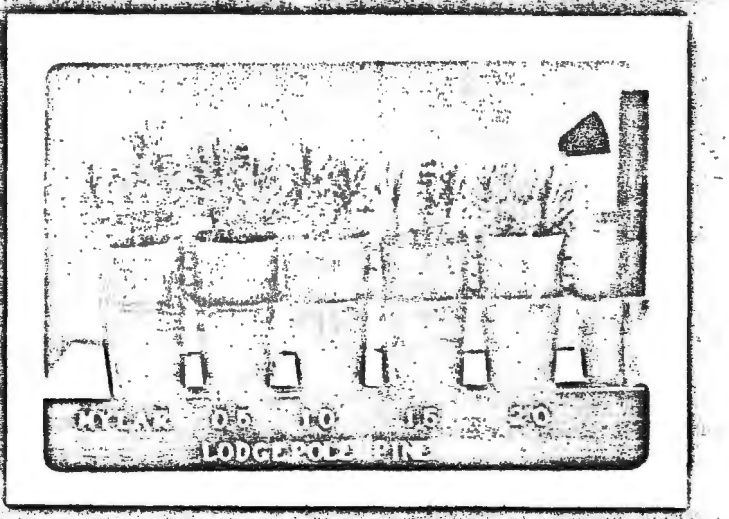
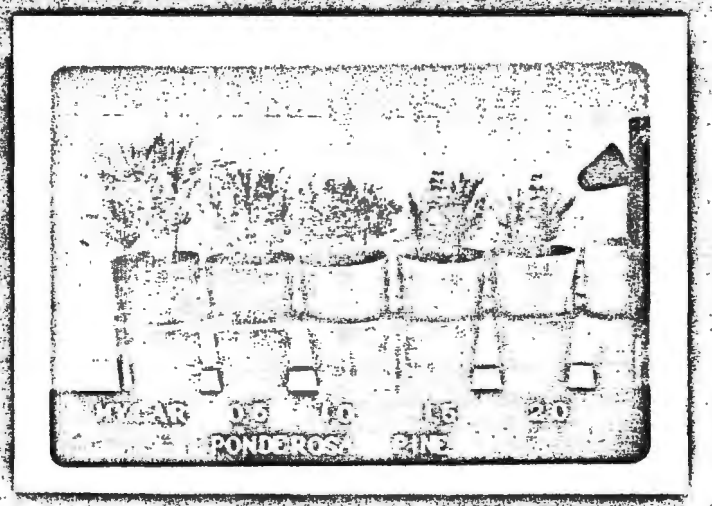
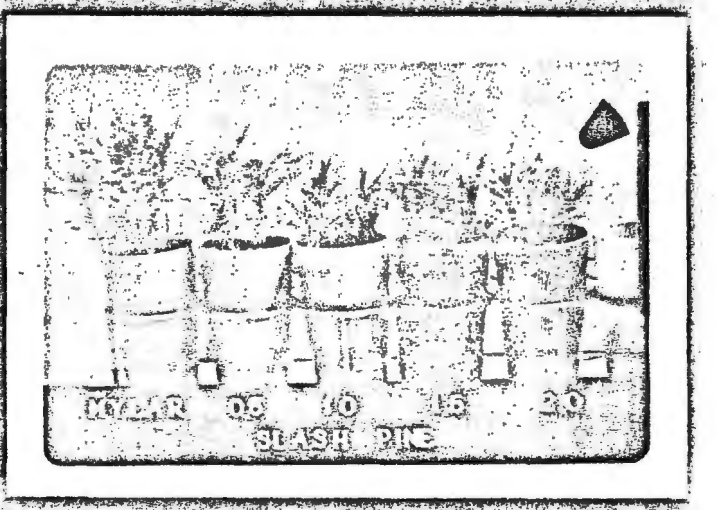





LODGEPOLE PINE

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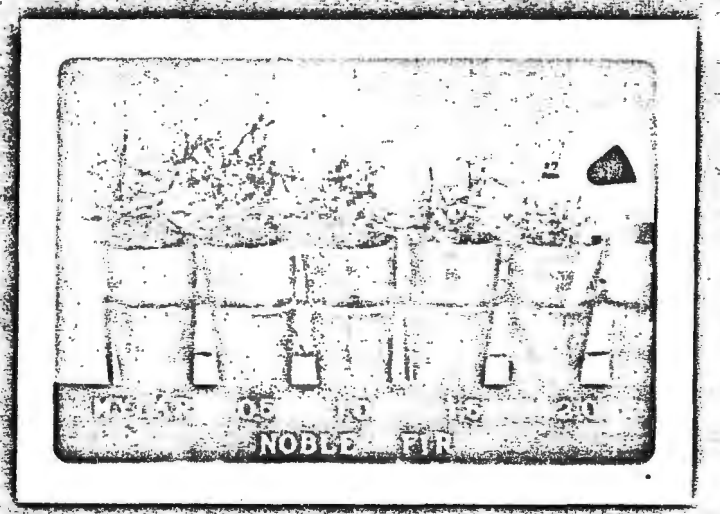
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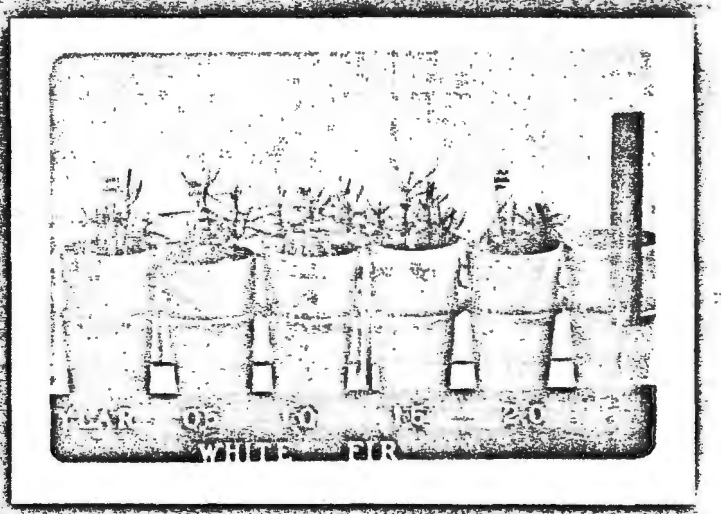
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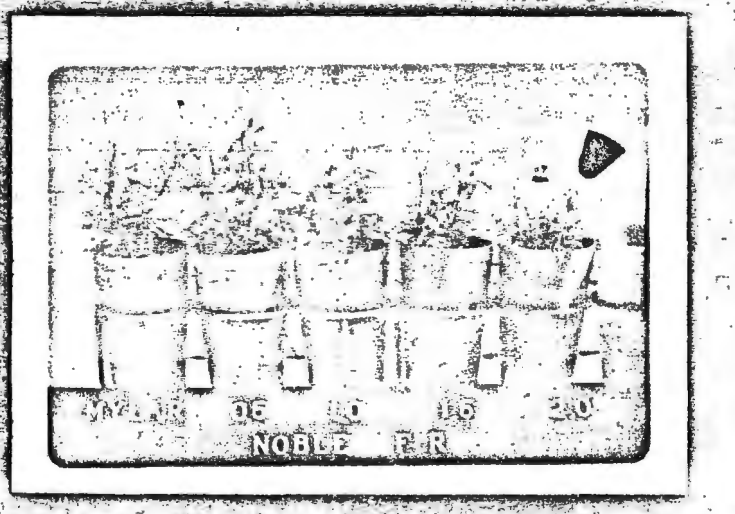
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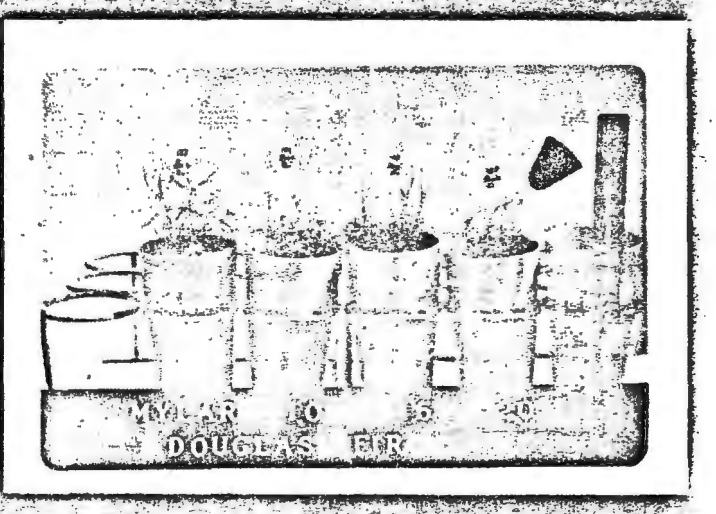
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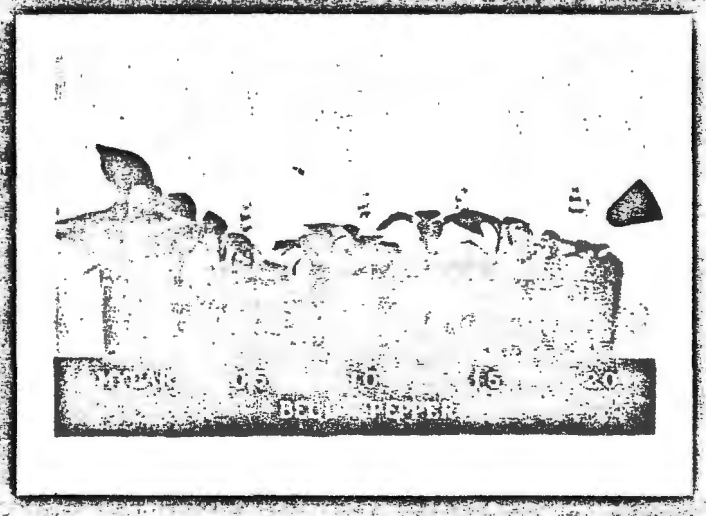

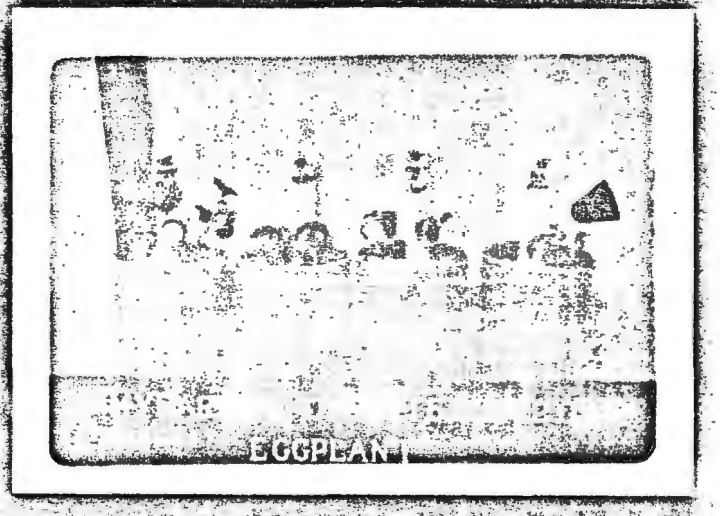
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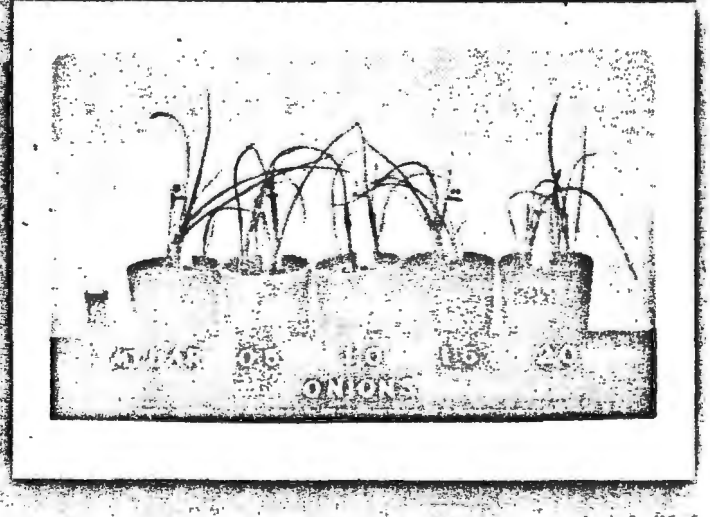
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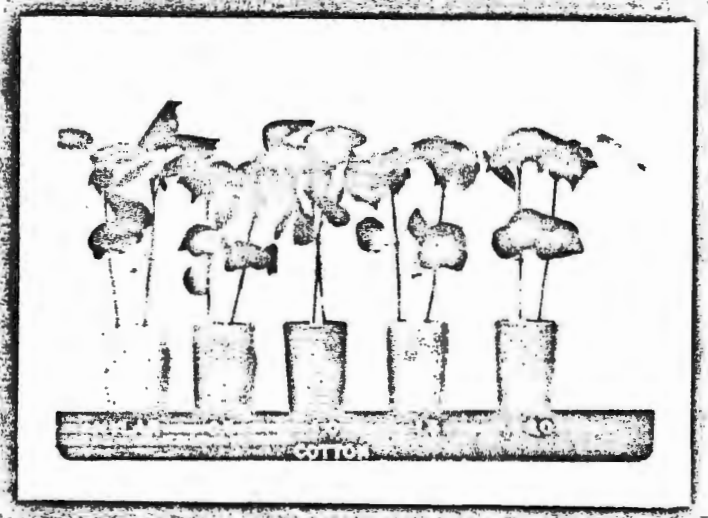
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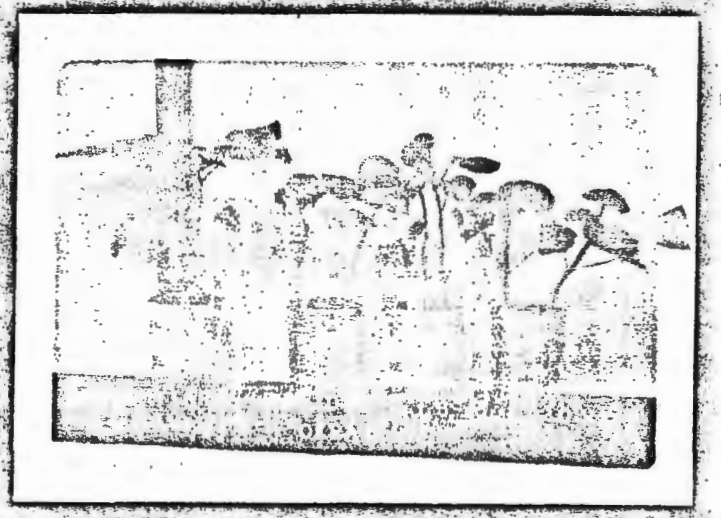
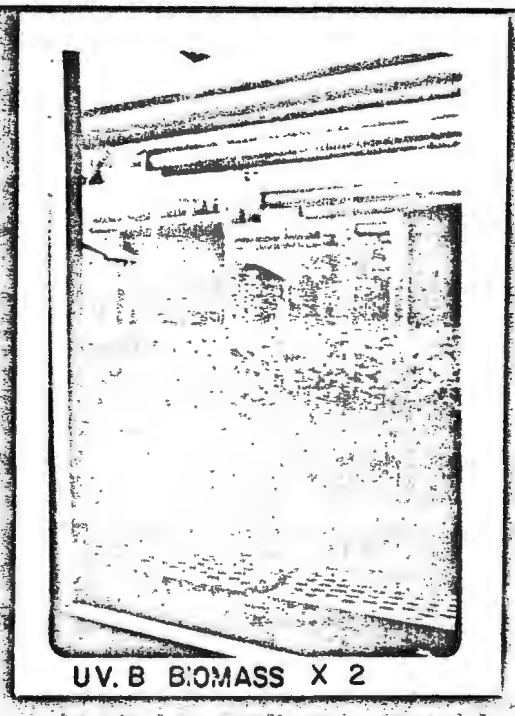
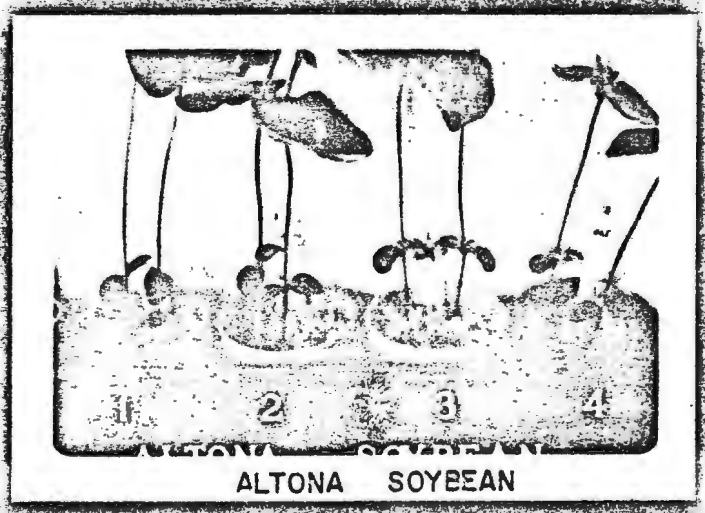




UV. B BIOMASS X 2

MYLAR BIOMASS



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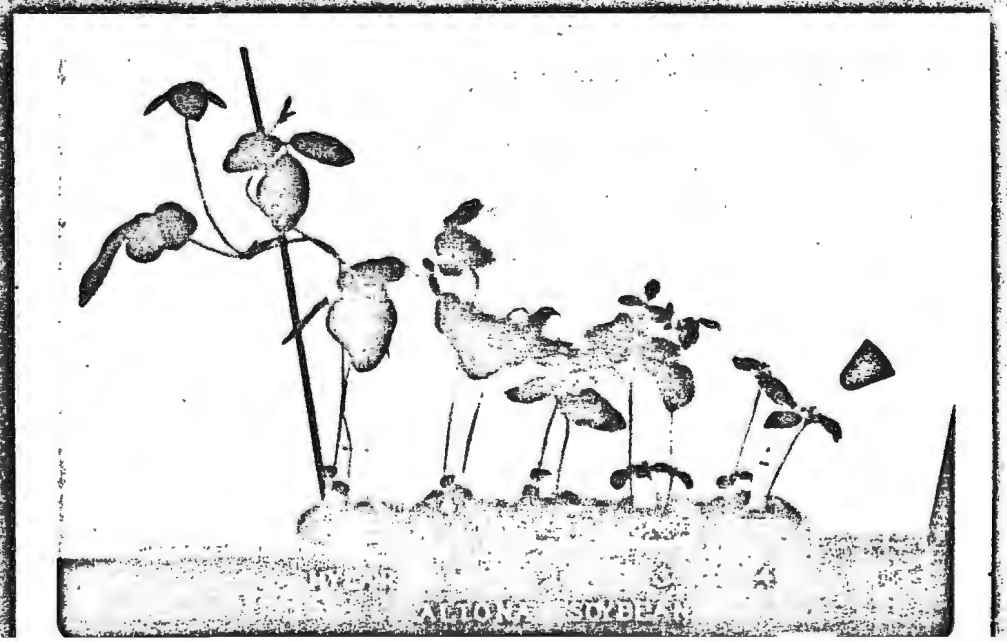

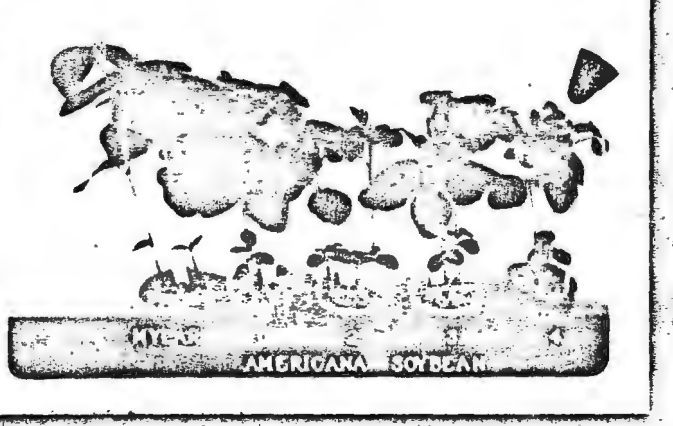
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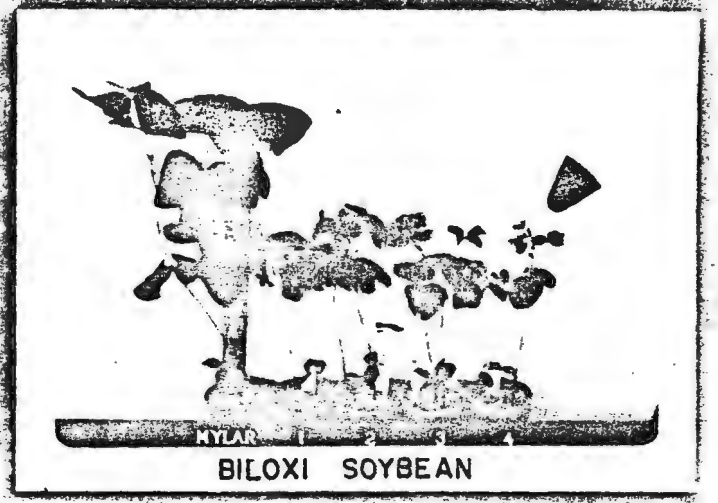
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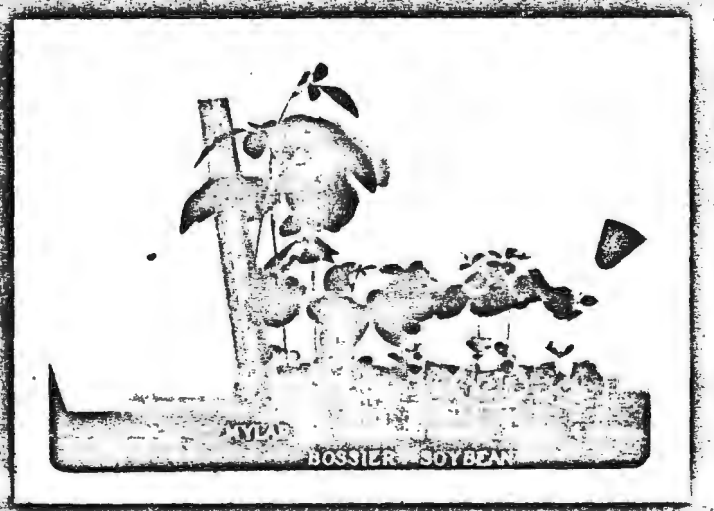
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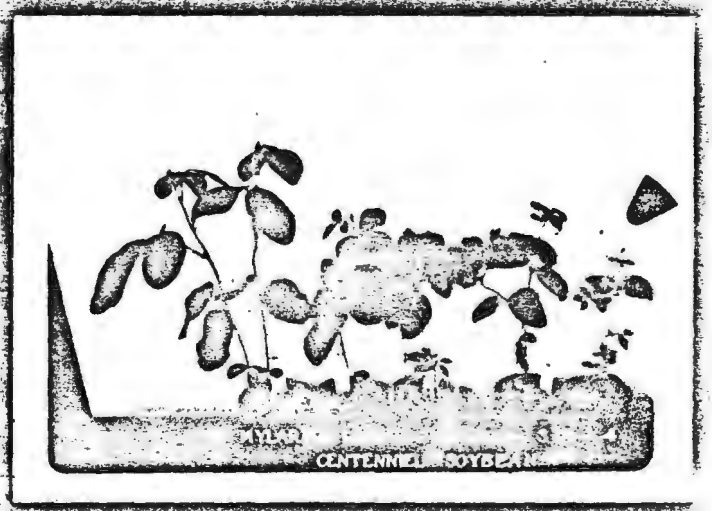
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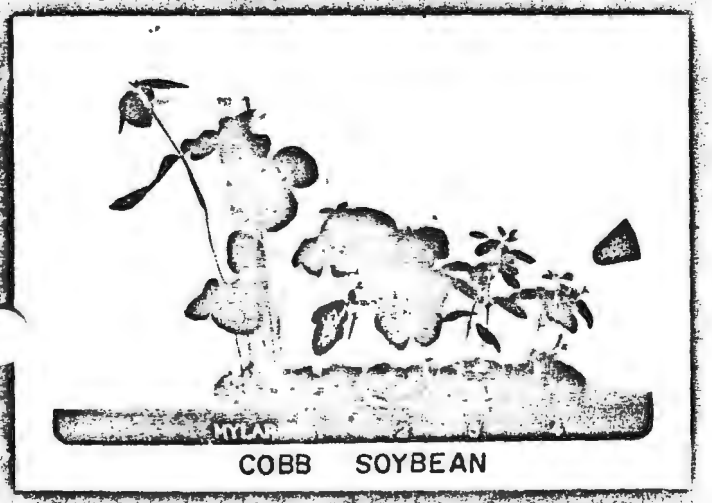
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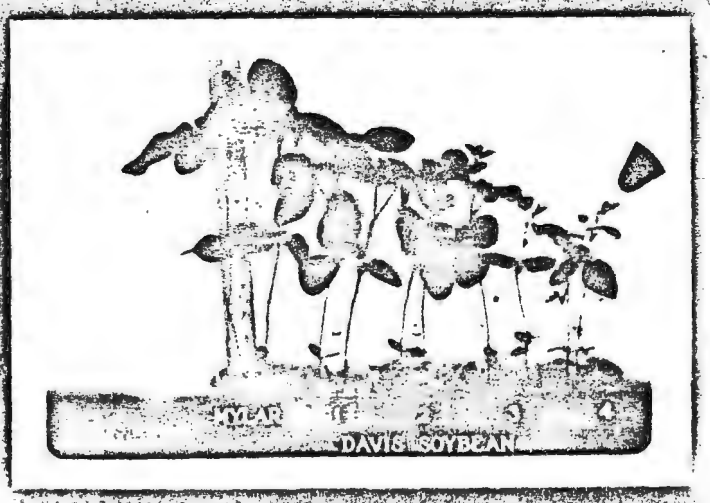
COBB SOYBEAN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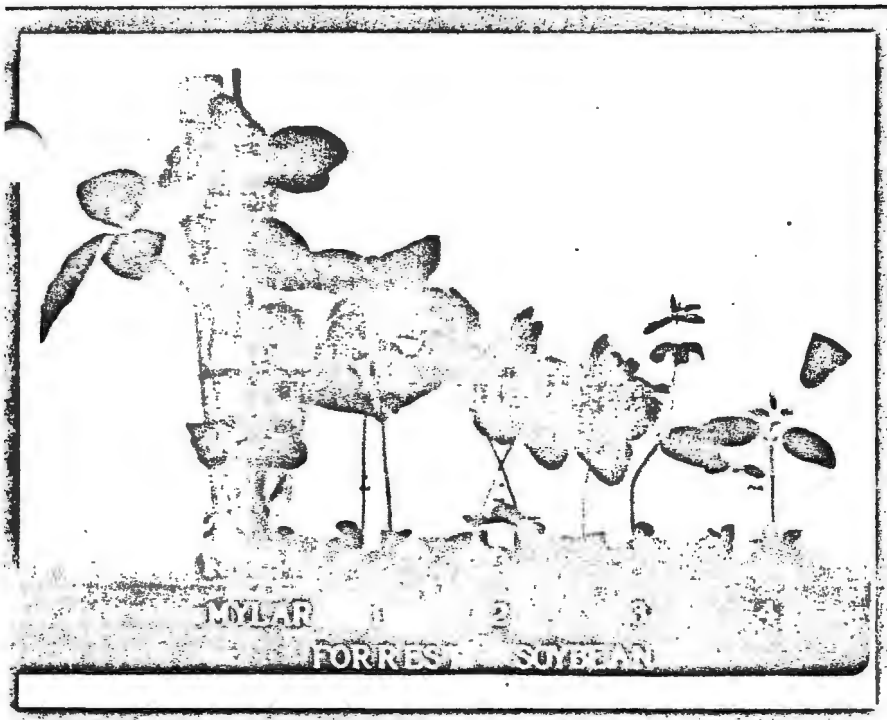
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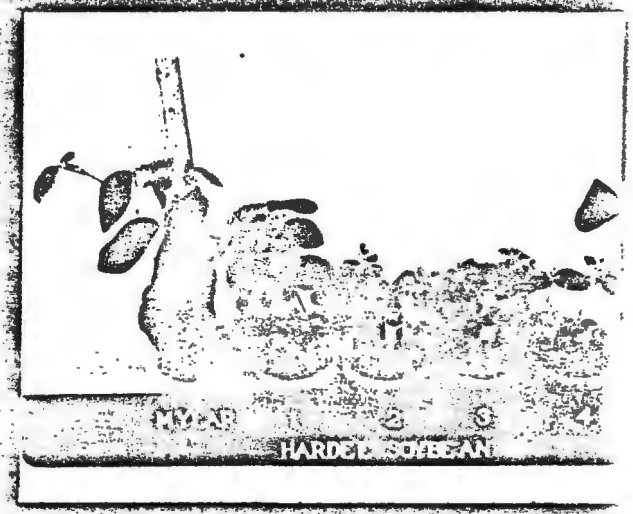
FORRESTER SOYBEAN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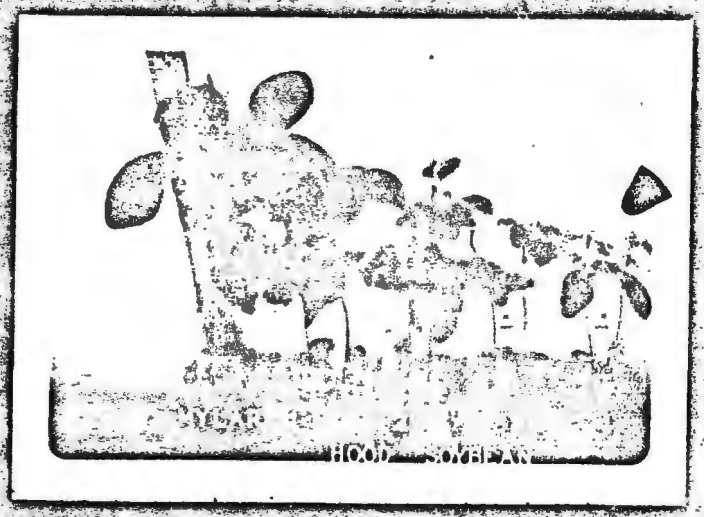
HARDEE SOYBEAN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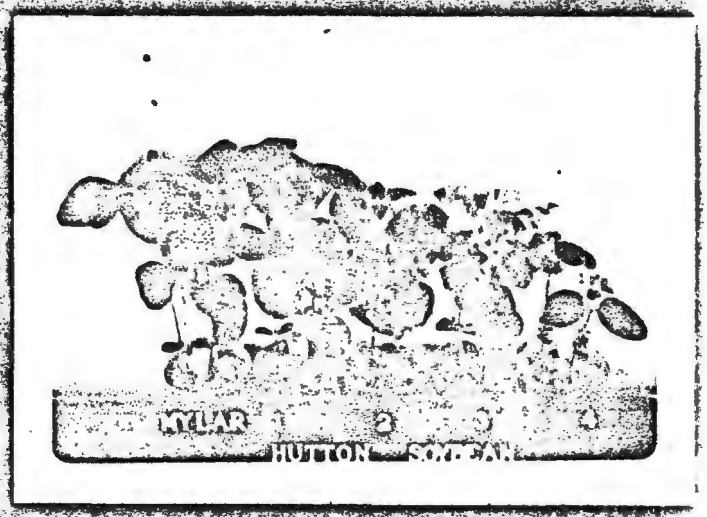
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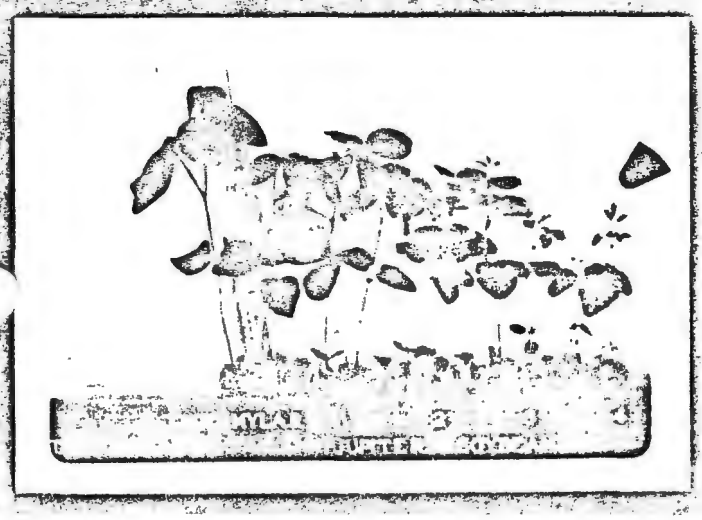
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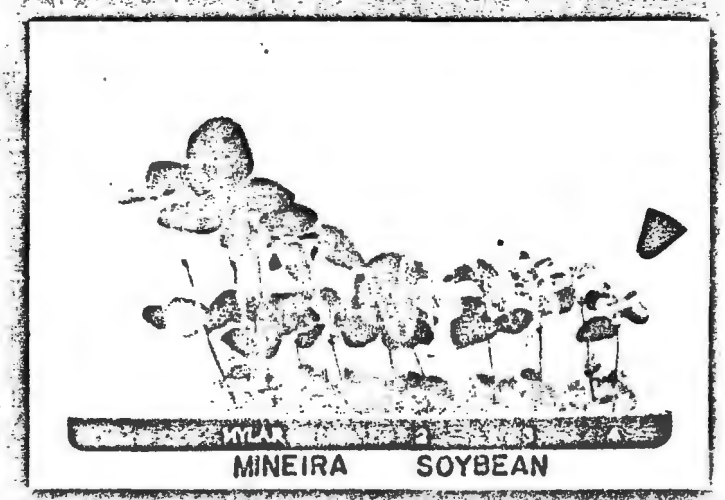
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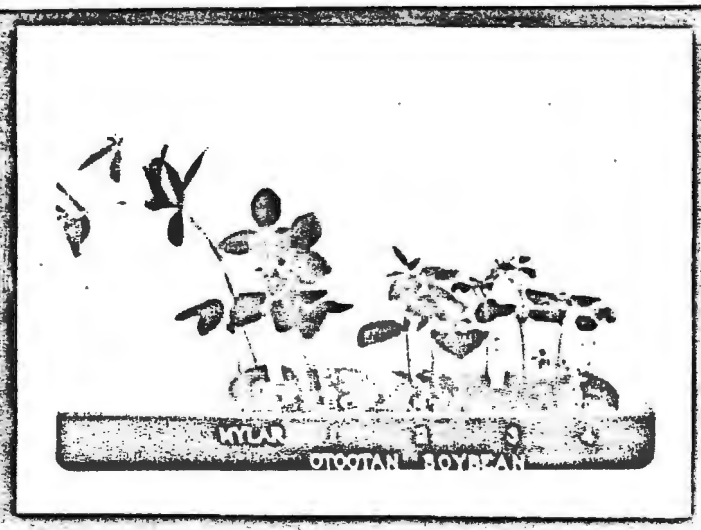
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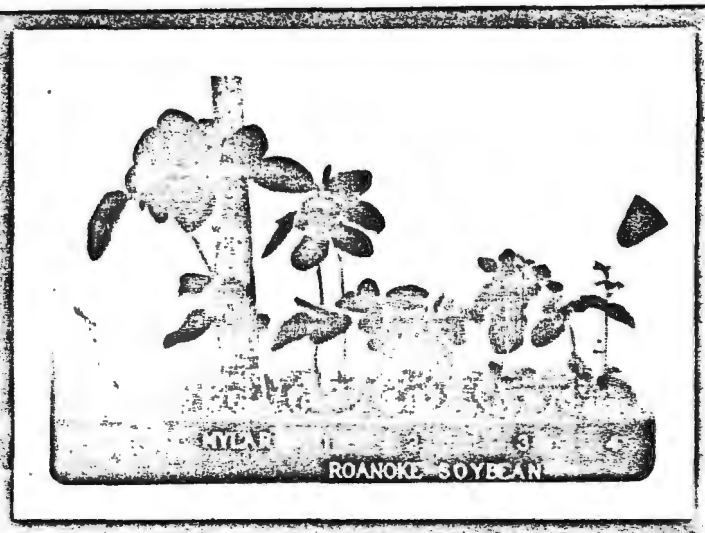
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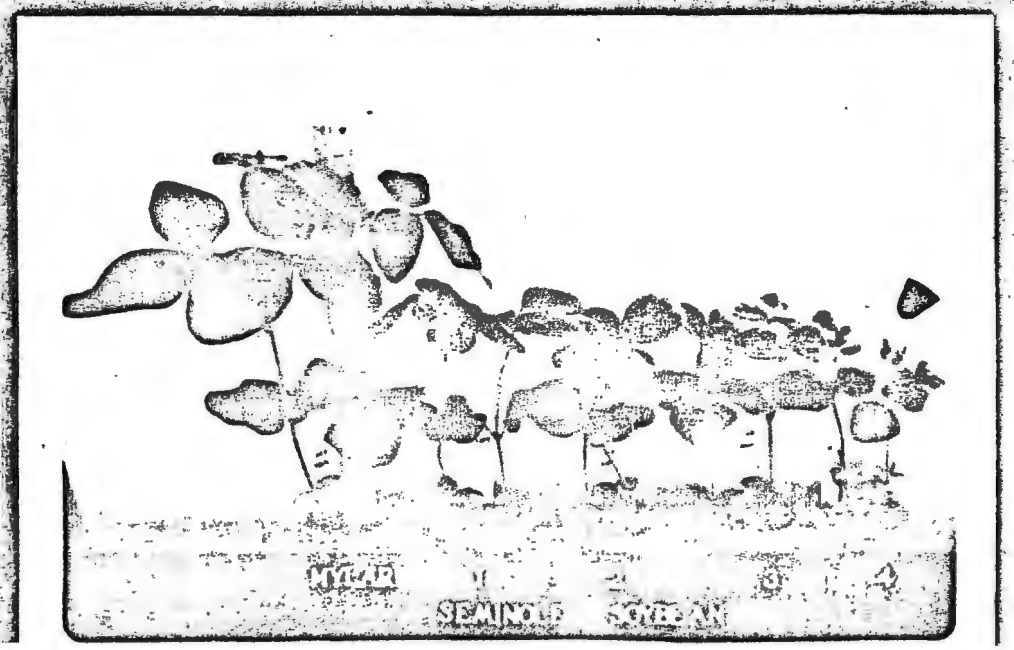
ROANOKE SOYBEAN


NTLR
SANTA MARIA SOYBEAN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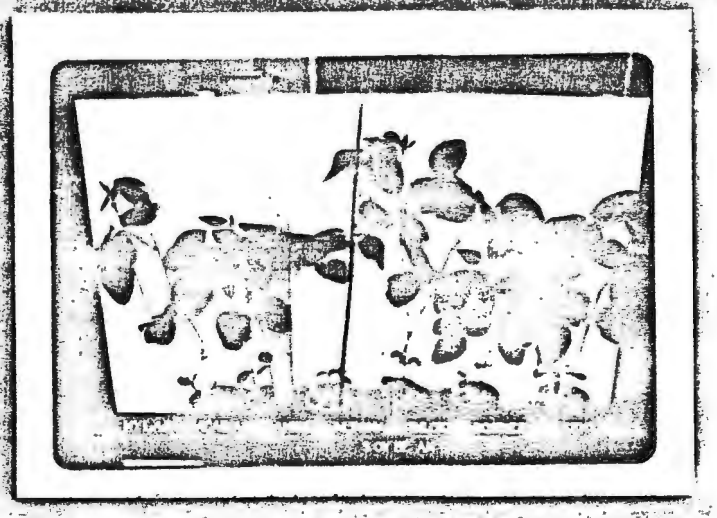
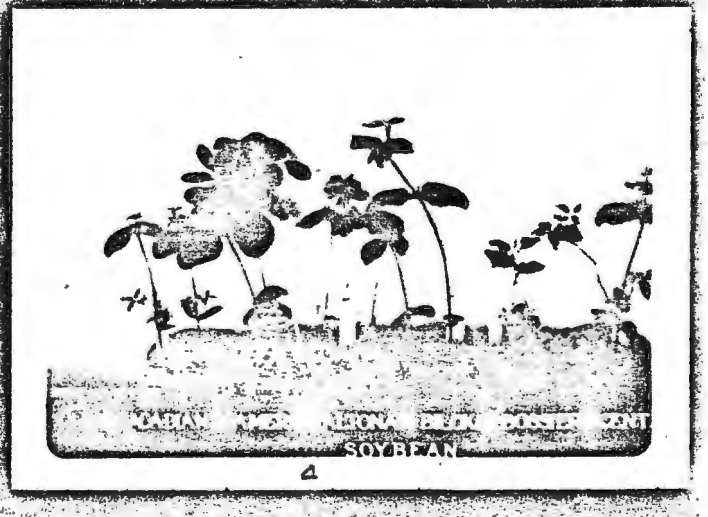
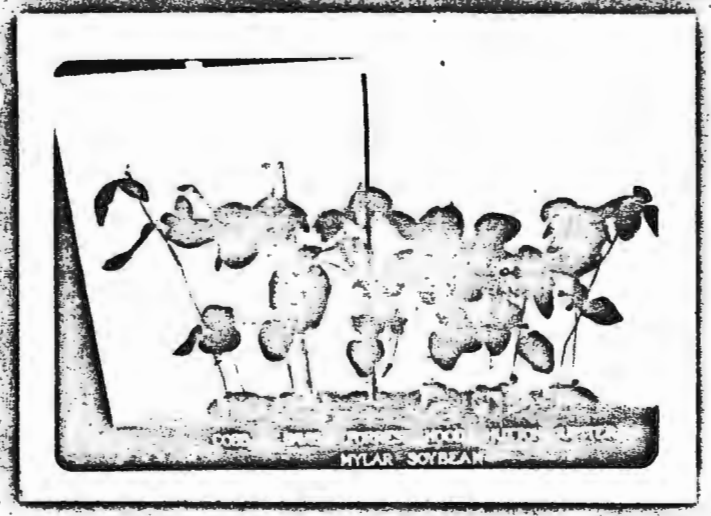
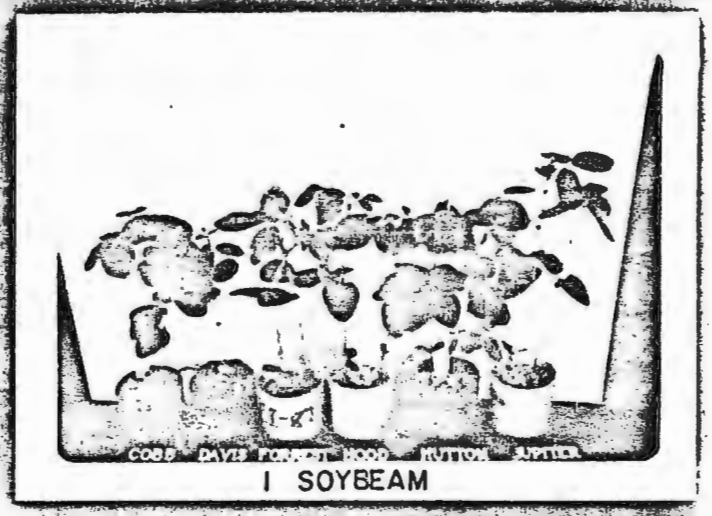



SOYBEAN
4


2 SOYBEAN





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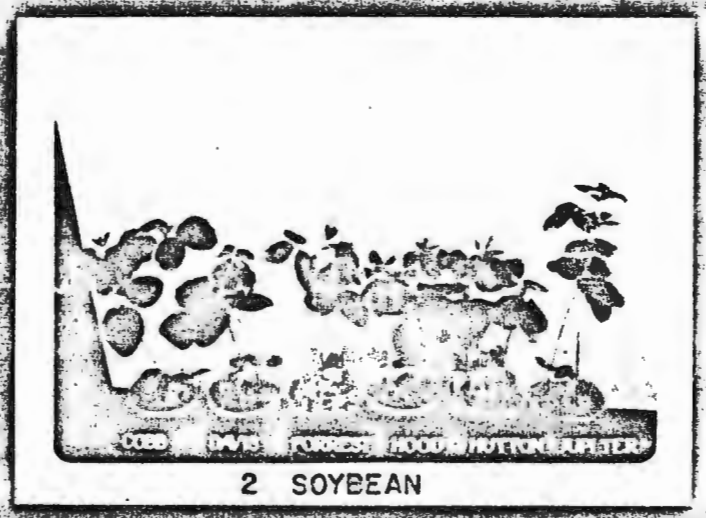

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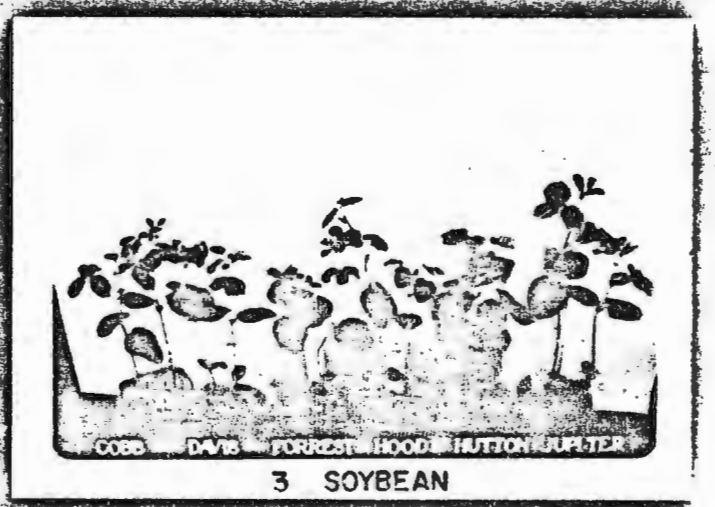
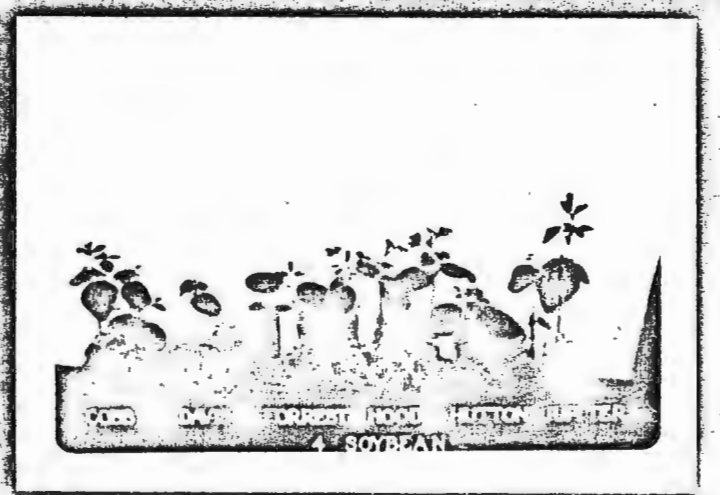
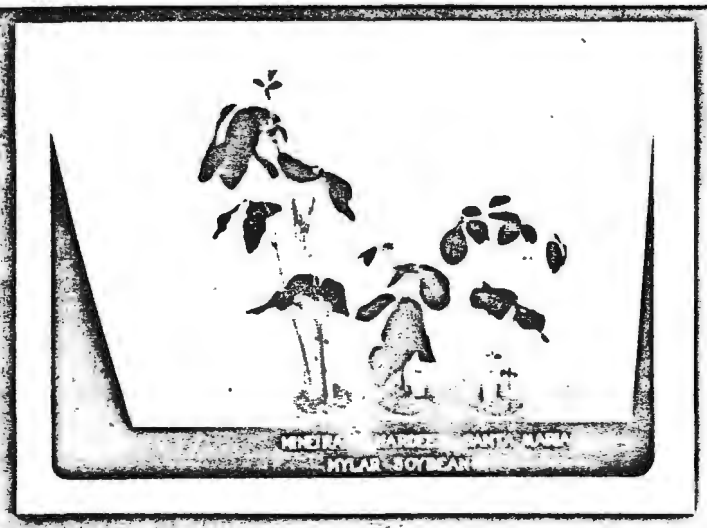
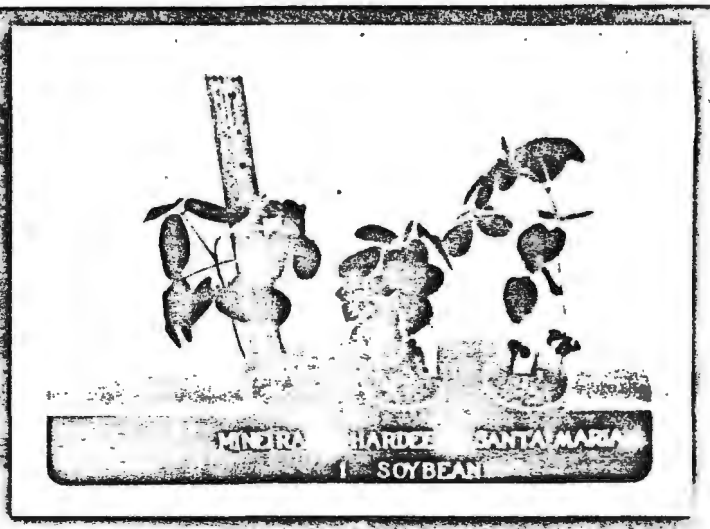


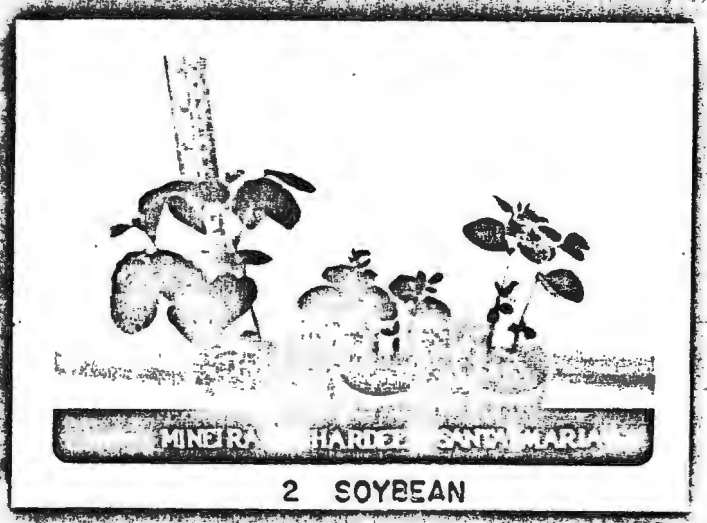
3 SOYBEAN



4 SOYBEAN


MINETRA HARDEE SANTA MARIA
MYLAR SOYBEAN


MINETRA HARDEE SANTA MARIA
1 SOYBEAN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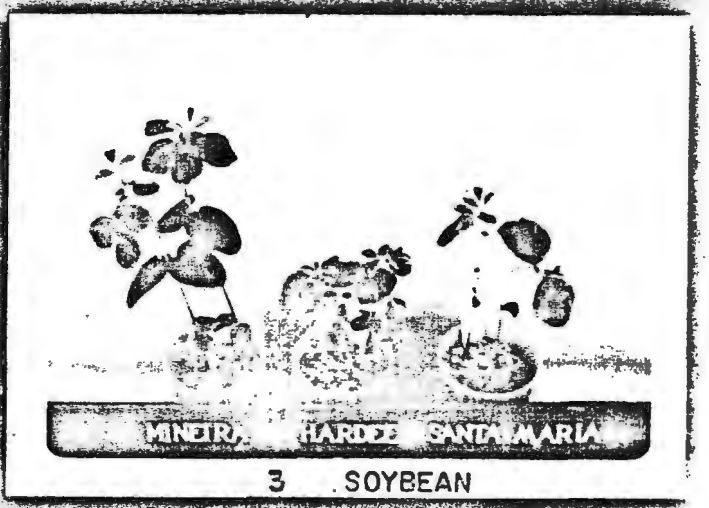
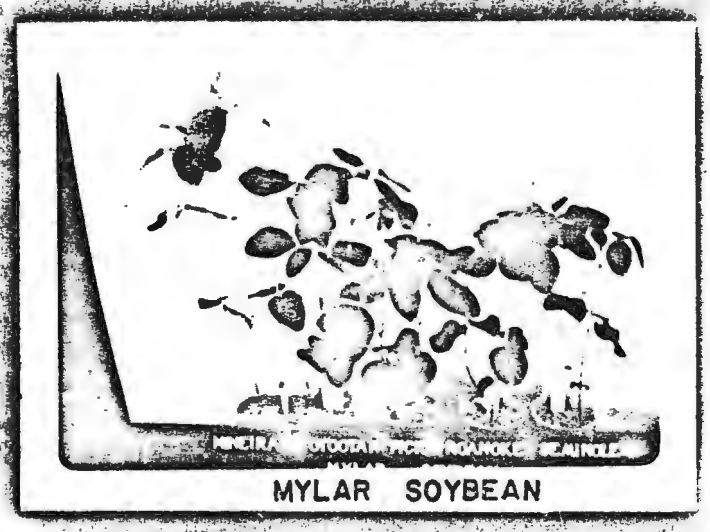
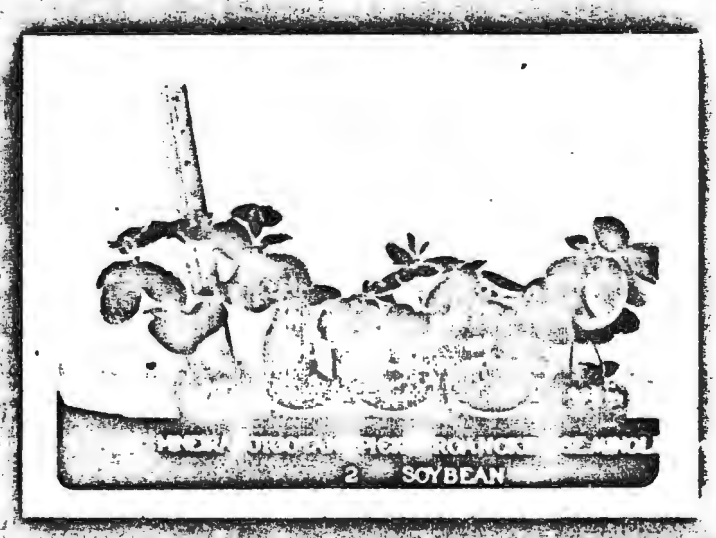
2 SOYBEAN

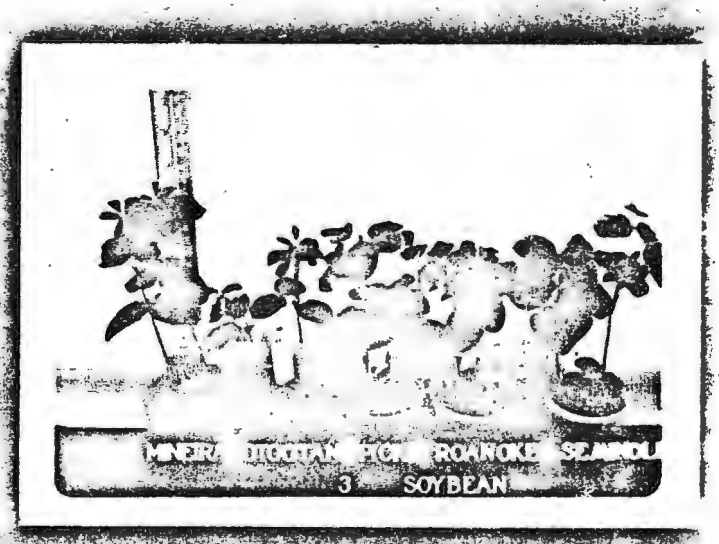

MINETRA HARDEE SANTA MARIA
3 SOYBEAN



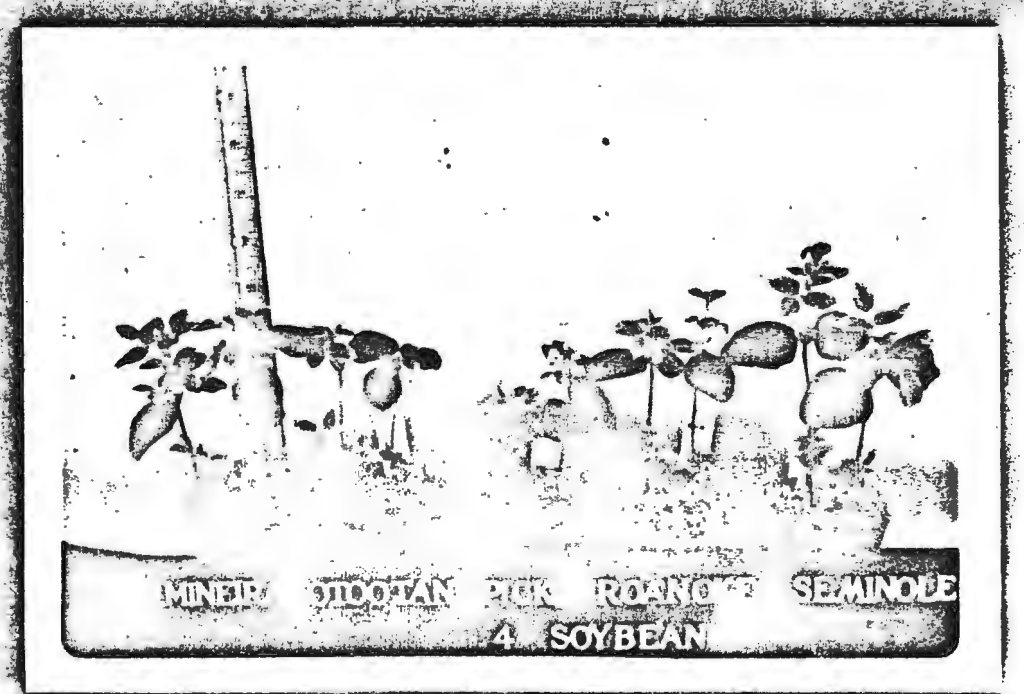
MYLAR SOYBEAN



2 SOYBEAN



3 SOYBEAN



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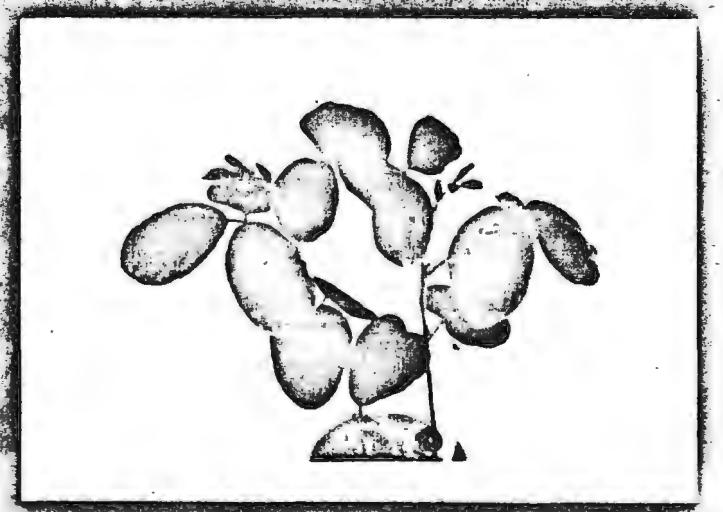

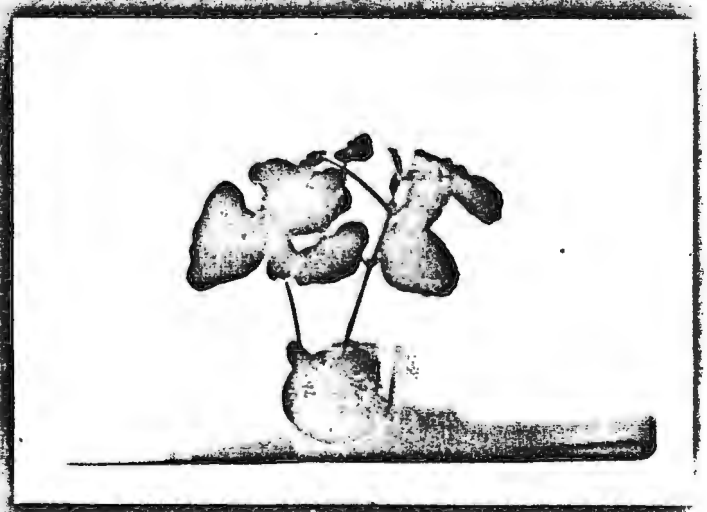

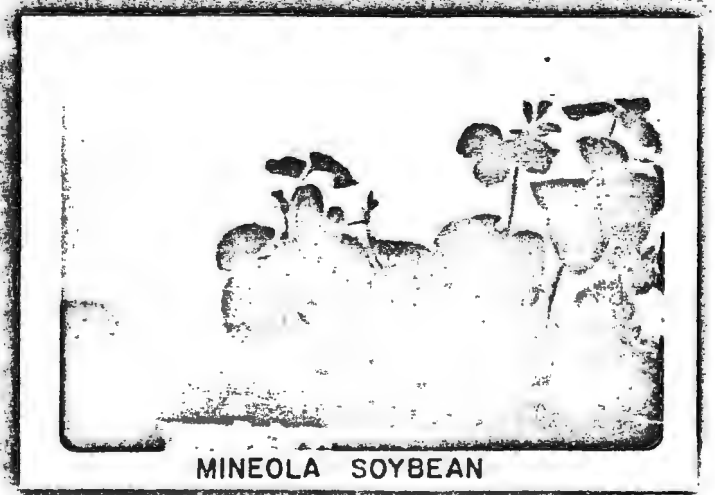

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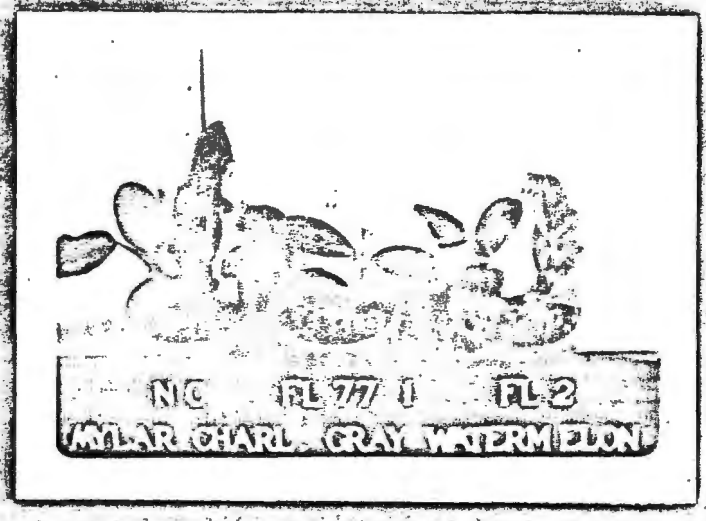
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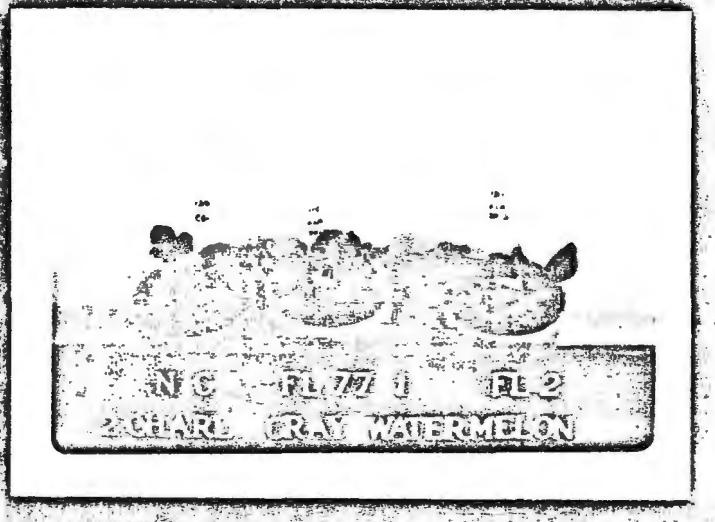
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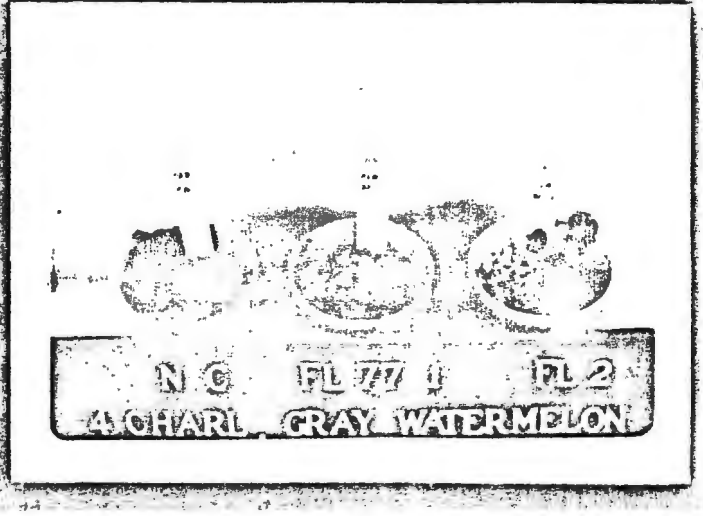
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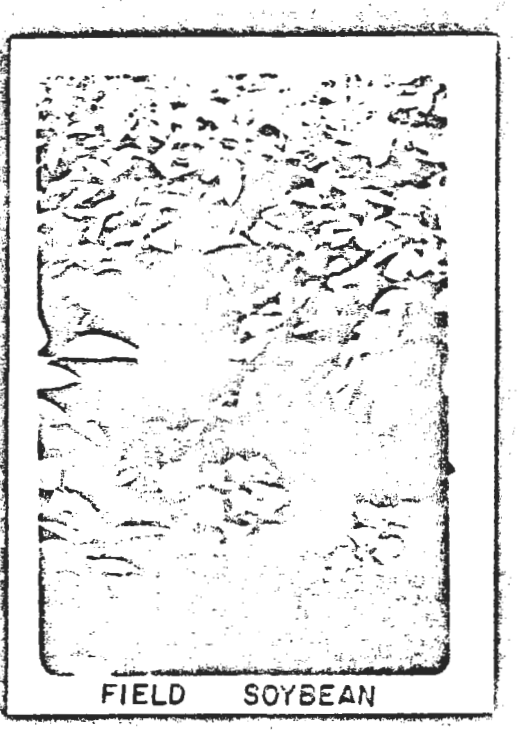
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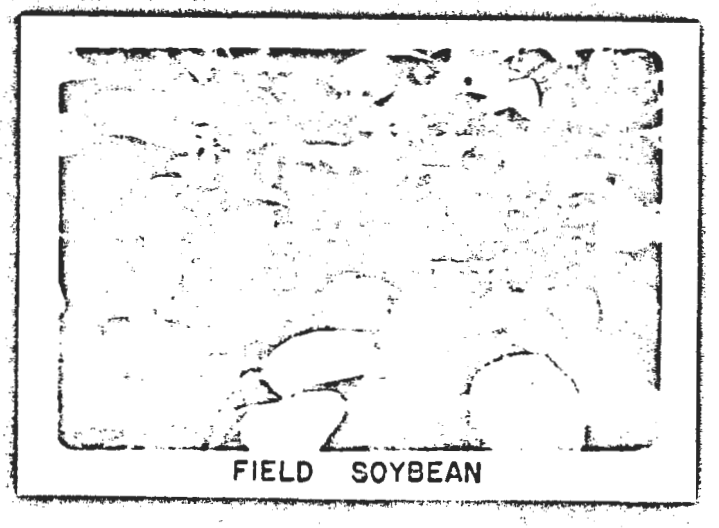
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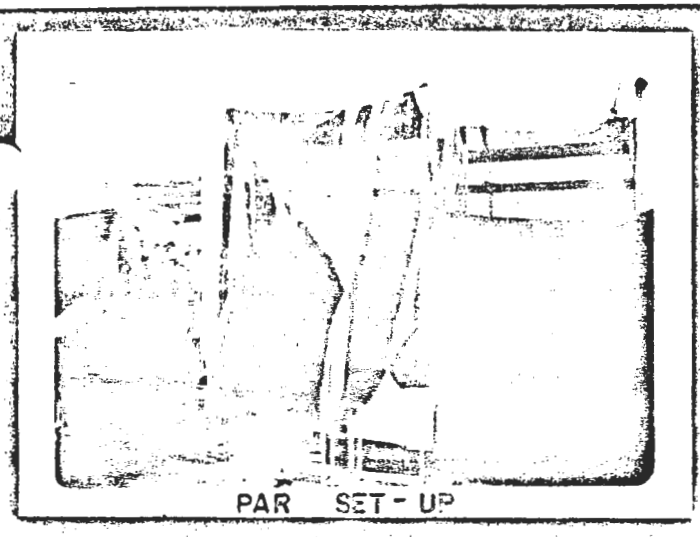
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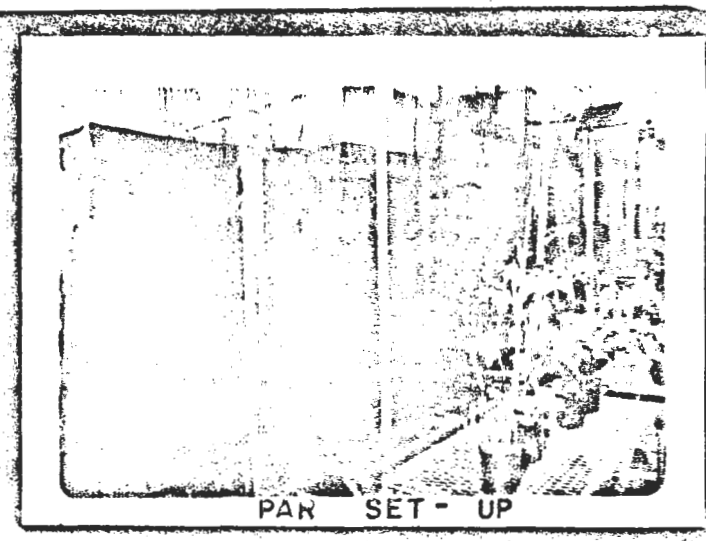
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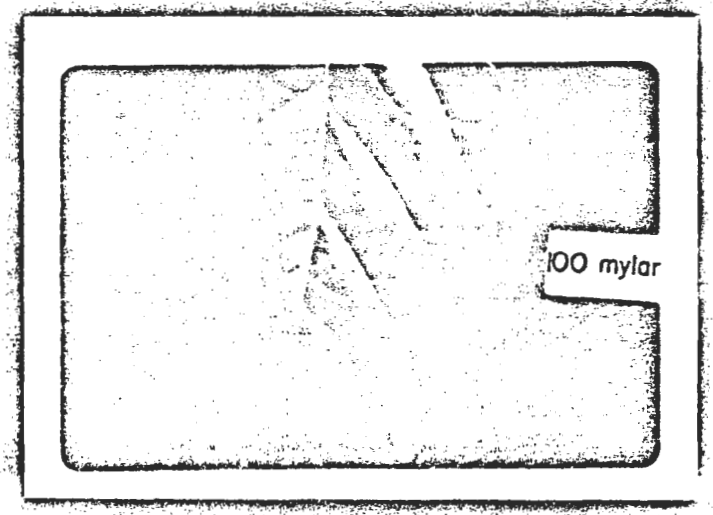
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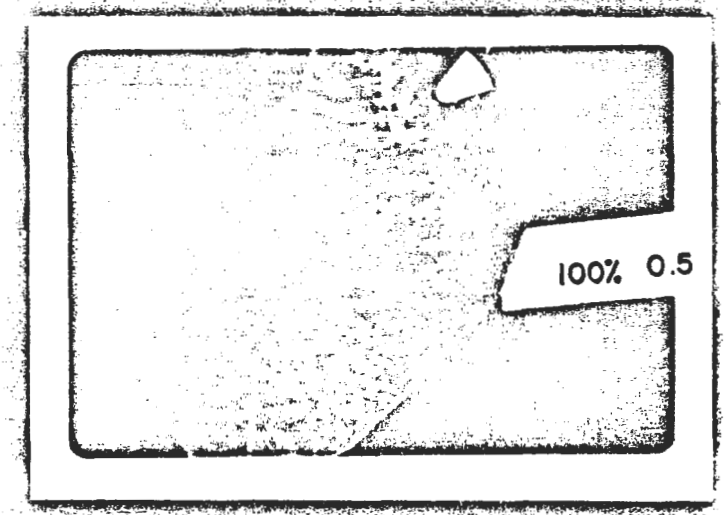
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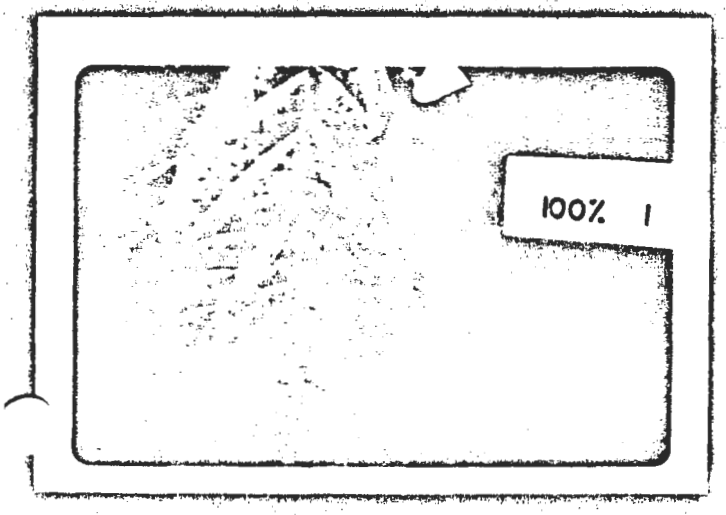
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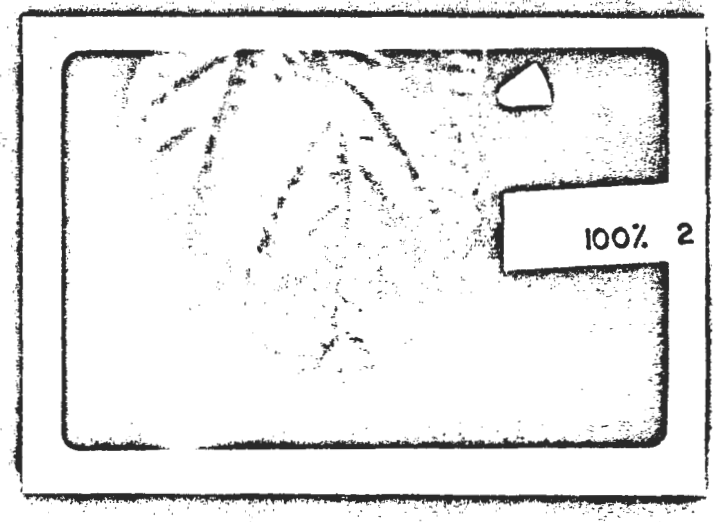
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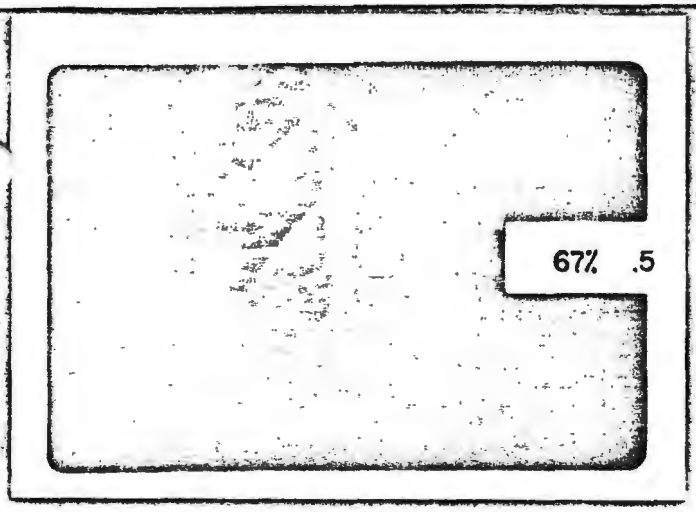
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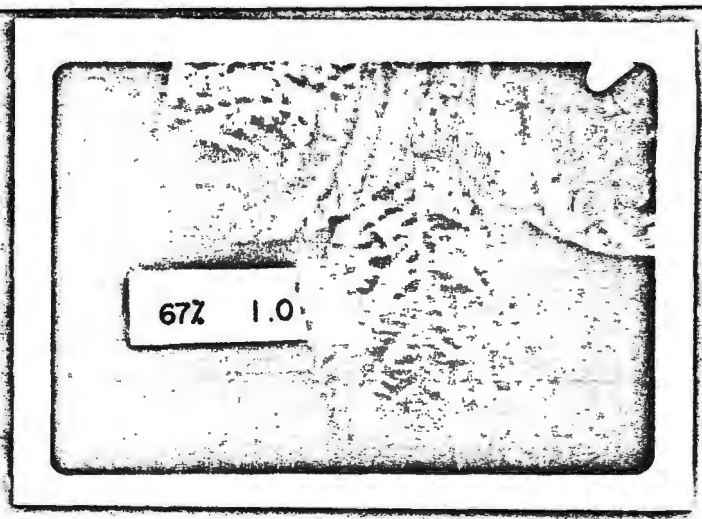
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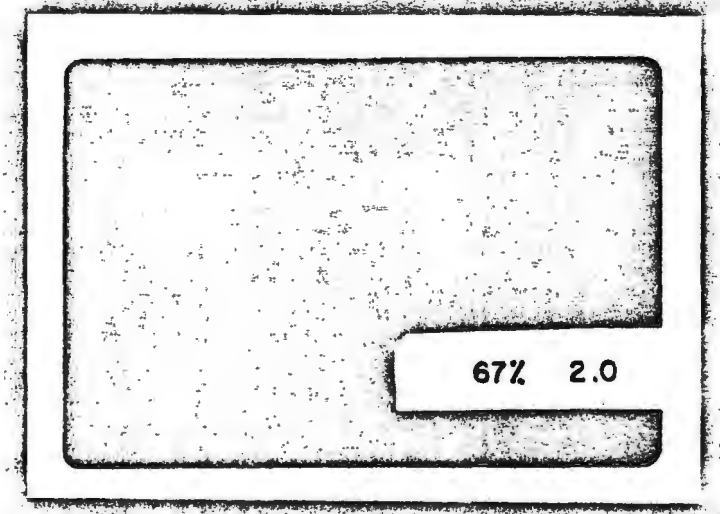
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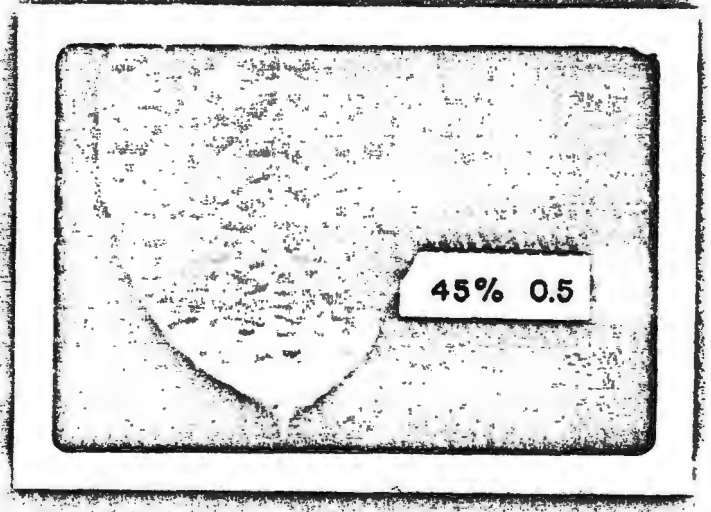
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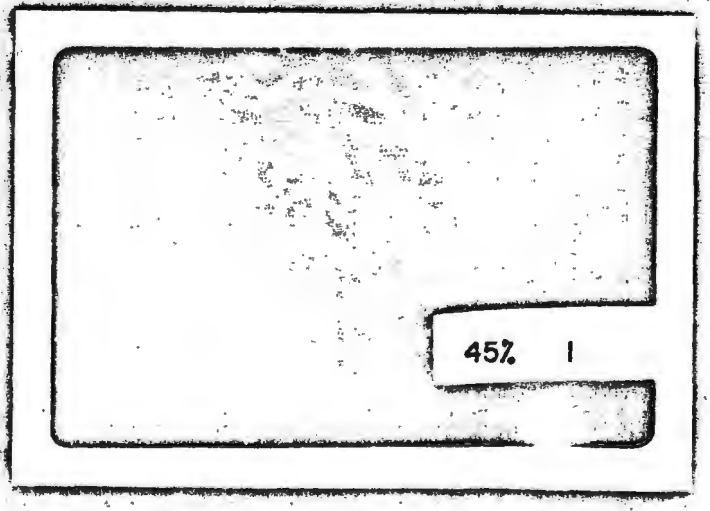
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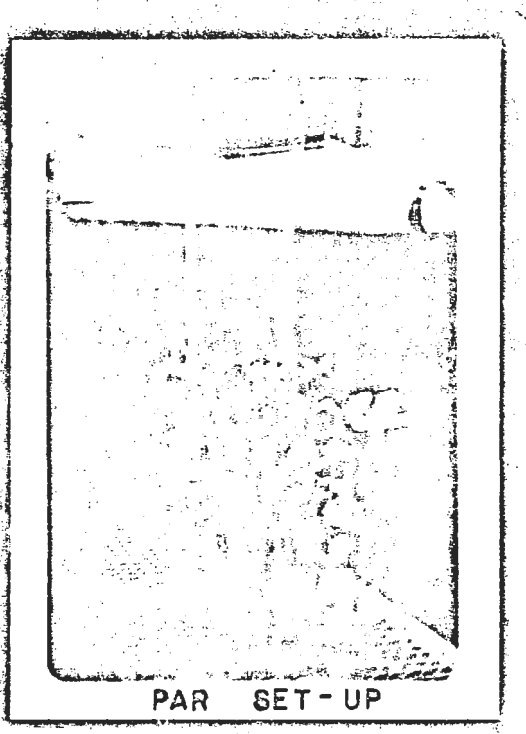

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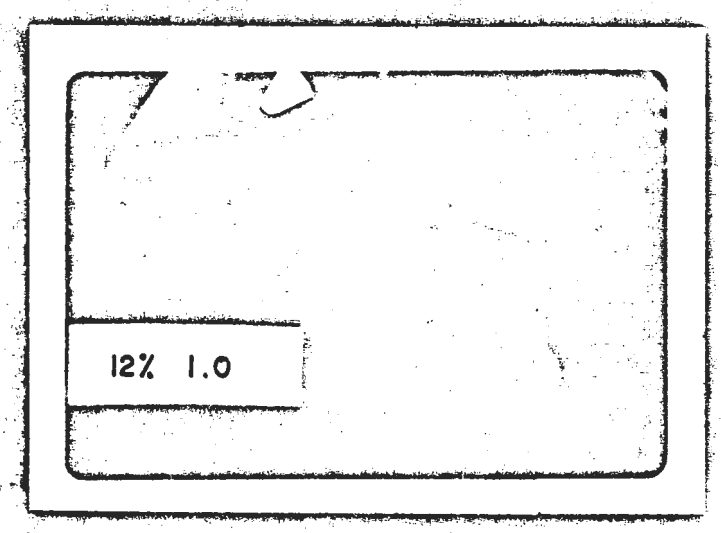

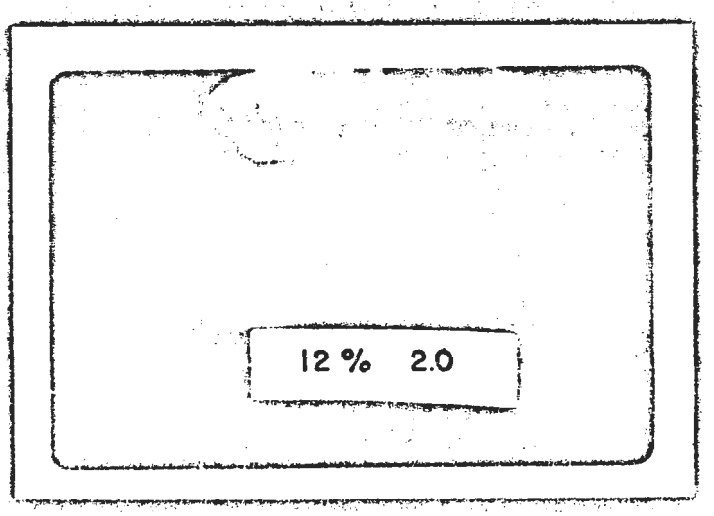

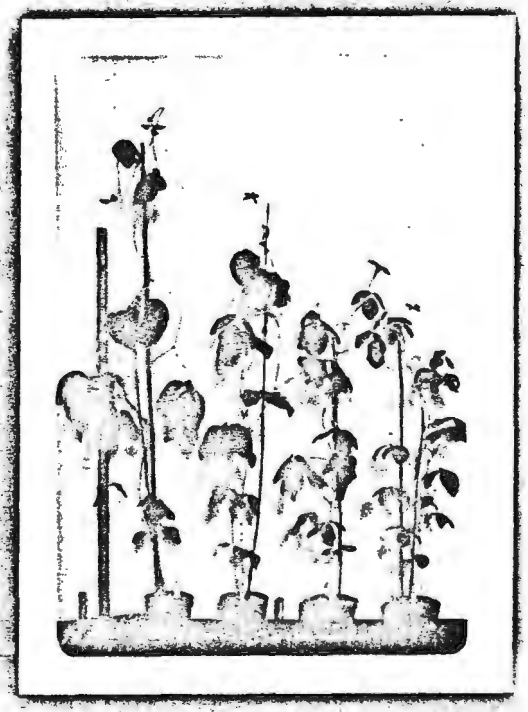

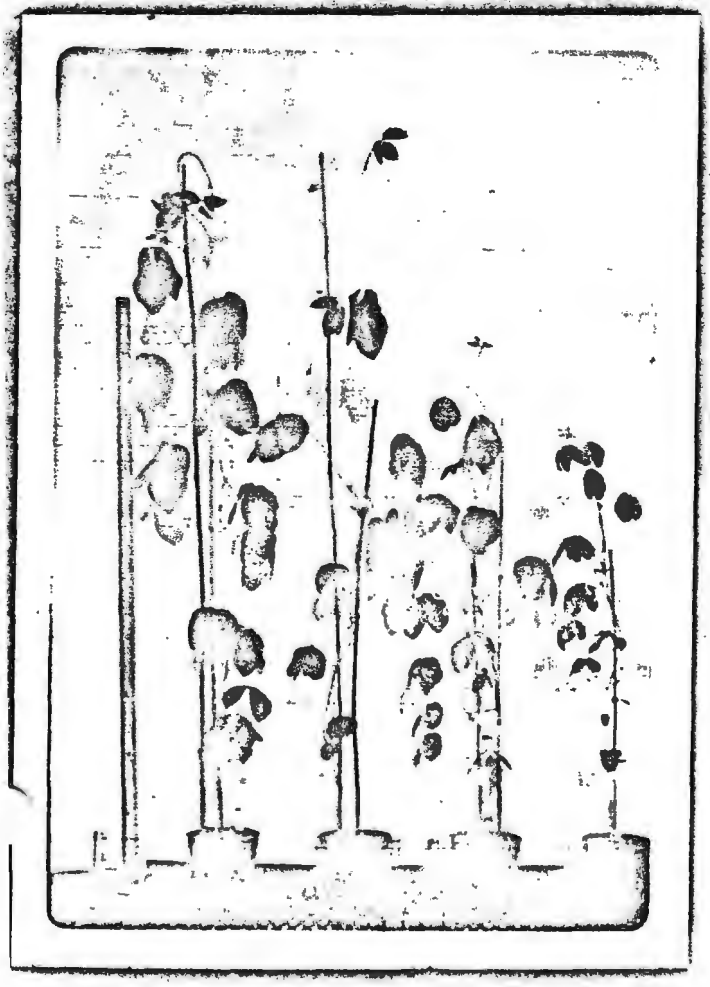

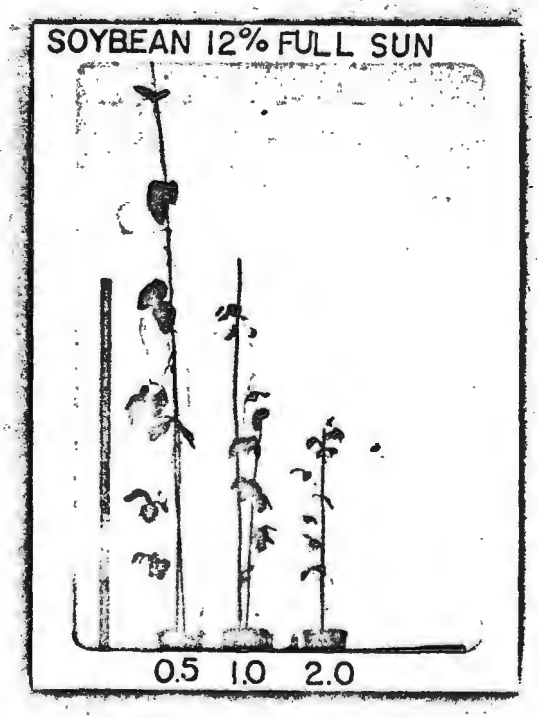
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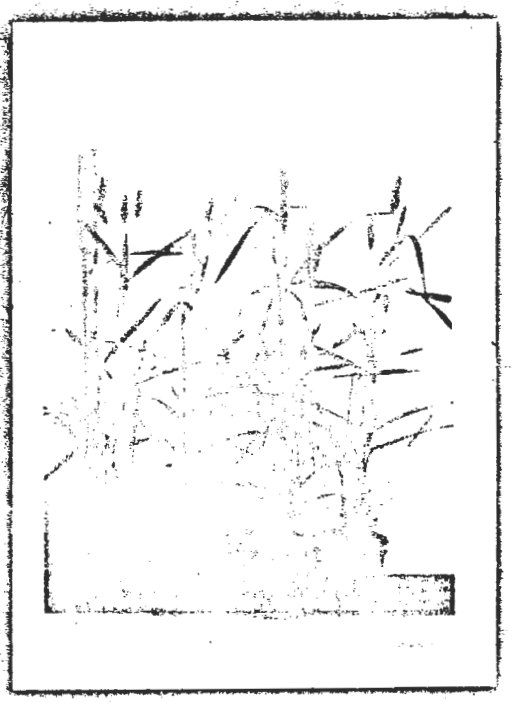

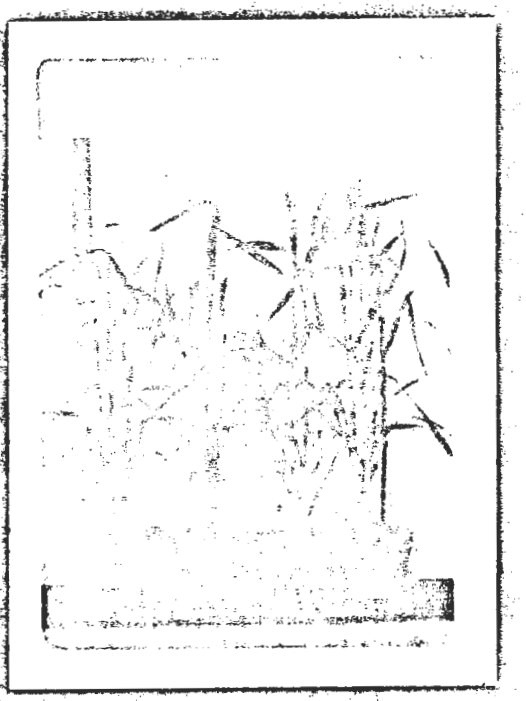

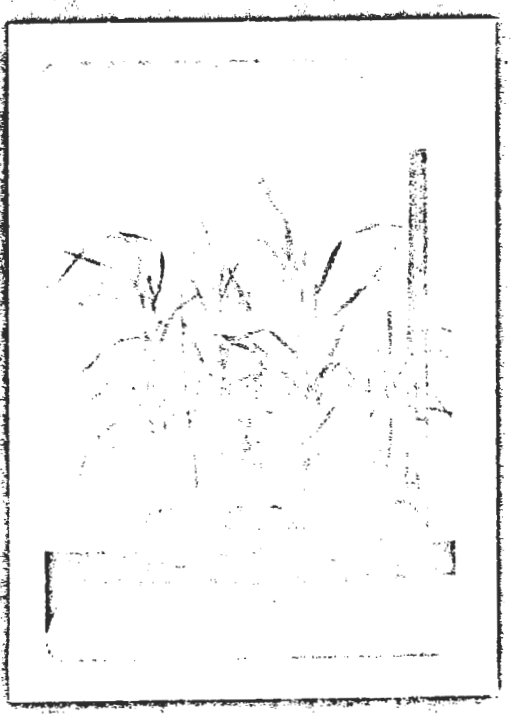

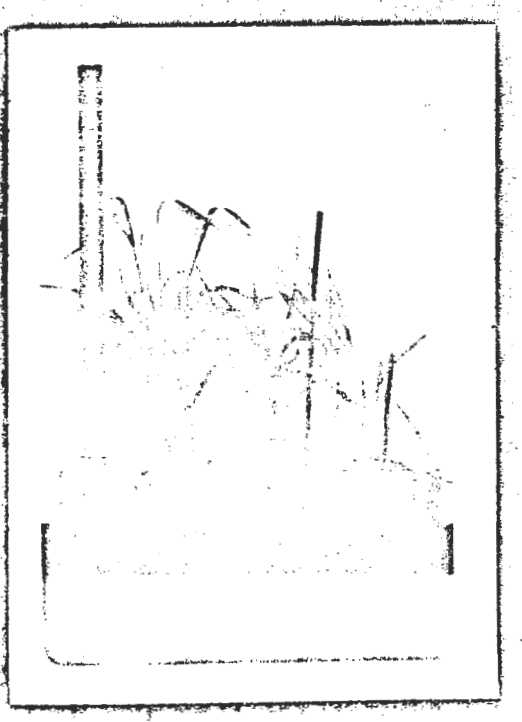

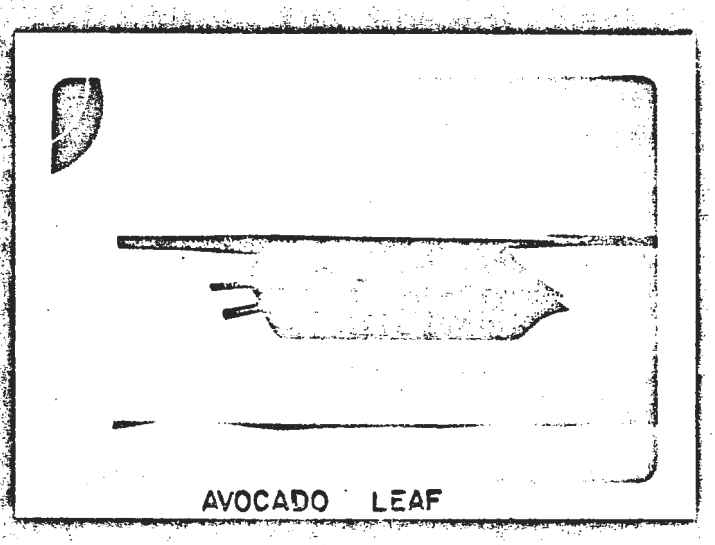

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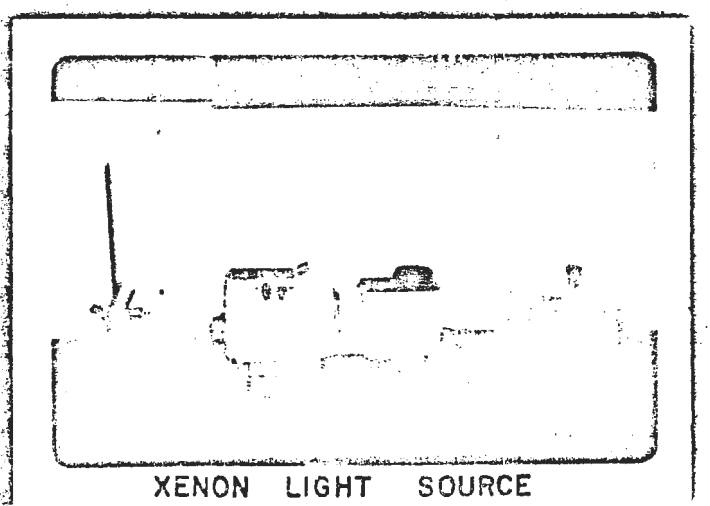

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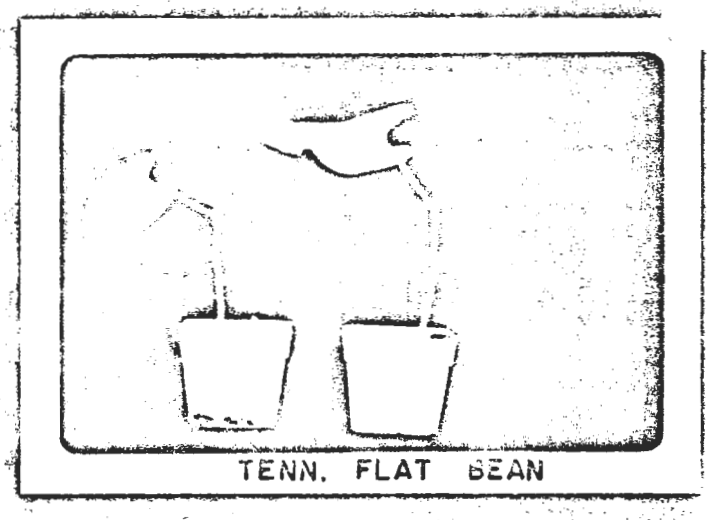

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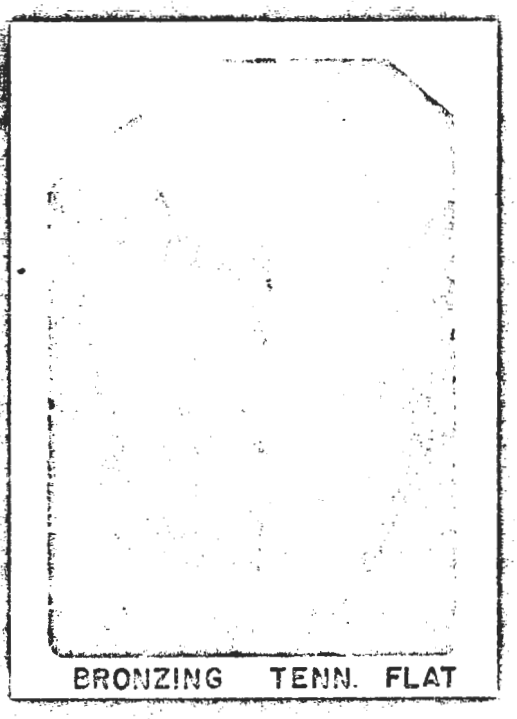

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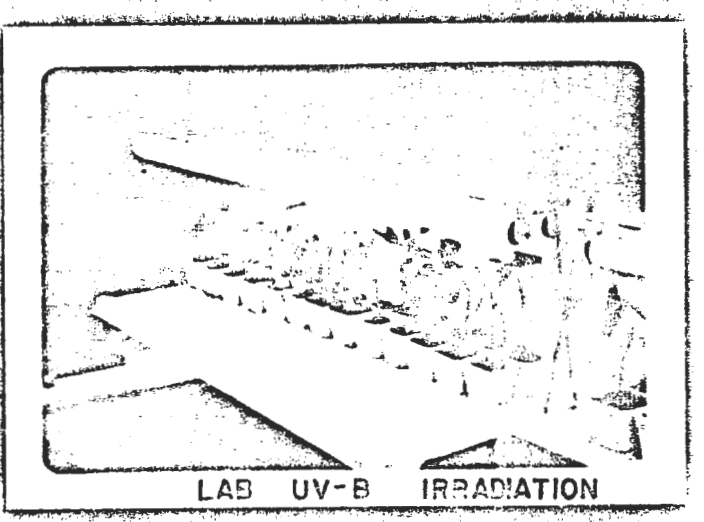

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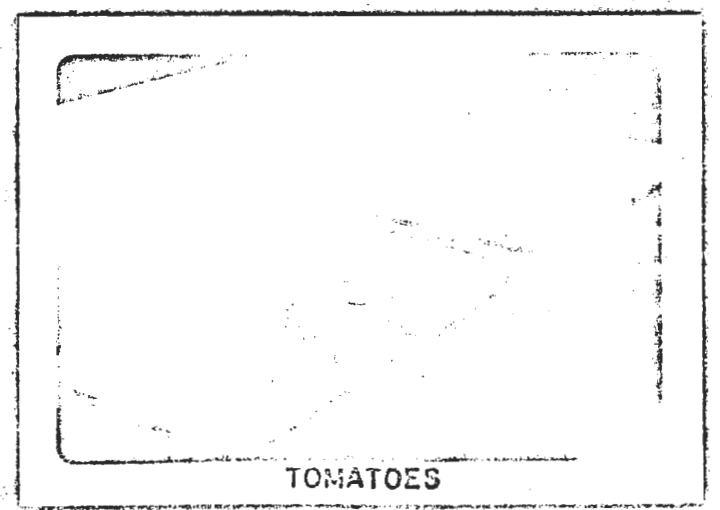

TOMATOES

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FINAL REPORT

ULTRAVIOLET EFFECTS OF PHYSIOLOGICAL ACTIVITIES OF BLUD-GREEN ALGAE

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EPA-IAG-D6-0168

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Environmental Protection Agency
BACER Program
Washington, D.C. 20460

Introduction

The blue-green algae (Cyanobacteria) are found widespread in nature, in soil, water, and in association with a variety of plant and marine life (2). Various species can tolerate a variety of climatic conditions and are found even in hot springs and arctic regions. These cells lack differentiated chloroplasts and contain chlorophyll in membranous structures; consequently, they have recently been classified as blue-green bacteria, analogous to photosynthetic bacteria. The cyanobacteria carry out a typical plant-type photosynthesis, however, with water photolysis and oxygen evolution as major features. Consequently, these ubiquitous organisms constitute a particularly useful microbial system for monitoring worldwide environmental effects on plants as might result from enhanced solar UV-B (280-320 nm) irradiation due to depletion of stratospheric ozone (10).

We have evaluated both Anabaena flos-aquae and the water fern Azolla as laboratory test systems for environmental studies. Azolla is an aquatic nitrogen-fixing plant which contains a symbiotic cyanobacterium, Anabaena, within its leaf cavity (4). This fern is also found worldwide, but is particularly important for its use as a green manure in rice paddies in the Orient. Many species of cyanobacteria fix atmospheric nitrogen and contribute to nitrogen input into soils in a variety of ways. Both systems appear to be particularly important contributors of nitrogen to rice culture.

Our studies show that the nitrogen-fixing enzyme system in cyanobacteria is particularly sensitive to UV-B damage. Furthermore, inhibition of nitrogenase activity (measured as acetylene reduction) takes place in the absence of any nucleic acid damage or lethal effects on the cells. These studies indicate, therefore, that measurement of acetylene reduction activity in nitrogen-fixing systems may provide a simple biochemical assay for assessing the effects of UV-B on plants.

Materials and Methods

Azolla caroliniana, a nitrogen-fixing water fern, was obtained from Dr. S. A. Peters, C. F. Kettering Foundation Laboratories, Yellow Springs, Ohio, and was grown on modified Hoaglands salts as described by Peters and Mayne (6). Anabaena flos-aquae (Lyngle.) Breb. ATCC 22664 was grown on nitrogen-free BG-11 medium (8). Cultures of plants and cyanobacteria were grown at 25°C in light chambers under cool white fluorescent lamps at light intensity of 10-20 watts/M^2. Measurements of total light intensity were made with a Yellow Springs Instrument Co. (Yellow Springs, Ohio) model 65A Radiometer equipped with a 6551 Radiometer probe having a constant wavelength response from 0.28 to 2.6 microns (reduced to 65% at 0.21 microns).

UV-B irradiation of samples was obtained using a bank of six 8-watt RPR 3000 A Rayonet photochemical reactor lamps (Southern New England Ultraviolet Co., 954 Newfield St., Middletown, Conn.) placed above cyanobacterial and plant material at 25°C in flat dishes covered with 5 mil cellulose acetate films. The unfiltered RPR 3000A lamp has, in addition to UV-B, a strong emission in the short wavelength region (λmax ~254 nm). Such lamps were used either singly or in multiples to increase irradiation.

(We are grateful to Drs. K. Eskins and H. J. Dutton of this Center for suggesting the use of these lamps as a source of UV-B radiation.) The lamps were aged 100 hours and did not significantly decrease in irradiance levels during prolonged use thereafter. As recommended by the Agricultural Equipment Laboratory of the Beltsville Agricultural Research Center (BARC), 5 or 10 mil cellulose acetate (CA) film was used to filter out low wavelength UV radiation from the lamps (5). The CA was pre-irradiated 6 hours and discarded after 30-40 hours of use. Since we have no knowledge of the actual targets involved, other than to exclude DNA, our data are reported as total incident UV-B light over the range indicated and does not assume any biological effectiveness of a particular wavelength.

UV-B irradiance levels in W/m^2 were measured with an Optronics Laboratories, Inc. Model 725 UV-B Radiometer (7). We calibrated this instrument against a Rayonet lamp which had been scanned at distances of 13 and 20 cm (5 mil CA filter) with the Instrument Research Laboratory, BARC, spectroradiometer over the 250-400 nm region. Integrated W/m^2 over the range of 280-320 nm at these distances were taken as reference points (0.44 and 0.82 W/m^2, respectively) and linearly extrapolated to provide estimates of higher UV-B irradiances.

Cyanobacterial suspensions of 40 ml were stirred during irradiation. Aliquots were removed, rapidly agitated to separate clumped cells, plated on BG-11 (N free) medium, and assayed for nitrogenase, fixation of $C^{14}O_2$ and hydrogen evolution. The data reported are typical examples selected from many experiments which all gave consistent results.

Acetylene reduction and hydrogen evolution were measured gas chromatographically on cyanobacterial and fern preparations incubated in light in screw-capped vials containing argon-acetylene or argon atmospheres. Samples of the gas phase were periodically withdrawn with gas-sampling syringes. The ethylene formed from acetylene was separated on columns of Poropak R (9) and hydrogen measured using a molecular sieve 5A column (1).

$C^{14}O_2$ fixation was measured on aliquots of either A. flos-aquae or fern fronds in growth media containing $Na_2HC^{14}O_3$. Samples were collected on glass fiber papers, rinsed with 6N HCl, and the incorporated C^{14} determined in a liquid scintillation counter using a water-miscible scintillation fluid.

Concentrations of A. flos-aquae in irradiated suspensions, determined by measurement of optical densities at 650 nm, were correlated with protein content (3). With our cultures, an optical density of 1.0 at 650 nm corresponded to approximately 200 µgrams algal protein per milliliter.

Results

Because of their extensive pigment system, cyanobacteria are known to be fairly resistant to short wavelength UV irradiation and to possess an active photoreactivation system (11). In our early studies, we confirmed both of these effects and determined killing curves for our strains using an unfiltered Rayonet UV lamp (Figure 1). Comparison of

Fig. 1

killing curves obtained by plating cell aliquots on plates which were immediately incubated in the light with those allowed to incubate in the dark 24 hours before illumination showed an active photoreactivation of UV killing.

Figure 2 shows that when CA is used as a filter to remove short

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Fig. 2

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wavelength UV, the killing effect is virtually eliminated, even though the measured UV-B radiation intensity has now been increased fivefold to approximately 2.1 W/m^2. Note also that although the time scale has changed from minutes to hours of irradiation, no lethal effect can be observed.

We attempted to increase the UV-B irradiation by using a curved bank of six lamps with a reflector to impinge the light more directly on the reaction vessel. Figure 3 illustrates the results of such an

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Fig. 3

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experiment in which the UV-B intensity has been approximately doubled to 5.2 W/m^2. These data indicate some killing; however, there was only a slow decline in the population of viable cells which suggests that only a fraction of the cells may be sensitive to high intensity UV-B. It would be of interest to use this approach as a means of selecting strains with either enhanced resistance or sensitivity to UV-B.

Two biosynthetic activities of A. flos-aquae were examined after exposure to sub-lethal doses of UV-B: fixation of $C^{14}O_2$ and nitrogen fixation (measured by acetylene reduction and hydrogen evolution). Table 1 lists the effects of total UV irradiation and UV-B on acetylene

Table 1

reduction by Anabaena and indicates a decline in activity of algae irradiated with UV-B in the absence of a lethal effect. For physiological studies, concentrations of suspensions of A. flos-aquae were increased tenfold. Plate counts of these suspensions indicated that, over the range of 6-80 µg protein/ml, identical survival curves were obtained allowing direct comparison of the results of viable cell count and physiological activity of the suspensions.

Data in Table 2 show that, under similar conditions of irradiation,

Table 2

effects of UV-B on CO_2 fixation were slight. From these results, it appears that the nitrogenase system is a more specific and sensitive target for UV-B damage in A. flos-aquae.

Experiments were performed to gain some insight into the nature of the nitrogenase inhibition by UV-B. Since nitrogenase is a multienzyme complex which can be assayed for in a variety of ways, we have also measured the effect of UV-B on the ability of the complex to photoevolve

molecular hydrogen. As can be seen in Table 3, the effect of UV-B on

Table 3

nitrogenase is negligible when this assay is used. Apparently, the activity of nitrogenase measured specifically by the acetylene reduction assay is the most sensitive indicator of UV-B damage.

Visible photobleaching of suspensions occurred after 6 hours irradiation with UV-B. However, no destruction of a specific pigment could be detected by examination of difference spectra of acetone extracts from irradiated and unirradiated cells.

Discussion

From a practical standpoint, it is obvious that assessment of the environmental effects of enhanced UV-B irradiation on biological material is going to require development of simple assay procedures with wide applicability. Our studies have consistently revealed a surprising sensitivity of the nitrogenase complex to UV-B irradiation. The UV-B irradiation level (ca. 3 W/m^2), which we find inhibitory to nitrogenase, is approximately the same as that of noon sunlight in the 280-330 nm region. The main drawback to this approach to this means of assessment of environmental damage is that it requires the use of those limited systems which possess nitrogenase activity.

It should be emphasized that, by performing direct microbiological plate counts on a large population of irradiated cells, we have ruled out the possibility that the UV-B effect observed on nitrogenase is due to nucleic acid damage. This finding suggests that the cellular target

may be another pigment associated with the nitrogenase complex or its electron transport system. Further studies on the action spectrum of this effect may help to reveal the cellular component involved as UV-B receptor.

The Azolla system provides an opportunity to examine the effect of UV-B on a plant and, simultaneously, its symbiont. Since nitrogenase activity (acetylene reduction) is exclusively a property of the symbiont, this specific physiological activity can be measured after irradiation of the fern. Measurement of fixation of $C^{14}O_2$ by the symbiosis serves as a general index of the physiological activity of the system. Data in Table 4 summarize such an experiment, in which $C^{14}O_2$ fixation and

Table 4

acetylene reduction are measured in UV-B-irradiated plants. Although there was a slow decline in general physiological activity of the plants as the culture aged, the nitrogenase activity of irradiated plants showed a significant decrease over control plants.

Information now available (12) on the effects of short wavelength UV irradiation on biological material has come virtually exclusively from studies of microorganisms. It seems likely, therefore, that microorganisms may again prove to be the material of choice to study biological UV-B effects. Nitrogen fixation consumes a substantial fraction of the energy of a cell in which it occurs; consequently, it is possible that a minor physiological disturbance would be expressed more readily in such a system. Furthermore, this assay (acetylene reduction) is readily adaptable to field studies and could serve as a convenient assay for a variety of environmental studies.

There seems little doubt that the green and blue-green algae will be organism of choice to study large populations of plant material under controlled conditions. Furthermore, since algal nitrogen fixation is confined to blue-green algae (cyanobacteria), we seem to have selected an ideal class of microorganism for evaluation of UV-B effects on plant material. Worldwide distribution of these organisms suggests that they might, in this way, serve as a convenient indicator of the extent of stratospheric ozone depletion.

Abstract

The effect of UV-B (280-320 nm) irradiation on physiological activities of Anabaena flos-aquae and the water fern Azolla caroliniana has been studied where lethal effects of irradiation are known to be absent. Nitrogenase activity specifically declined at low levels of UV-B, under conditions which had little effect on general physiological activity of the irradiated cells. These findings indicate that measurement of acetylene reduction (nitrogenase assay) may serve as a simple biochemical assay to assess environmental UV-B damage to plants due to depletions of stratospheric ozone.

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Table 1.

Effect of UV-B on nitrogenase activity of A. flos-aquae

Irradiation time[a]	Acetylene reduction[b]		
	Control	UV-B	UV[c]
h	nmol/h/mg protein		
0	1,490	1,490	945
0.5	---	---	370
1	---	---	105
2	---	---	10
3	1,300	840	---
6	1,350	340	---

[a]UV-B, 2.1 W/m^2, cell suspension, 40 ml; protein 65 µg/ml.

[b]Aliquots, 5 ml of suspensions incubated in light in atmosphere of argon-90%, acetylene 10% for assay.

[c]Rayonet lamps without cellulose acetate filter, 10 W/m^2 separate experiment, 40 µg/ml algal protein.

Table 2

Effect of UV-B on fixation of $^{14}CO_2$ by

A. flos-aquae[a]

Irradiation time[a] h	$^{14}CO_2$ fixed		
	Control	UV-B	UV[b]
	cpm/mg protein/min in light		
0	9,300	9,200	8,800
2	9,800	7,400	70
4	9,200	5,700	
6	7,800	5,500	

[a]Cell suspension, 37 ml; protein, 50 µg/ml.
UV-B, 2.1 W/m^2.

[b]Rayonet lamps without cellulose acetate filter,
10 W/m^2.

Table 3

Effect of UV-B on photoevolution of H_2 by

A. flos-aquae

Irradiation time[a] h	H_2 evolution[b]	
	Control	UV-B
	nmol/h/mg protein	
0	460	460
3	350	343
6	265	215

[a]Cell suspensions, 40 ml, 80 µg protein/ml, exposed to 2.1 W/m^2 UV-B.

[b]Aliquots, 5 ml, of suspension incubated anaerobically (argon atm.); 30 W/m^2 white light for assay.

Table 4

Effect of enhanced irradiation with UV-B on $^{14}CO_2$ fixation and acetylene reduction by Azolla

Irradiation time[a] days	Control		UV-B enhanced	
	$^{14}CO_2$ fixed[b]	Acetylene reduced[c]	$^{14}CO_2$ fixed[b]	Acetylene reduced[c]
1	24,000	450	20,200	300
2	17,800	380	15,200	100
4	7,200	320	5,900	130
6	4,350	350	4,700	100

[a]Visible light, 10 W/m^2, supplemented with UV-B, 2 W/m^2.

[b]cpm/g plants (wet)/min in visible light, 30 W/m^2.

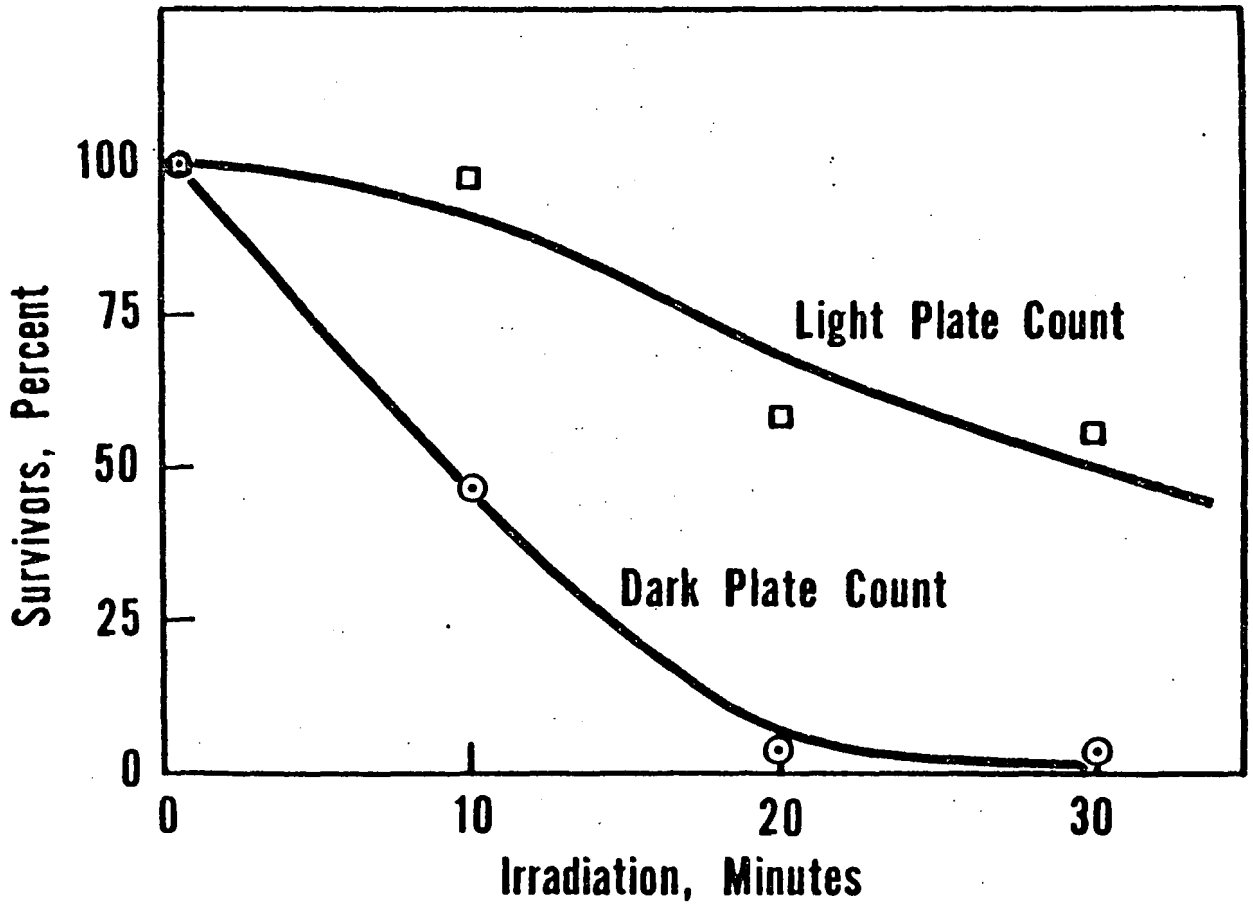
[c]nmol/g plants (wet)/h; argon atm., visible light, 30 W/m^2.

Figure Legends

Fig. 1. UV killing and photoreactivation of A. flos-aquae. Single, unfiltered, 8W Rayonet lamps, 15 cm from surface of stirred cell suspension. Algal protein, 6 μg/ml; total light, 2.7 W/m^2.

Fig. 2. UV-B irradiation of A. flos-aquae. Six Rayonet lamps in flat bank array held 17 cm from surface of stirred cell suspension (40 ml, 6 μg protein/ml). Total light, 5 W/m^2; UV-B, 2.1 W/m^2. Cellulose acetate filter (CA), 10 mil.

Fig. 3. Effect of higher UV-B intensity on A. flos-aquae. Six Rayonet lamps in curved reflector fixture held 17 cm from surface of stirred cell suspension (40 ml, 7.6 μg protein/ml). Total light, 12.5 W/m^2; UV-B, 5.2 W/m^2. Cellulose acetate filter, 10 mil.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50
25
0
Survivors, Percent
Light Plate Count
Dark Plate Count
0
10
20
30
Irradiation, Minutes

Figure 1

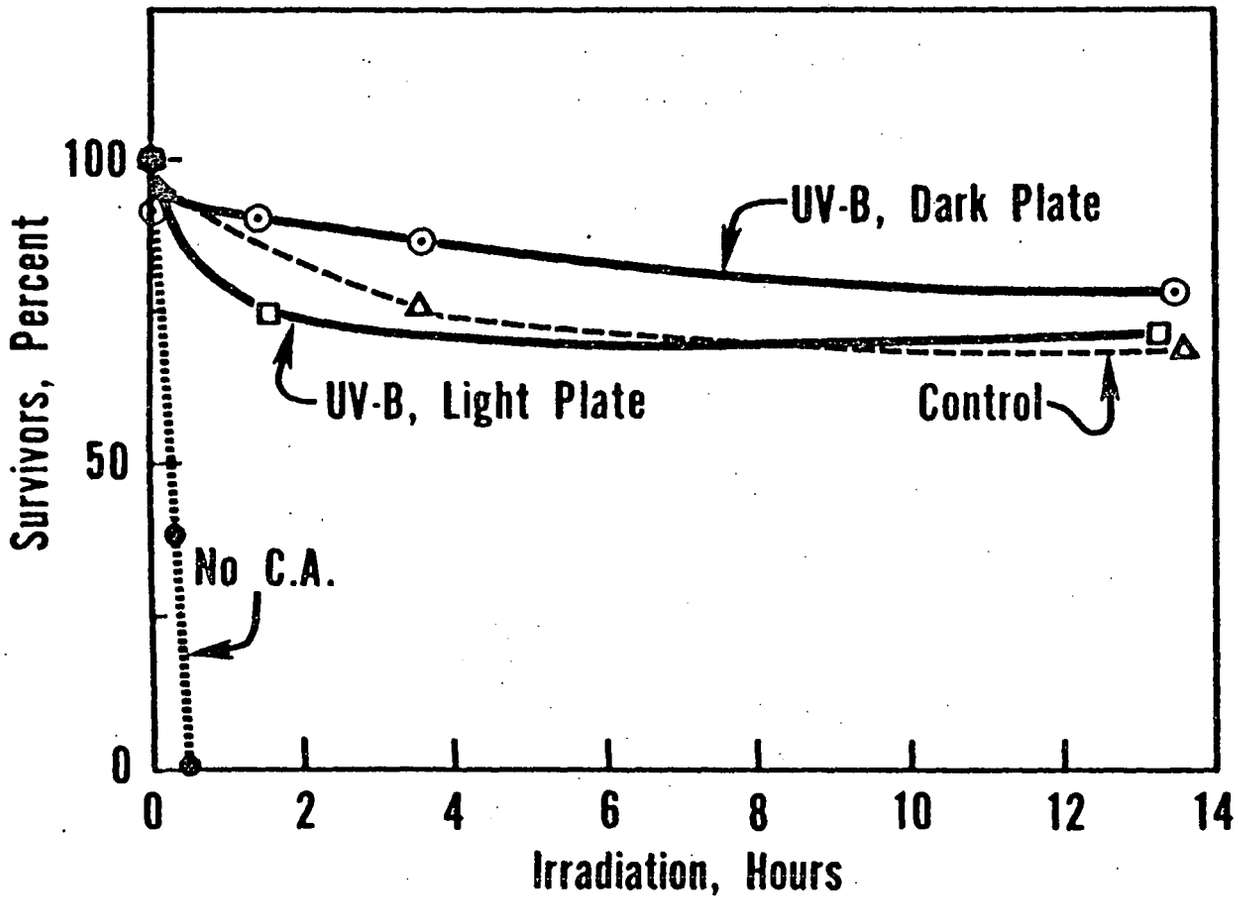
100
50
0
Survivors, Percent
UV-B, Dark Plate
UV-B, Light Plate
Control
No C.A.
0
2
4
6
8
10
12
14
Irradiation, Hours

Figure 2

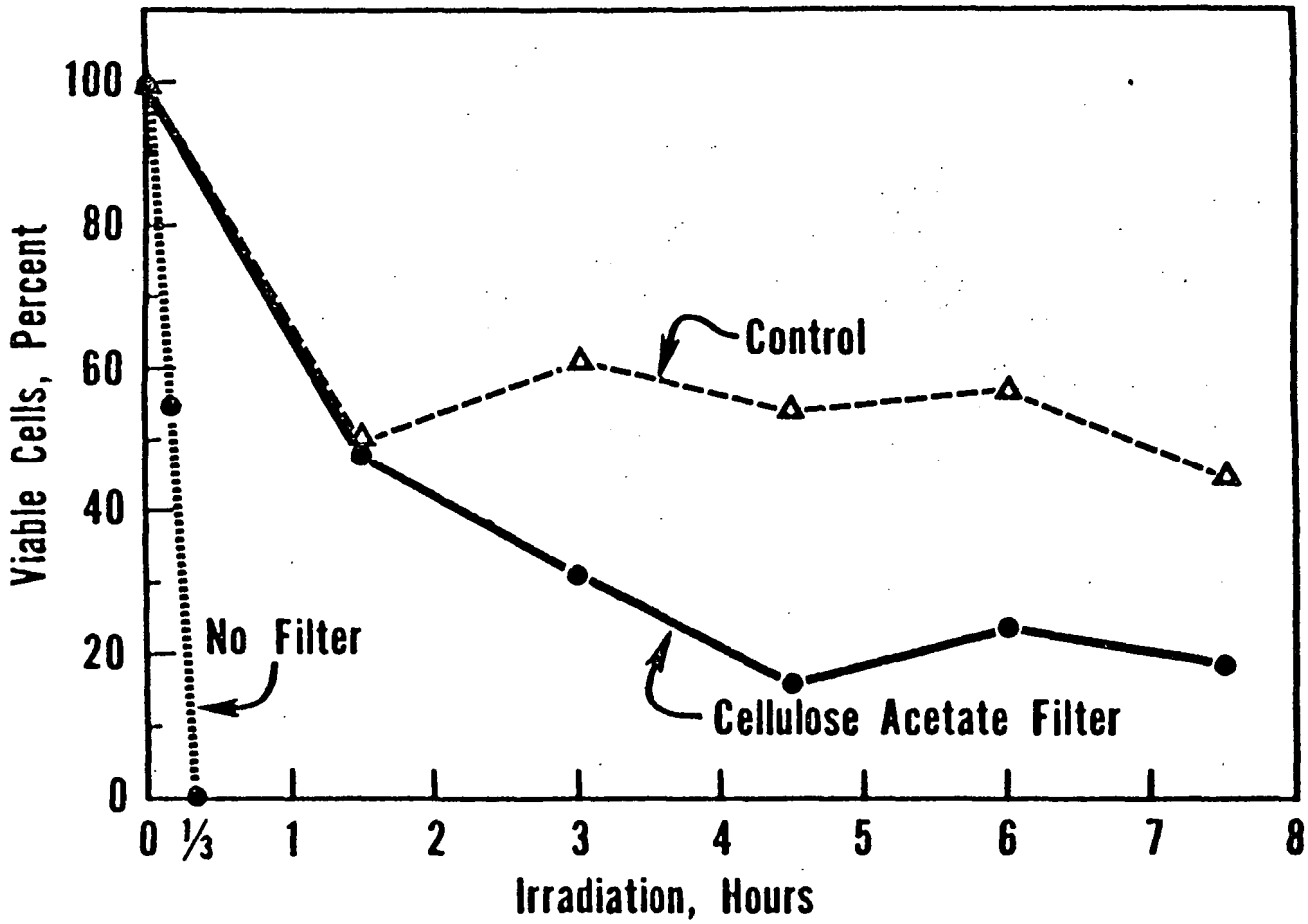
100
80
60
40
20
0
Viable Cells, Percent
Control
No Filter
Cellulose Acetate Filter
0
⅓
1
2
3
4
5
6
7
8
Irradiation, Hours

Figure 3

SIRA File # 142.25

FINAL REPORT

IMPACT OF SOLAR UV-B RADIATION ON CROPS AND CROP CANOPIES

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TABLE OF CONTENTS

SUMMARY

Effects of UV-B radiation (280 to 320 nm) on 'Bragg' and 'Altona' soybeans, 'Little Marvel' peas, 'Rutgers' tomatoes, and 'Golden Cross Bantam' sweet corn were investigated under greenhouse conditions. UV-B irradiance was provided by FS-40 sun lamps filtered with 0.127 mm (5 mil) cellulose acetate film (UV-B enhanced) or 0.127 mm (5 mil) Mylar film (control). Three different radiation doses were tested: 1.31 (treatment T_1), 1.64 (treatment T_2), and 2.25 (treatment T_3) UV-B sun equivalent units ($UV\text{-}B_{seu}$) where 1 $UV\text{-}B_{seu}$ = 15.98 mWatts m^{-2} weighted by EXP $(-[\lambda - 265)/21.2]^2)$ from 290 to 330 nm. Most effects were studied within 4 to 7 weeks after seeding.

In soybeans, peas, and tomatoes (C_3 plants), exposure to UV-B doses T_2 and T_3 caused significant depressions in biomass accumulation, photosynthetic pigment contents, and leaf CO_2 uptake rates. Leaf pigment extracts in 80% aqueous acetone from UV-B-treated plants of soybeans and peas showed considerable increase in absorption in the wavelength region of 330 nm to 400 nm with increased UV-B doses. Hill reaction measurements with chloroplast preparations of both soybeans and tomatoes showed significant reductions when seedlings were exposed to 2.25 $UV\text{-}B_{seu}$. Significant inhibitions of RuDP-Carboxylase were obtained in soybean leaf extracts at all three UV-B doses and in tomato leaf extracts at T_2 and T_3. An apparent decrease in soluble proteins was also observed in soybean leaf extract while higher levels of proteins were present in UV-B-treated tomato leaves.

In sweet corn (C_4 plant), seedlings exposed to 2.25 UV-B_{seu} had significantly lower biomass accumulations than those of the controls. Plant height and leaf area gradually decreased with increasing levels of UV-B radiation. Only corn seedlings exposed to the highest treatment (2.25 UV-B_{seu}) showed a significant inhibition in leaf photosynthetic rates. Activities of PEP-Carboxylase in crude extracts from corn leaves were significantly suppressed under the two highest UV-B doses (1.64 and 2.25 UV-B_{seu}). Although not statistically significant, some stimulation of PEP-Carboxylase activity and photosynthetic rate was obtained in corn plants exposed to 1.31 UV-B_{seu}. No differences in proteins of corn among treatments and controls were detected.

Continued exposure of soybean and pea seedlings to UV-B radiation caused development of abnormal leaf pigmentation, such as leaf chlorosis and bronzing, which increased in severity with increased doses of UV-B radiation. In addition, phenomena such as distortion of leaf blades and reduction of leaf sizes were commonly seen in the most intense UV-B treatment (T_3). Light microscope observations of 'Bragg' soybean leaf tissue showed that chlorosis and bronzing were limited primarily to palisade cell layers. Often there was a sharp border separating chlorotic and green pigmentation areas. This border was demarcated by major veins. Chlorosis and bronzing pigmentation patterns indicated they may be caused by a compound mobilized in vascular tissue. This compound may cause a general alteration in phenol metabolism in response to enhanced UV-B. Electron micrographs showed that there was a substantial reduction in the amount of chloroplast lamellae and starch content in the palisade cells of chlorotic areas, whereas green tissue from the same

leaf showed no abnormal structures. Spongy mesophyll tissue in the chlorotic regions contained green chloroplasts of normal size, with other organelles being similar in appearance to those in the controls. Bronzing pigmentation initially occurred in the cell wall regions of adaxial epidermal cells, and later appeared in the walls of palisade cells. Bronzed cells showed collapsed walls and degraded cytoplasm. The degraded quality of plastids in the palisade cells constituted another distinctive feature of bronzed leaf mesophyll tissue. Control tissue contained typical (chlorophyllous) palisade cells, whereas a variety of cell types, based primarily on the ultrastructure of their plastids, were found in bronzed palisade tissues. These types were referred to as "vesiculate", "lamellate", "alamellate", and "lytic" cell types. The lytic cell type was the most commonly found cell type in palisade layers of bronzed areas. This type showed large vacant areas in transverse sections.

The presence of mixed cells (containing more than one type of plastid), as well as plastid structures found in some cell types, indicated that UV-B enhancement could be causing lesions in plastid nucleic acids and/or proteins.

No visual development of chlorosis or bronzing was found in corn leaves. At the highest level of UV-B radiation, corn leaf tissue appeared to be unaffected by UV-B enhancement. On the ultrastructural level, no deleterious effects were apparent in the structure of cell organelles in bundle sheath and mesophyll cells, as compared to the control tissue.

SECTION I

GENERAL METHODS AND PROCEDURES

The purpose of these studies was to investigate the effects of higher levels of solar ultraviolet radiation in the 280 to 320 nm bandwidth (UV-B radiation) on agronomic crops. Several crops were grown and irradiated with different levels of UV-B radiation under greenhouse conditions in order to provide data for the assessment of plant responses to increases in UV-B radiation that would reach the earth's surface if man-induced (or natural) perturbations result in a decrease of stratospheric ozone concentrations. At the end of each experimental period, measurements or analyses were performed to relate treatment to growth, photosynthesis and its component biochemical reactions, and ultrastructure of these crop plants.

Procedures that were used to set up UV-B enhancement regimes in the greenhouse are covered in this section. These procedures include materials used, environmental conditions, and measurements and computations of irradiance outputs of filtered UV-B lamps (Westinghouse FS-40 sun lamps)[1/] in the UV-B wavelength range. Details on specific experiments, analyses, and results appear in the following sections.

1/ Mention of this proprietary product, or any other proprietary product in this report, is for the convenience of the reader only, and does not constitute endorsement by the U.S. Department of Agriculture, the U.S. Environmental Protection Agency, or the University of Florida.

1) Plant Materials and Greenhouse Regime

Soybeans (Glycine max L. cv. 'Bragg' and 'Altona'), peas (Pisum sativum L. cv. 'Little Marvel'), tomatoes (Lycopersicum esculentum L. cv. 'Rutgers') and sweet corn (Zea mays L. cv. 'Golden Cross Bantam') were selected for these UV-B effect investigations because of their agronomic and economic importance. Three sequential seedings were investigated at different times as follows: the first seeding on May 6, 1977 for 'Bragg' and 'Altona' soybeans and for 'Little Marvel' peas; the second seeding on July 20, 1977 for 'Bragg' soybean and 'Rutgers' tomatoes; the third seeding on October 4, 1977 for sweet corn and on October 12, 1977 for 'Bragg' soybean. Seeds for each cultivar or species were planted directly in 15-cm diameter plastic pots (3 to 5 seeds/pot) containing a mixture of equal proportion of vermiculite and potting soil, and were placed on tables in a greenhouse.

Light fixtures containing two Westinghouse fluorescent FS-40 sun lamps and filter systems were suspended above the pots to provide supplemental UV-B fluxes (Figure 2). Sun lamp radiation was filtered either through 0.127 mm (5 mil) UV-B radiation transmitting cellulose acetate (UV-B enhanced) or 0.127 mm (5 mil) UV-B radiation absorbing Mylar S (Mylar control). For comparative evaluation in some experiments, a second set of control plants were also grown at the same time in the greenhouse without exposure to any filtered sun lamp systems (no UV control). Starting from the day of seed planting, the FS-40 lamps were turned on for 6 hrs daily, from 10:00 EDT to 16:00 EDT (9:00 EST to 16:00 EST). Cellulose acetate filters were changed twice a week. UV-B flux densities in each treatment were checked daily and distances between lamps

and plant apex were adjusted to ensure that seedlings or plants in each specific treatment received the desired experimental dose of UV-B radiation. For the controls, the distance between Mylar-filtered lamps and plant apex were adjusted to the same distances of the corresponding cellulose acetate-filtered treatments. No artificial light sources were used to extend greenhouse daylength or to supplement greenhouse daylight that was natural sunlight transmitted through the lascolite greenhouse roof. The midday photosynthetically active radiation (PAR 400 to 700 nm) in the greenhouse was about 450 to 500 $\mu E\ m^{-2}\ sec^{-1}$ above the sun lamp fixtures and 220 to 250 $\mu E\ m^{-2}\ sec^{-1}$ at plant height under the lamps. Temperatures inside the greenhouse during the period of growth of soybeans, peas, and tomatoes of the first and second seeding fluctuated between 20°C (night time) and 35°C (daytime), and those during the growth of sweet corn and 'Bragg' soybean of the third seeding changed from as low as 3°C (night time) to 30°C (daytime). Humidities averaged from 95% (night time) to 40% (daytime). The greenhouse was cooled during the day by forced draft evaporative cooling. During the growth period, plants were checked and watered daily to ensure adequate moisture. Liquid fertilizers were applied weekly, starting from the second week after seed planting, at a rate of 0.6 g of 20-20-20 Sunniland fertilizer per pot. Ten days after germination, seedlings were thinned to one plant per pot to ensure uniform seedlings for each set of experiments.

At the end of each predetermined experimental period of growth, typical plants having similar size in each treatment were chosen for growth analyses or photosynthetic measurements. Samples of fresh leaves were selected and used for analyses and studies of photosynthetic component

reactions and ultrastructure.

2) Measurements and Computations of the Irradiance Output (290 - 330 nm) of FS-40 Sun Lamps

On April 28, 1977, UV-B flux densities were measured with a Gamma Scientific Spectroradiometer at ground level under a clear sky at the Horticultural Unit, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida. The spectroradiometer was connected to a Hewlett-Packard computer system to acquire and process the data. Data scans from 280 to 340 nm were collected at 30-min intervals, starting at 7:35 EST and ending at 15:02 EST. Unweighted UV flux densities were printed at 1-nm intervals in units of Watts m^{-2} nm^{-1}. A weighting function, $EXP(-[\lambda-265)/21.2]^2)$, was used to simulate DNA absorption (Carns et al., 1977), and weighted flux values were also printed at 1-nm intervals in units of mWatts m^{-2} nm^{-1}. This weighting function has been referred to as A Σ 21. Both unweighted and weighted UV flux densities were summed over the 280 to 340 nm wavelength range for each scan (Table 1). "Standard" solar day unweighted and weighted flux density curves were extrapolated to early and late hours of the day (Table 1, Figure 1).

In order to obtain the whole day irradiance in unweighted Watts·sec m^{-2} and weighted mWatts·sec m^{-2}, both the unweighted and weighted UV-B flux densities were summed over each 30-min observation (including extrapolated and interpolated observations), multipled by 30 min per observation, and multiplied by 60 sec per min. UV-B unweighted and weighted flux densities were then computed for a "square value", 6-hr equivalent period (Figure 1) by dividing the above whole-day irradiance by the number of seconds in 6 hrs (6 x 60 x 60).

We also compared the A Σ 21 weighting function with another one developed by Carns et al. (1977). This function, termed A Σ 9, is $[1/4\ (\lambda/\lambda o)^9]^4$ x EXP$[4-(\lambda/\lambda o)^9]$ where λo = 228.178 nm, and the function has a maximum value at about 266 nm. Weighted UV-B flux densities based on 5-nm intervals were computed as shown above. This weighting function was not used to express UV-B treatment levels in this report, but are included for comparisons. Results of these computations were:

Whole-day Irradiance		6-hr Flux Density	
Unweighted	Weighted	Unweighted	Weighted
(Watts sec m^{-2})	(mWatts sec m^{-2})	(Watts m^{-2})	(mWatts m^{-2})
227.8 x 10^3	345.1 x 10^3 (A Σ 21)	10.55	15.98 (A Σ 21)
	87.2 x 10^3 (A Σ 9)		4.04 (A Σ 9)

Thus, the averaged UV-B weighted flux density for this 'Gainesville standard' solar day (April 28, 1977) equals 15.98 mWatts m^{-2} based on the earlier weighting function. This value was adopted as 'standard' UV-B sun equivalent unit (seu) and UV-B enhancement was expressed as $UV\text{-}B_{seu}$ where 1 $UV\text{-}B_{seu}$ = 15.98 mWatts m^{-2}.

Carns (personal communication) found that the 'Beltsville standard' sun gave a $UV\text{-}B_{seu}$ of 3.06 mWatts m^{-2} based on the latter weighting function. Our $UV\text{-}B_{seu}$ based on the 'Gainesville standard' sun and the latter weighting function was 4.04 mWatts m^{-2}.

Supplemental UV-B irradiance was provided by means of Westinghouse FS-40 fluorescent sun lamps filtered with 0.127 mm (5 mil) of UV-B transmitting cellulose acetate (Transil Wrap Co., Doraville, Georgia). Two 40-watt FS-40 tubes were mounted in a 1.22-m fixture and one layer of cellulose acetate filter was clamped under the

fluorescent tubes to the edges of the fixture reflector (Figure 2). All measurements were taken inside the greenhouse after 20:00 EDT (19:00 EST). UV-B spectral energy flux densities were measured with a Gamma Scientific Spectroradiometer which was set up with sensor oriented perpendicular to the fluorescent tubes directly below the midpoint of the tubes. The lamps that had been aged for 100 hrs were turned on for about 15 to 20 min before actual measurements were started. The spectroradiometer was zeroed and readings in millivolts were taken at 5-nm intervals from 280 to 330 nm. Different flux densities at twelve different distances between the spectroradiometer sensor and sun lamps were obtained by varying the height of the lamp fixture hanging above. Readings in equivalent sunburn units (S.U. hr^{-1}) at each corresponding distance were also taken at the same time with a Solar Light Meter Model SSI 7880 (Solar Light Co., Philadelphia). This portable instrument was used for daily checks of the UV-B irradiance output. At each calibration distance, the spectroradiometer output was read at 5-nm wavelength intervals from 280 to 330 nm. These readings were converted to UV-irradiance, and thence to the A Σ 21 weighted irradiance by $EXP(-[\lambda-265)/21.2]^2$, and the total irradiance from 290 to 330 nm was computed (Table 2).

Figure 3 shows the total weighted irradiance in the wavelength region 290 to 330 nm as a function of distance. Correlation between total UV-B weighted irradiance and sunburn units was almost linear (Figure 4). Values in sunburn units were also plotted as a function of distance from sensor to middle of the tubes (Figure 5) and this curve was found convenient for daily checks of the radiation output

from FS-40 lamps.

We computed the A Σ 9 weighted irradiances at each distance for each 5-nm interval by multiplying the irradiances in Table 2 by the ratio of the A Σ 9/A Σ 21 weighting function (Table 3). From these data we found that the ratio of the average weighted irradiance based on the A Σ 9 function to that based on the A Σ 21 function was 0.525. This factor could be applied to the left ordinate of Figure 3. We also found that the average ratio of the UV-B_{seu} based on A Σ 9 to the UV-B_{seu} based on A Σ 21 was 2.08. This factor can be applied to the right ordinate of Figure 3 to compute the UV-B_{seu} based on the A Σ 9 weighting function.

Three following UV-B dose treatments based on the A Σ 21 weighting function were used as appears in the experimental methods and results of the next sections: 1.31 UV-B_{seu} for treatment T_1, 1.64 UV-B_{seu} for treatment T_2, and 2.25 UV-B_{seu} for treatment T_3. These treatments correspond to 2.72, 3.41 , and 4.68 UV-B_{seu}, respectively, based on the A Σ 9 weighting function. These latter values are given for reference, and will not be used in this report.

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TABLE 1

SOLAR RADIATION AT GROUND LEVEL AS MEASURED WITH A GAMMA SPECTRORADIOMETER ON APRIL 28, 1977 AT THE HORTICULTURAL UNIT IN GAINESVILLE, FLORIDA

Time	Unweighted Flux ($W\ m^{-2}$)	Weighted Flux ($mW\ m^{-2}$)
7:05	0.800 (extrapolated value)	0.400 (extrap. value)
7:35	1.726	1.336
8:05	2.565	2.288
8:35	3.652	3.663
9:05	4.808	5.618
9:35	5.900 (interpolated value)	7.850 (interp. value)
10:05	7.003	10.070
10:35	7.767	12.261
11:05	8.560	14.070
11:35	9.308	16.366
12:05	9.665	17.212
12:35	9.796	17.478
13:05	9.658	17.044
13:35	8.922	15.390
14:02	8.500	13.450
14:32	7.667	11.226
15:02	6.660	9.288
15:35	5.330 (extrap. value)	7.120 (extrap. value)
16:05	4.000 (extrap. value)	5.150 (extrap. value)
16:35	2.800 (extrap. value)	3.250 (extrap. value)
17:05	1.470 (extrap. value)	1.200 (extrap. value)
SUM	$126.557\ W\ m^{-2}$	$191.73\ mW\ m^{-2}$

Σ unweighted = $227.8 \times 10^3\ W \cdot sec\ m^{-2}$ Σ weighted = $345.1 \times 10^3\ mW \cdot sec\ m^{-2}$

TABLE 2

WEIGHTED UV-B IRRADIANCE (A Σ 21) AS A FUNCTION OF WAVELENGTH AND DISTANCE OF LAMPS FROM THE SPECTRORADIOMETER

Distance[1/]	18.40	20.65	27.95	28.60	33.34	33.65	39.37	41.30	52.38	54.60	64.15	65.10
Wavelength												
290	0.900	0.930	0.845	0.507	0.845	0.789	0.732	0.479	0.676	0.394	0.394	0.620
295	2.506	2.378	1.868	1.868	1.784	1.670	1.501	1.472	1.189	1.076	0.877	0.934
300	3.489	3.179	2.519	2.398	2.223	2.142	1.846	1.751	1.334	1.266	1.050	1.064
305	2.159	1.971	1.533	1.428	1.340	1.290	1.102	0.991	0.811	0.728	0.581	0.631
310	0.975	0.891	0.686	0.650	0.599	0.582	0.495	0.448	0.357	0.327	0.261	0.282
315	0.347	0.310	0.242	0.223	0.210	0.204	0.172	0.152	0.127	0.109	0.088	0.099
320	0.093	0.083	0.065	0.057	0.057	0.055	0.047	0.041	0.035	0.029	0.024	0.027
325	0.020	0.018	0.014	0.013	0.012	0.012	0.010	0.009	0.008	0.006	0.005	0.006
330	0.004	0.004	0.003	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001
SUM[2/]	10.493	9.764	7.775	7.146	7.072	6.746	5.907	5.345	4.538	3.936	3.281	3.664
TOTAL[3/]	52.47	48.82	38.88	35.73	35.36	33.73	29.54	26.72	22.69	19.68	16.41	18.32

[1/] Distance perpendicularly from center of sensor to midpoint of lamp tubes in cm.

[2/] Sum, mWatts m^{-2} nm^{-1}.

[3/] Total = Sum x 5nm, mWatts m^{-2}.

TABLE 3

WEIGHTED UV-B IRRADIANCE (A Σ 9) AS A FUNCTION OF WAVELENGTH AND DISTANCE OF LAMPS FROM THE SPECTRORADIOMETER

Distance[1]	18.40	20.65	27.95	28.60	33.34	33.65	39.37	41.30	52.38	54.60	64.15	65.10
Wavelength												
290	0.777	0.803	0.730	0.438	0.730	0.681	0.632	0.414	0.584	0.340	0.340	0.535
295	1.773	1.683	1.322	1.322	1.263	1.182	1.062	1.042	0.841	0.761	0.621	0.661
300	1.812	1.651	1.308	1.245	1.154	1.112	0.959	0.909	0.693	0.657	0.545	0.552
305	0.723	0.660	0.513	0.478	0.449	0.432	0.369	0.332	0.272	0.244	0.195	0.211
310	0.180	0.164	0.127	0.120	0.111	0.107	0.091	0.082	0.066	0.060	0.048	0.052
315	0.029	0.026	0.020	0.019	0.017	0.017	0.014	0.013	0.011	0.009	0.007	0.008
320	0.003	0.003	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001
325	-	-	-	-	-	-	-	-	-	-	-	-
SUM[2]	5.297	4.990	4.022	3.624	3.726	3.533	3.128	2.793	2.468	2.072	1.757	2.020
TOTAL[3]	26.49	24.95	20.11	18.12	18.63	17.67	15.64	13.97	12.34	10.36	8.79	10.10

[1] Distance perpendicularly from center of sensor to midpoint of lamp tubes in cm.

[2] Sum, mWatts m^{-2} nm^{-1}.

[3] Total = Sum x 5nm, mWatts m^{-2}.

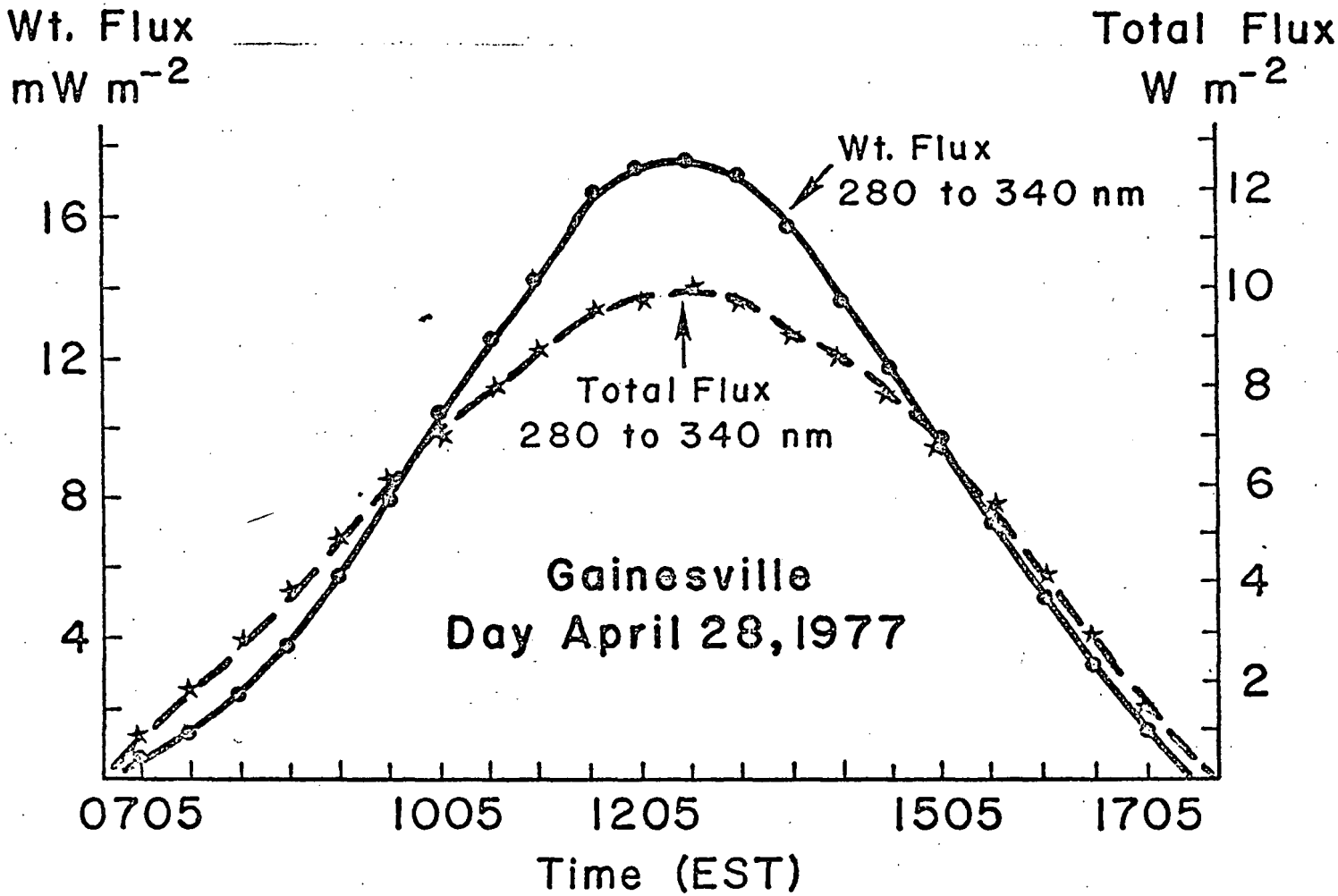

Figure 1. Weighted flux density and total (unweighted) flux density of UV-B radiation on April 28, 1977, at Gainesville, Florida.

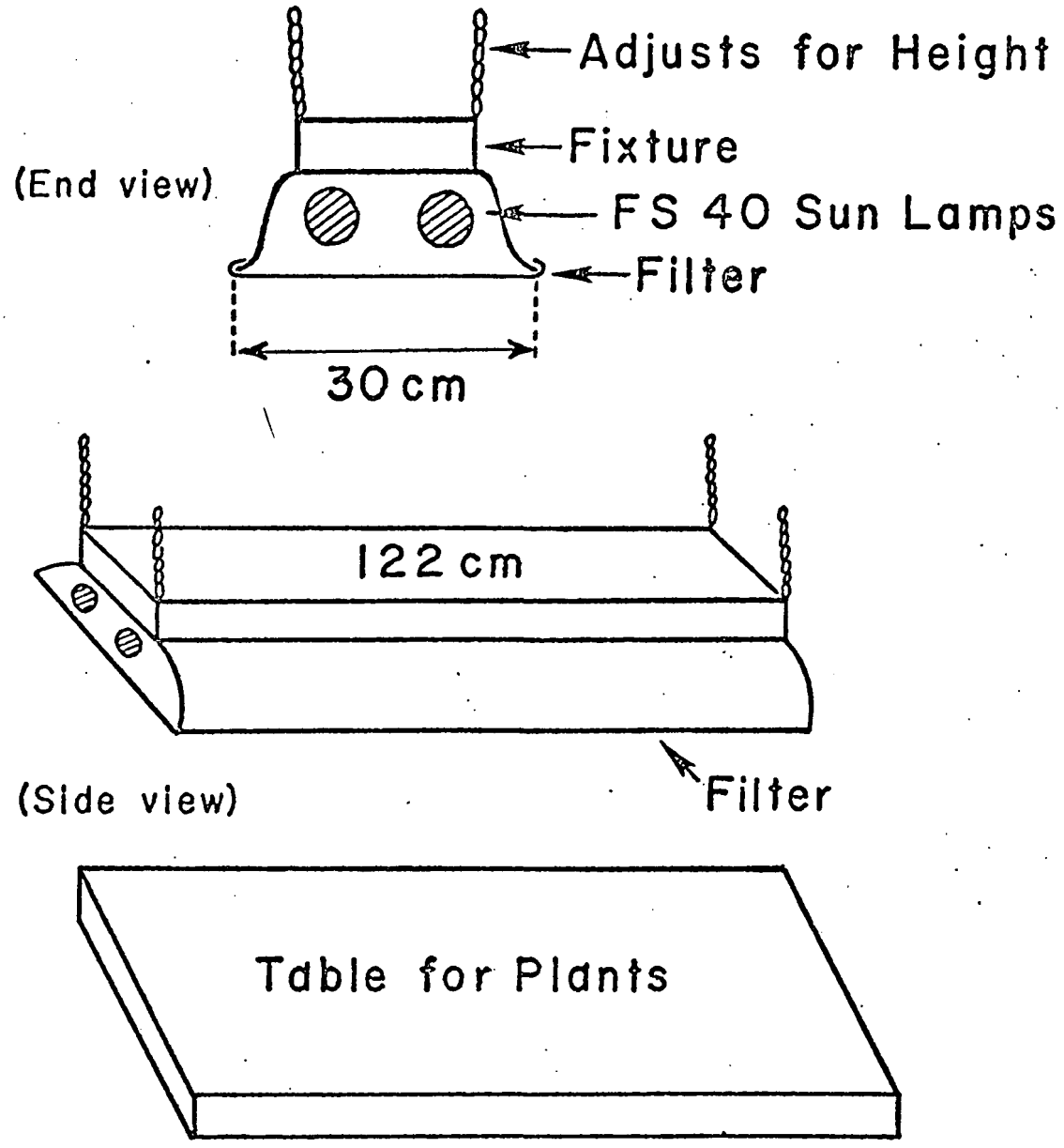

Figure 2. Setup for UV-B radiation enhancement in the greenhouse.

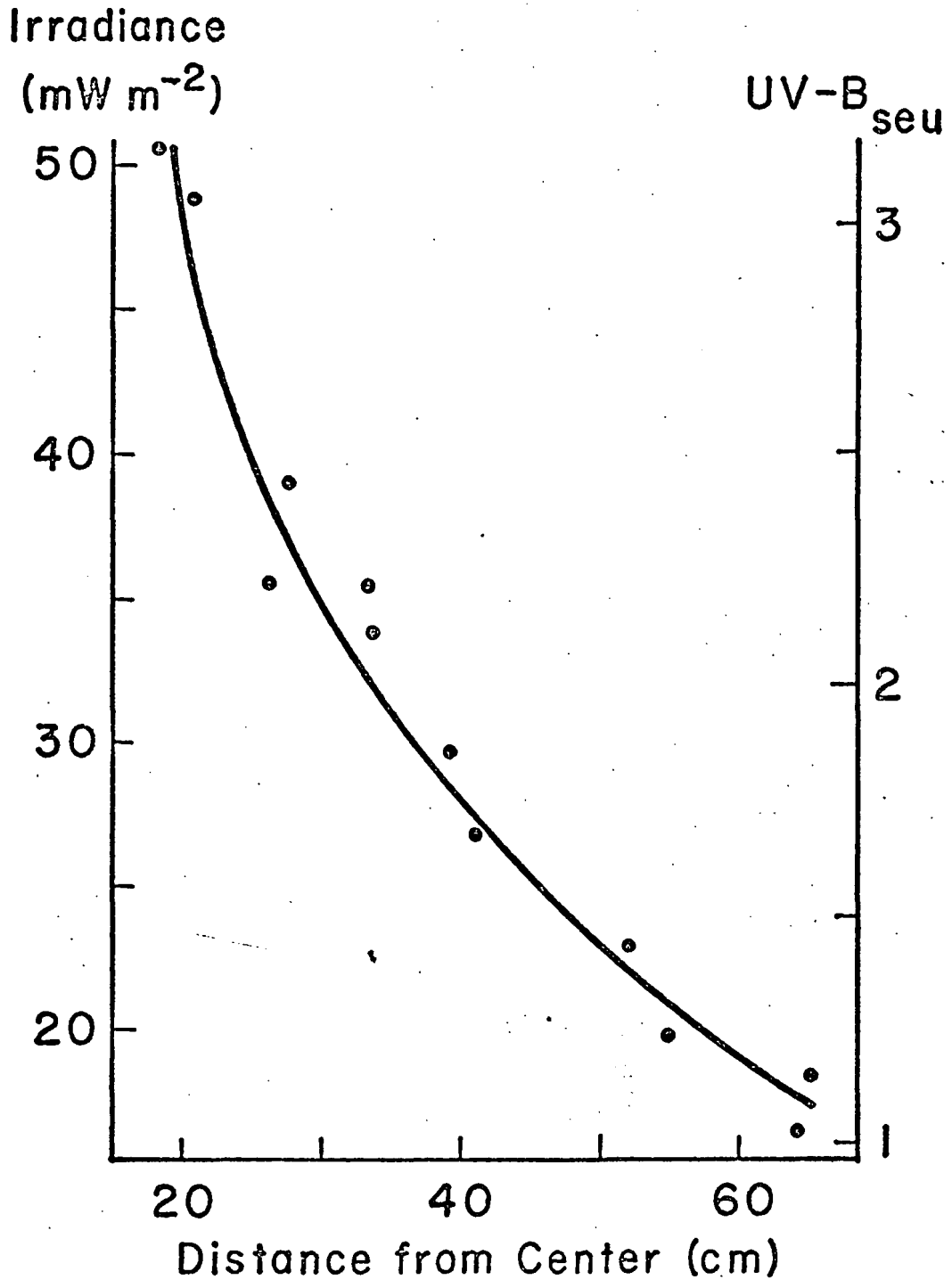

Figure 3. Weighted UV-B irradiance output and corresponding UV-B$_{seu}$ values at different distances from two FS-40 sun lamps (measurements were taken inside the greenhouse after 20:00 EDT) (1 UV-B$_{seu}$ = 15.98 mW m^{-2}).

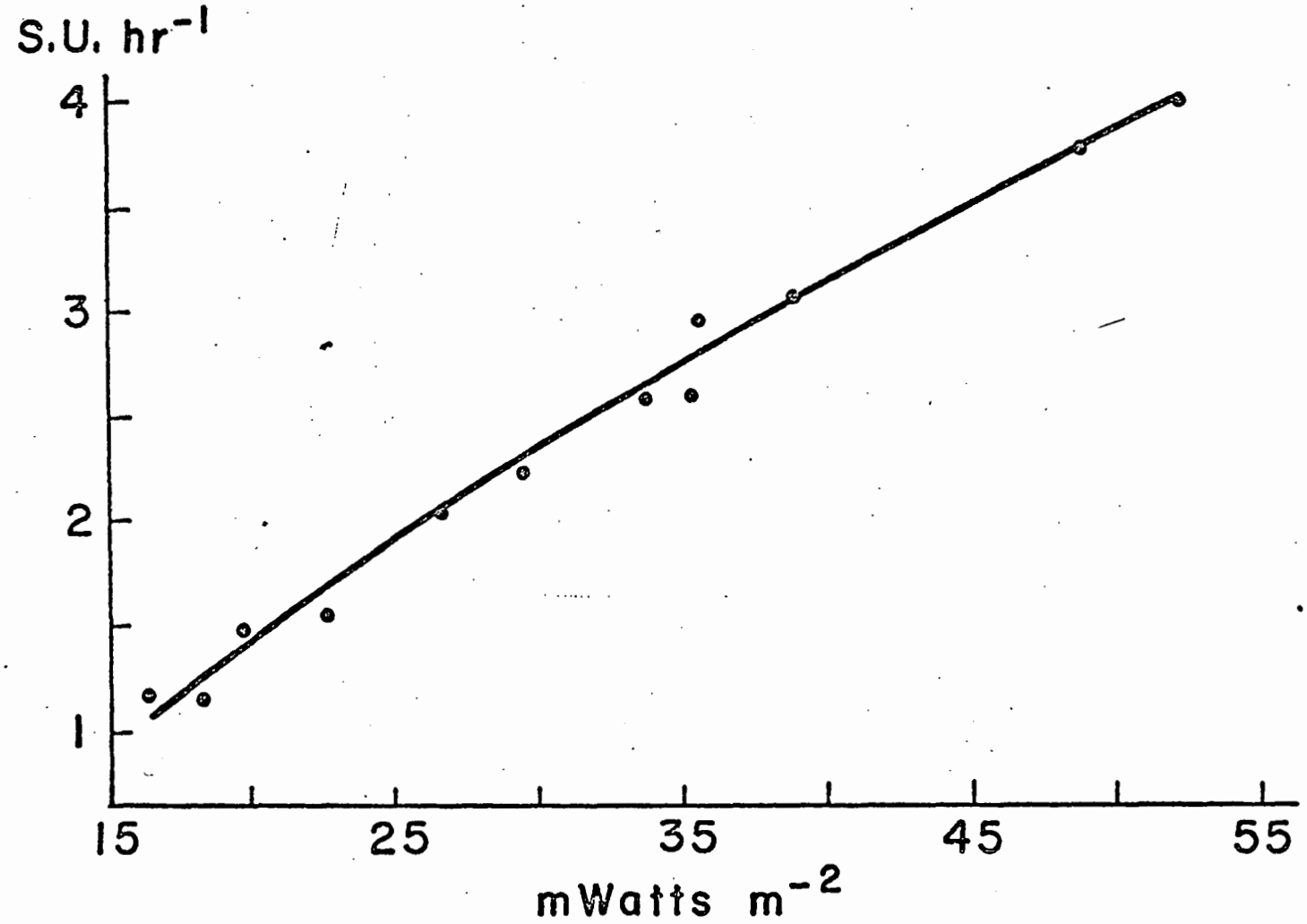

Figure 4. Relation between UV-B irradiance from two FS-40 sun lamps and sunburn units.

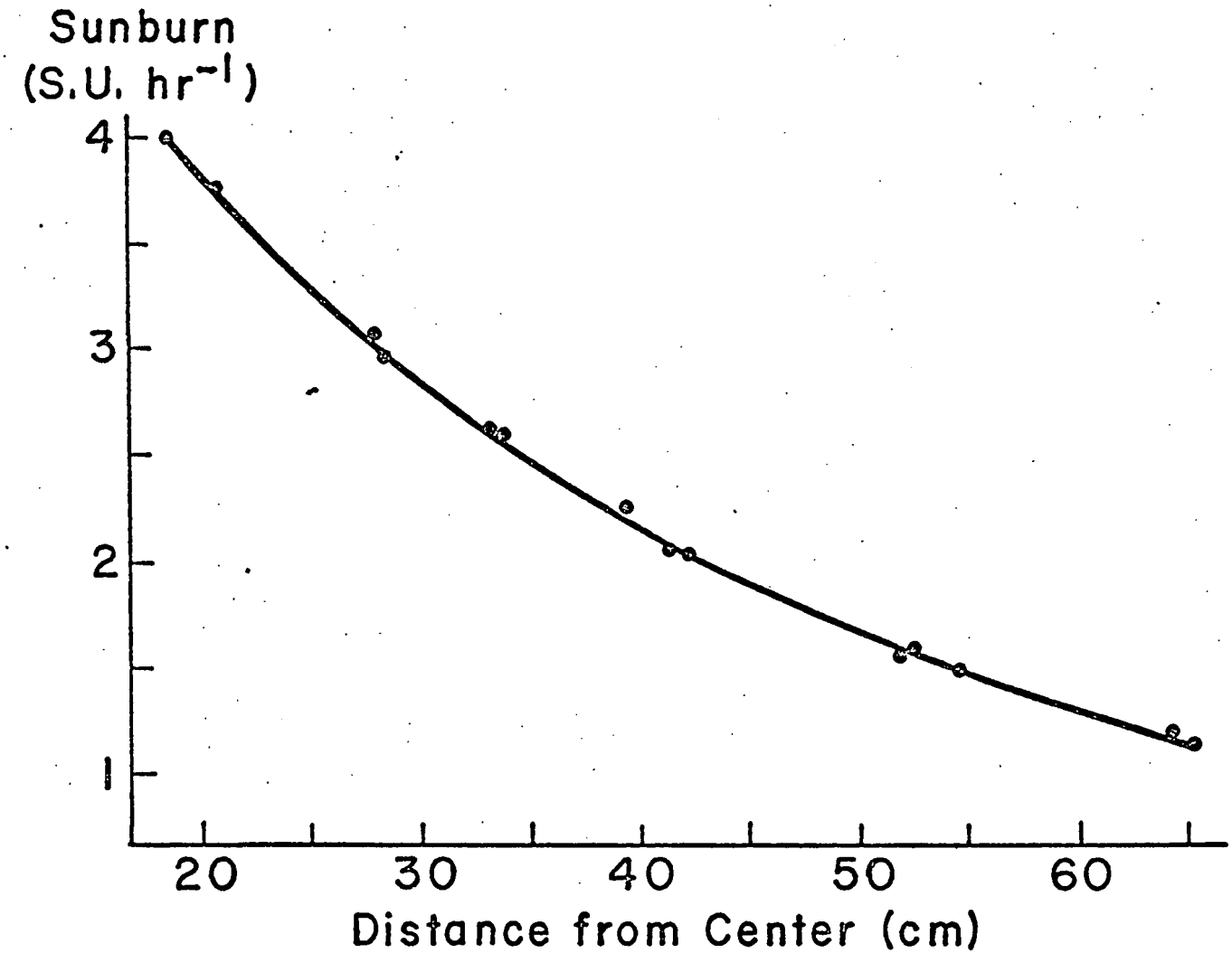

Figure 5. Sunburn units of two FS-40 sun lamps as a function of distance.

SECTION II

EFFECTS OF SUPPLEMENTAL UV-B ON GROWTH OF SOME AGRONOMIC CROP PLANTS

INTRODUCTION

Plant biomass accumulation that reflects a summation of effects through the growth period appears to be one of the best parameters for comparison and evaluation of plant response to specific experimental treatments. Studies that were carried out in both field and controlled environment conditions showed that UV-B radiation significantly reduced growth and biomass accumulation of many plant species (Caldwell et al., 1975; Biggs and Basiouny, 1975; Sisson and Caldwell, 1976; Van et al., 1976). In this section, greenhouse experiments were conducted to deal with growth and development of some agronomic crops that were exposed to different doses of UV-B enhanced irradiation.

EXPERIMENTAL METHODS AND PROCEDURES

Fresh weights and dry weights per plant in the UV-B treated and control plots were determined for soybeans, peas, and sweet corn. Measurements were made on soybeans and peas at 35 days after planting (planting date - May 6, 1977; harvesting date - June 10, 1977, with 210 hours of exposure to enhanced UV-B radiation) and on sweet corn at 45 days after planting (planting date - October 4, 1977; harvesting date - November 18, 1977, with 270 hours of exposure to enhanced UV-B radiation). Plants were carefully removed from pots and the soil around the roots was gently washed away with water. The roots, after washing to free them of soil and vermiculite, were then blotted with paper towels. Each plant was put in an air tight polyethylene bag and fresh weight was determined within 2 hours after

collection.

Plant height and total leaf area of sweet corn were also measured at 43 days after planting. Height of the above ground main stem was taken from the stem base to the terminal shoot. Length and width in the middle of each leaf were measured and leaf area was computed. Total leaf area per plant was the summation of areas of individual leaves of the plant.

Dry weight was determined after drying the samples in an oven at 70°C for 48 hours. Fresh weights and dry weights were measured for the whole plant for soybeans and peas, and separately as shoots and roots for sweet corn.

RESULTS AND DISCUSSION

For purpose of evaluating the response of important agronomic crops to supplementary UV-B radiation, plants were grown in a greenhouse with different doses of UV-B radiation. Fresh weights and dry weights of greenhouse-grown soybean, peas, and sweet corn that were exposed to an enhanced UV-B irradiation regime are presented in Tables 1 and 2.

The data from these Tables demonstrate that the effects of UV-B radiant energy on growth are dose-related. Fresh and dry weight of soybeans, peas, and sweet corn were significantly reduced when plants were grown under high levels of UV-B radiation in the greenhouse. At the highest UV-B dose of the experiment (2.25 $UV\text{-}B_{seu}$), growth was reduced to 30-40% of the Mylar control in both soybeans and peas (Table 1).

'Altona' soybean seemed to suffer more severely under UV radiation than 'Bragg' soybean, both in fresh and dry weights. No statistical test was performed as regard to UV response for these 2 cultivars of

soybeans. 'Little Marvel' pea, being classified as "sensitive" in respect to UV-B radiant energy (Van et al., 1976), also showed highly significant reductions under 2.25 UV-B_{seu}. Dry weights in general were reduced to about the same degree as fresh weights for all three crops.

A general visual observation was that soybean and pea seedlings respond to continuous UV radiation at 1.64 and 2.25 UV-B_{seu}. Chlorotic and bronzing symptoms in leaves that were exposed to UV-B radiation were observed both in peas and in soybeans. Furthermore, soybeans exposed continuously to 2.25 UV-B_{seu} also showed abnormal curvature of the shoots and distortion of leaves. Some dark brown areas or spots around the vein tissues also appeared in some areas near the central regions of young leaf tissues. Plants growing under Mylar filter controls were healthy and similar in appearance to untreated control plants.

In both cultivars of soybeans, dry weights were reduced to a lower level than fresh weight. Dry matter accumulation of control 'Bragg' soybeans irradiated through a Mylar filter was more than twice that of plants exposed to 2.25 UV-B_{seu}. The dry weight accumulation of 'Altona' plants under the same dose of UV was only one third of the Mylar control plants. Also, when irradiated under 1.64 UV-B_{seu}, the 'Altona' dry weight was lower than the 'Bragg', 60% vs. 75% with respect to the Mylar control, respectively, for the two cultivars. Similar observations were noted in fresh weight accumulation, 38% vs. 49%, with respect to the Mylar control at 2.25 UV-B_{seu}, and 74% to 85% with respect to the Mylar control at 1.64 UV-B_{seu}, for 'Altona' and 'Bragg', respectively.

At 1.64 UV-B_{seu}, 'Little Marvel' pea plants showed no significant differences from the Mylar control in both fresh and dry weight (Table 1).

However, pea plants under 2.25 UV-B_{seu} of irradiation accumulated only one half of the biomass of Mylar control plants.

In sweet corn, no symptoms of chlorosis or bronzing were observed on the entire surface of the leaves of UV-B treated plants throughout the experimental period. Corn plants under continuous UV-B radiation were similar in appearance, but not in size, to the Mylar control and no UV control plants. Plants exposed to UV-B had significantly lower fresh weights and dry weights than those of the controls (Table 2). From the control to the highest UV-B exposed treatments, patterns of decrease in both fresh weights and dry weights of the tops were very similar to those of the whole plant. Data from Table 2 also showed that UV-B radiation influenced the biomass accumulation of roots, although to a lesser extent than that of shoots. In the two enhancement treatments of 1.64 and 1.31 UV-B_{seu}, root biomass was larger than in the Mylar control, but not larger than the no UV-B treatment.

Significant reductions to 65% in both total fresh weight and dry weight relative to the Mylar control and to less than 60% relative to the untreated control were observed when corn plants were exposed for 44 days to 2.25 UV-B_{seu}. Biomass accumulation of the Mylar control plants was less than that of the untreated control plants.

Height and total leaf area measurements of corn are shown in Tables 3 and 4, respectively. Mean values of the plants treated with UV-B radiation differed significantly between treatment and control. Plant height and leaf area decreased with increasing levels of UV irradiation. Analyses of data showed that these decreases are significant.

Caldwell et al. (1975) reported a decrease in biomass when field-grown

soybeans and corn were exposed to a UV-B enhanced irradiance regime that simulated a 0.11 atm-cm decrease of atmospheric (stratospheric) ozone. Under greenhouse conditions, UV-B enhancement (a simulation of a 50% atmospheric ozone depletion) caused a significant decrease in both plant fresh and dry weight of 'Little Marvel' peas, 'Hutton' soybean, and other agronomic crops (Van et al., 1976). 'Pioneer 3364A' corn also showed some biomass reduction under this level of UV-B enriched regime. Our short-term greenhouse experiments indicate the potential of enhanced UV-B irradiance to significantly suppress growth of sensitive higher plant species. These results would be used to aid in relating adverse responses to anticipated increases in UV radiation that could result from stratosphere ozone depletion.

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TABLE 1

EFFECT OF UV-B RADIATION ON FRESH AND DRY WEIGHTS IN SOYBEANS (TWO CULTIVARS) AND IN PEAS

Species[1]	Treatment[2]	Fresh weight[3] (g plant^{-1})	Dry weight[3] (g plant^{-1})
'Bragg' soybean	Mylar control	40.09 (100)**a	6.15 (100)**a
	1.64 (T_2)	34.25 (85) b	4.61 (75) b
	2.25 (T_3)	19.80 (49) c	2.66 (43) c
'Altona' soybean	Mylar control	39.99 (100)**a	6.77 (100)**a
	1.64 (T_2)	29.40 (74) b	4.09 (60) b
	2.25 (T_3)	15.23 (38) c	2.23 (33) c
'Little Marvel' pea	Mylar control	10.53 (100)* a	1.07 (100)* a
	1.64 (T_2)	9.71 (92) a	1.04 (97) a
	2.25 (T_3)	4.69 (45) b	.59 (55) b

[1] Plants were grown in the greenhouse, planted - May 6, 1977; harvested - June 10, 1977.

[2] UV-B enhancement dose in sun equivalent units ($UV\text{-}B_{seu}$). 1.64 $UV\text{-}B_{seu}$ in Treatment T_2 and 2.25 $UV\text{-}B_{seu}$ in Treatment T_3. Duration of UV-B exposure was 210 hours.

[3] Numbers in parentheses represent the percentage responses with respect to the Mylar control. Values with different letters in the same column are significantly different at the 0.05 (*) or 0.01 level (**) in the Duncan Multiple Range Test, each cultivar considered separately.

TABLE 2

EFFECT OF UV-B RADIATION ON GROWTH OF SWEET CORN[1/]

Treatment[2/]	Fresh weight (g plant^{-1})[3/]			Dry weight (g plant^{-1})[3/]		
	Top	Root	Total	Top	Root	Total
No UV control	69.94* a	13.04* a	77.98 (100)* a	5.12* a	0.99* a	6.11 (100)* a
Mylar control	59.53 ab	10.42 b	69.95 (90) ab	4.43 ab	0.77 bc	5.20 (85) ab
1.31 (T_1)	51.49 b	11.30 ab	62.79 (81) b	4.00 b	0.88 ab	4.88 (80) b
1.64 (T_2)	56.07 ab	10.51 b	66.58 (85) ab	4.21 ab	0.78 bc	4.99 (82) ab
2.25 (T_3)	35.92 c	9.36 b	45.28 (58) c	2.86 c	0.65 c	3.51 (57) c

1/ Planted - October 4, 1977; harvested - November 18, 1977.

2/ UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$). Duration of UV-B exposure was 260 hours. No UV control, i.e. plants grown in the greenhouse without exposure to any filtered sun lamps.

3/ Values in parentheses represent percentage response with respect to the no UV control.

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 3

EFFECT OF UV-B RADIATION ON HEIGHT OF SWEET CORN[1/]

Treatment[2/]	Plant height (cm)	% of control
No UV control	44.1* a	(100)
Mylar control	39.9 bc	(90)
1.31 (T_1)	35.4 de	(80)
1.64 (T_2)	37.6 cd	(85)
2.25 (T_3)	34.4 e	(78)

1/ Planted - October 4, 1977; harvested - November 16, 1977.

2/ UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$). Duration of UV-B exposure was 250 hours.

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 4

EFFECT OF UV-B RADIATION ON LEAF AREA OF SWEET CORN[1/]

Treatment[2/]	Total leaf area plant^{-1} (cm^2)	% of control
No UV control	957.0* a	(100)
Mylar control	893.7 ab	(93)
1.31 (T_1)	785.7 b	(82)
1.64 (T_2)	832.3 ab	(87)
2.25 (T_3)	607.7 c	(64)

[1/] Planted - October 4, 1977; harvested - November 16, 1977.

[2/] UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$). Duration of UV-B exposure was 250 hours.

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

SECTION III

EFFECTS OF SUPPLEMENTAL UV-B RADIATION ON PHOTOSYNTHETIC PIGMENT CONTENT, LEAF PHOTOSYNTHETIC RATE, AND HILL ACTIVITY OF AGRONOMIC CROPS

INTRODUCTION

Photosynthesis is undoubtedly of great importance to growth and yield of plants. It provides means by which radiant energy is absorbed and used to produce reducing power and chemical energy for the reduction and transfer of CO_2 from the free condition to carbohydrates (Hendricks, 1967; Garrard and Brandle, 1975).

Monochromatic 254-nm radiation (UV-C) has been reported to reduce growth and inhibit several component reactions of photosynthesis in algae and some other higher plants (Arnold, 1933; Shavit and Avron, 1963; Jones and Kok, 1966; Mantai and Bishop, 1967; El-Mansy and Salisbury, 1971, 1974). Photobiological data obtained using UV-C radiation can serve only as information for comparative purpose since there are appreciable quantitative and qualitative differences in response to UV-B radiation as opposed to radiation at 254-nm (Caldwell, 1977). Furthermore, the biologically potent waveband shorter than 280 nm would not be present at the earth's surface even if the ozone layer were reduced to 40% of its present thickness (Green et al., 1974). UV-B radiation occurs naturally in solar radiation reaching the earth and would be intensified if the atmospheric ozone layer was reduced. Thus, any consideration and investigation of biological effects of increased solar UV radiation due to reduced atmospheric ozone should be confined to the waveband between 280 and 315 nm (UV-B) (Caldwell, 1977).

Information and knowledge of UV-B radiation effects of biological

systems have accumulated during the last few years. UV-B radiation has been reported to reduce photosynthesis, growth, and biomass accumulation in a number of agronomic crops and plants (Van et al., 1976; Sisson and Caldwell, 1976; Brandle et al., 1977).

The objective of the experiments appearing in this section is to evaluate the potential effects of an increase in UV-B radiation on photosynthesis of selected agronomic crops. Studies include analyses of chlorophyll and carotenoid content and measurements of leaf photosynthesis as well as Hill activity that is associated with the photochemical reactions and electron transport system in chloroplasts.

MATERIALS AND METHODS

(1) Extraction and determination of chlorophyll and carotenoid

Total chlorophyll and carotenoid content was extracted by a modification method as described by Starnes and Hadley (1965). Approximately 0.5 g fresh weight leaf tissues, with midribs removed, of 35-day old 'Altona' and 'Bragg' soybeans and 'Little Marvel' peas were macerated at full speed for 3 min in a pre-chilled Sorvall Omni-Mixer in 15 ml of ice cold 80% aqueous acetone. The supernatant was decanted and vacuum filtered through one layer of Whatman No. 1 paper in a Buchner funnel. The residue was homogenized a second time for 2 min with 10 ml of 80% acetone and the homogenate was quantitatively transferred to the funnel and vacuum refiltered to ensure that all chlorophyll and carotenoid had been extracted. The filtrate was brought to 100 ml with 80% acetone solution in a volumetric flask and allowed to incubate at room temperature for 1 hr. A 10-ml aliquot was taken and centrifuged at 1,000 *g* for 5 min. The absorbance of the

supernatant was read at 663, 652, and 645 nm with a Model 25 Beckman Spectrophotometer. The concentrations of total chlorophyll and those of chlorophyll a and b were calculated using equations of Arnon (1949). These values were then used to compute the chlorophyll content on a fresh weight basis. The approximate content of carotenoids in the acetone extract was determined by measuring the absorbance at 480 nm and calculated according to equation described by Liaaen-Jensen and Jensen (1971).

The absorbance of the 80% acetone leaf pigment extract was then recorded continuously from 710 nm to 330 nm with the Model 25 Beckman Spectrophotometer at a wavelength scanning speed of 100 nm/min and at a 5 cm/min chart speed. The absorbance value at 665 nm was arbitrarily chosen as unity and the absorbance values at other wavelengths were expressed relative to it.

(2) Photosynthesis measurements

Leaf net photosynthetic rates were measured on soybeans, tomatoes, and sweet corn by net CO_2 uptake of whole, attached leaves in an air-sealed leaf chamber as described by Wolf et al. (1969). Leaves that were selected for photosynthetic measurements were the center leaflets of the top 3rd and 4th trifoliate (soybeans), or those of the top 4th and 5th multifoliate (tomatoes). The corresponding lateral leaflets were removed before measurements and resultant wounds were sealed with petroleum jelly. For sweet corn, fully developed leaves at the top 2nd and 3rd position were used for experiments.

CO_2 uptake rates were measured on 38-to 42-day old soybean and tomato plants and 35-day old sweet corn. The Plexiglas chamber containing the leaf was attached to a closed gas-flow system containing a Model 215A

Beckman IR gas analyzer, pumps, and flow meters. Air was circulated by a pump sequentially through a flask containing water to provide humidity, through the leaf chamber, through a $CaSO_4$ desiccant to dehumidify the air stream, through the IR gas analyzer, and back to the pump. Photosynthetically active radiation (PAR) was furnished by a combination of a 400-Watt Lucalox lamp (General Electric LU 400/BU) and a 400-Watt Multi-Vapor Mercury lamp (General Electric MV 400/BUH) mounted in a single reflective fixture. The lamp irradiance was filtered through 6.5 cm of circulating chilled water. The PAR photon flux density was measured with a Lambda Instruments quantum sensor, Model LI-185. PAR flux density was controlled by adjusting the distance between the light source and leaf chamber, or with neutral (white) cheesecloth between the light source and leaf chamber. Temperature inside the leaf chamber containing the whole attached leaf during measurement was determined by a constantan-copper thermocouple inserted into the abaxial side of the leaf. Leaf areas were obtained after CO_2 uptake measurement by placing leaves against blue print paper and exposing them to light for about 1 min. The leaf imprint was then cut out and measured with a leaf area meter. Net CO_2 exchange rates were expressed as mg CO_2 uptake $dm^{-2}hr^{-1}$.

(3) Hill activity measurement

Leaf samples of 6-week old 'Bragg' soybeans and 'Rutgers' tomatoes, with midribs removed, were macerated in a cold Sorvall Omni-Mixer with ice-cold extraction solution consisting of 50 mM phosphate buffer (pH 7.6), 0.35 M sucrose, 2 mM EDTA-Na_2, 5 mM $MgCl_2$, 1 mM $MnCl_2$, 20 mM Na-ascorbate, and 0.1% BSA (w/v). For each gram of plant material, 5 ml of extraction medium was used. Homogenization was performed at full speed during two

20-sec periods, separated by a 2-min interruption. The homogenate was then strained through 8 layers of cheesecloth and filtered through 20 μm nitex nylon screen. These steps were performed as fast as possible in cold conditions within an ice chest. The suspension was centrifuged at 1,000 *g* for 5 min at 4°C and the supernatant was quickly separated from the chloroplast pellet and discarded. The pellet was resuspended in a suspension solution having composition similar to the grinding solution except that Na-ascorbate and BSA were omitted. The chloroplast suspension was stored in ice and assayed for Hill activity.

Hill activity measurements were performed at room temperature (≈22°C) in cuvettes of 1 cm light path. The total 3 ml reaction mixture contained 50 mM phosphate buffer (pH 7.6), 2 mM EDTA-Na_2, 5 mM $MgCl_2$, 1 mM $MnCl_2$, 0.025 mM 2,6-dichlorophenolindophenol (DCPIP), and chloroplast suspension (8 to 14 μg of chlorophyll). Light was provided by a 750-W tungsten projector bulb giving a PAR photon flux density of 800 μeinsteins m^{-2} sec^{-1} at the surface of the cuvette. Absorbancy of the reaction mixture was determined at 590 nm with a Model 25 Beckman Spectrophotometer immediately before and immediately after being irradiated for 30 sec at room temperature. Hill activity was expressed as μmoles of DCPIP reduced mg^{-1} chlorophyll hr^{-1}.

Chlorophyll in the chloroplast suspension was determined with slight modification by a method described by Mbaku (1976). Aliquots of 0.4 ml of chloroplast suspension were put in test tubes, 0.6 ml of 100% acetone was added and the contents were stirred vigorously with a Vortex mixer. Test tubes were covered with parafilm and placed in the dark for 10 min. Five ml of 80% acetone was added, and the contents were stirred and placed

in the dark for another 10 min. This was repeated, as necessary, until the homogenate residue was visually white, indicating that all chlorophyll was extracted. Mixtures were then spun at 1,500 *g* for 15 min, supernatants were taken up and absorbances at 663, 652, and 645 nm were measured. Total chlorophyll content in mg/ml of chloroplast suspension was then computed based on Arnon's equations (1949):

$$\text{Chl (mg/ml)} = 0.15\ [(2.02 \times A_{645}) + (0.802 \times A_{663})]$$

or

$$\text{Chl (mg/ml)} = \frac{0.15\ (A_{652} \times 100)}{34.5}$$

RESULTS AND DISCUSSION

(1) Pigment content

Both cultivars of soybean and 'Little Marvel' pea plants exposed to UV-B radiation for 200 hrs generally had lower chlorophyll content than those of Mylar control (Table 1). Increasing the UV-B level from 1.64 to 2.25 $UV\text{-}B_{seu}$ resulted in significantly reducing the total chlorophyll content, from 75% to 65% of the control in 'Bragg' soybean, and from 83% to 80% of the control in pea. Chlorophyll content in 'Altona' soybean was 78% of the control at the dose of 1.64 $UV\text{-}B_{seu}$ of UV radiation, and this inhibition remained unchanged at higher level of radiation (2.25 $UV\text{-}B_{seu}$). Chlorophyll a, which accounted for 70% to 80% of total chlorophyll in both soybean and pea, decreased in much the same pattern as the total chlorophyll with increasing level of UV-B radiation. The ratio of chlorophyll a to chlorophyll b, except the case of 'Bragg' soybean, was not affected.

Table 2 showed the effect of UV-B irradiation on carotenoid content in acetone extracts from leaves of soybeans and peas. Both UV-B doses

significantly reduced the total amount of carotenoids in all species tested. Inhibition was highest in 'Bragg' soybean and slightly less in 'Altona' and 'Little Marvel' pea. Also in 'Bragg' soybean, difference between the two UV-B levels was significant.

When soybeans and peas were grown under a UV-B enhancement regime, a difference in the absorption spectrum in the wavelength region 330 nm-400 nm was observed when the 80% acetone leaf pigment extract was scanned from 710 nm to 330 nm. Absorption values of pigment extracts from 400 nm down to 330 nm increased with higher doses of UV-B exposure (Figures 1, 2, and 3), showing that the pigments in acetone solution extracts from the UV-B treated plants absorbed more radiation near the UV-B waveband (280 to 320 nm) than those of the control. Interference by acetone absorption in the ultraviolet region below 330 nm prevented determinations of the absorption spectra of the pigment solutions below this wavelength.

Reductions in total chlorophyll as a result of exposing plants to UV-C radiation have been reported in soybean (Tanada and Hendricks, 1953), tobacco (Wu et al., 1973; Skokut et al., 1977), onion (El-Mansy and Salisbury, 1974), and other plant species (El-Mansy and Salisbury, 1971). When bean and cabbage were grown in a greenhouse under a UV-B regime designed to simulate a 50% ozone depletion, no reduction of chlorophyll was found in either species (Thai, 1975). Plants exposed for 300 hrs under the same UV-B dose in a growth chamber had significant reductions of 26% in bean and 14% in cabbage with respect to the control.

In our greenhouse experiments, visual symptoms such as discoloring and bronzing in leaf tissues resulting from UV-B damage were common in soybeans and peas. Mechanisms through which total chlorophyll was reduced

by UV-B radiation, as expressed by chlorosis or bronzing of leaves, would indicate many possibilities. Observations of increased absorption of the acetone pigment extract near the UV-B waveband would indicate that the chlorophyll pigments per se or chlorophyll-protein complexes may be to some degree a protective adaptation of the leaves to UV radiation. These protective pigments would be the site of absorption of a great part of UV radiation impinging the leaves (Basiouny and Biggs, 1975). The reductions in chlorophylls and other pigments (carotenoids) may result either from inhibition of synthesis or from breakdown of the pigments or their precursors (El-Mansy and Salisbury, 1974). UV-B may also induce non-enzymic photooxygenation of the chlorophylls and carotenoids, resulting in accumulation of these pigments as oxygenated forms (Monties, 1974). Whether UV radiation directly affects molecular and/or cellular systems is not well-documented at the present time. Questions on reductions in photosynthetic pigments under UV-B radiation are not clear currently and are still open for further investigations.

(2) Photosynthesis

Rates of net photosynthetic CO_2 uptake for leaves of control plants and plants which received different doses of UV-B radiation are given in Tables 3 and 4 for soybeans, Table 5 for tomatoes, and Table 6 for sweet corn. Mean net photosynthetic rates of the UV radiation-treated plants were in general depressed below the controls. The highest value of significant depression was about 50% with respect to the control for 'Bragg' soybean under 1.64 $UV\text{-}B_{seu}$ (Table 4). As can be seen in Tables 4 and 5 the rates of carbon dioxide uptake were unusually low in leaves of 'Bragg' soybean and tomatoes of the second seeding. We cannot explain

this phenomenon. Many uncontrolled factors and conditions may have affected both the control and the UV-B treatments during the summer experiment. Environmental conditions during the period of plant growth, such as air and soil temperature, and light intensity, are among important factors greatly affecting the rates of photosynthesis. Net CO_2 uptake rates of leaves as low as 1.1 and 5.3 mg CO_2 $dm^{-2}hr^{-1}$ were reported when soybean plants were grown in a growth chamber with a light intensity of 1,000 Lux and 4,200 Lux, respectively (Bowes et al., 1972). These rates increased up to 24.4 mg CO_2 $dm^{-2}hr^{-1}$ at 20,000 Lux of maximum light during growth. Leaf net photosynthetic rates of summer and winter grown greenhouse plants differ significantly. Hesketh (1968) found higher rates from plants grown during the summer months under his greenhouse conditions. The leaves of all our treatments of both soybeans and tomatoes turned pale green while growing in the greenhouse before the CO_2 exchange measurements were made. Unfortunately, we do not have photomicrographs of sections. Also it should be mentioned that the photon flux density (PAR) used during the CO_2 uptake measurements of plants from the first seeding (Table 2) was 1,400 $\mu E\ m^{-2}sec^{-1}$ and the temperatures inside the leaf chamber (under the leaf) as determined by a thermocouple were 30°-31°C. During the measurements of CO_2 uptake rates for 'Bragg' soybean and 'Rutgers' tomatoes from the second seeding (Tables 4 and 5), the PAR was 700 $\mu E\ m^{-2}sec^{-1}$, and the temperature inside the leaf chamber averaged only about 25-26°C. Bowes et al. (1972) showed that soybeans grown under high irradiance conditions gave high leaf photosynthetic rates and required high irradiance for light saturation, whereas leaves from soybeans grown at low irradiances had low maximum rates of photosynthesis and showed light saturation of low

irradiance.

Disregarding the unexplained factors that caused significantly lower rates of photosynthesis of plants from the second seeding, compared with the other seedings, UV-B radiation decreased the rates of photosynthesis in both 'Bragg' soybean (Table 4) and 'Rutgers' tomatoes (Table 5). Under 2.25 and 1.64 UV-B_{seu} leaf net photosynthesis was significantly reduced in both plant species. Tomato leaves irradiated with 1.31 UV-B_{seu} also showed significant reduction in photosynthesis while similarly treated 'Bragg' soybean leaves did not. No significant differences among the three controls were observed. In both species, mean values of both Mylar controls for treatment T_3 (2.25 UV-B_{seu}) and T_1 (1.31 UV-B_{seu}) were less than those of no UV control; also the photosynthetic rates of Mylar control for T_1 was slightly higher than those of Mylar control for T_3 but not significantly different. This may be due partly to the shading of solar irradiance by the lamp fixtures which would result in less natural light received by the Mylar control plants than by the no UV control plants. In tomatoes, no significant differences among UV treatments were observed. In 'Bragg' soybeans however, there was significant difference (at 0.01 level) between the 2.25 UV-B_{seu} and the 1.64 UV-B_{seu} treated leaves; plants that received 1.64 UV-B_{seu} had much lower photosynthetic rates than those treated with 2.25 UV-B_{seu} (Table 4). Also from the first seeding, 'Altona' soybean leaves irradiated with 1.64 UV-B_{seu} had significantly lower values of net CO_2 uptake than those that received a higher dose of UV-B (2.25 UV-B_{seu}). These unexplainable increases in CO_2 uptake rates in soybean plants exposed to 2.25 UV-B_{seu} with respect to plants treated with 1.64 UV-B_{seu} were not well documented for further comment at present time.

In corn, the UV-B radiation-treated plants (1.31 UV-B_{seu}) exhibited a significant increase in photosynthesis rates per unit leaf area over plants in other treatments and in controls (Table 6). Also, plants receiving 1.64 UV-B_{seu} have photosynthetic rates slightly higher than those of the Mylar control (but not significantly different). Only the treatment of plants irradiated with 2.25 UV-B_{seu} showed significant reductions in net photosynthesis when compared to the no UV control plants. With regard to the per-plant total leaf area, as can be seen in Table 4 of Section II the total leaf area of corn plants receiving 1.31 UV-B_{seu} was lower than that of the Mylar control and significantly lower than that of the no UV control. Plants irradiated with 1.64 UV-B_{seu} were also lower in total leaf area with respect to both controls. In plants exposed to a 2.25 UV-B_{seu} regime, significant reductions to 64% and 68% in leaf area relative to the no UV control and the Mylar control, respectively, were observed.

Information concerning the efects of UV-B radiation on photosynthesis has been accumulating in the past few years. Studies using a wide range of plant species have shown that an enhanced UV-B radiation regime does effectively depress leaf net photosynthesis rates. Van et al. (1976) measured the leaf photosynthetic rates of several agronomic plants which were grown in the greenhouse and in growth chambers under 6 hrs of daily exposure during plant growth to UV-B irradiance equivalent to a 50% ozone depletion. Of the species tested in the greenhouse, mean net photosynthetic rates of UV radiation-treated plants of pea, cabbage, collard, soybean, oat, and rice were significantly depressed below the control plant photosynthetic rates. Corn plants in the UV-B enhanced treatment showed approximately 5% increase over the Mylar control in photosynthetic rates. Plants

such as tomato, rye, peanut, and digitgrass did not show any pronounced net photosynthetic reductions. However, in a growth chamber having the same UV-B enrichment but a lower PAR, all seven species (pea, bean, tomato, collard, cabbage, corn, and oat) showed apparent reduction in net photosynthesis under the UV-B enhanced treatment. Greenhouse-grown plants of Pisum sativum, after 4 hrs of exposure to UV-B irradiation, also showed significant depression in photosynthetic rates (Brandle et al., 1977). In Rumex patientia, hourly photosynthetic determinations over a one-day period showed that significant reduction of photosynthesis was detected after only 2 hrs of exposing 5-week old plants to the UV-B irradiance (Sisson and Caldwell, 1976). After 7 hrs of UV treatment, the photosynthetic rates of the UV-radiation-treated plants were depressed 15% below the control plants.

Results from studies with effects of UV-B enhanced regime on plants by Van et al. (1976) indicated that in their greenhouse experiments, all plants possessing the C_3 pathways of carbon assimilation showed pronounced reductions in net photosynthetic rates. Plants having the C_4 pathways (such as corn, pearl millet, digitgrass, and sorghum) did not exhibit any significant reduction in net photosynthesis. In their growth chamber-grown plants, all plants tested, whether C_3 or C_4, showed significantly reduced CO_2 uptake rates. Those differential responses to UV-B enhancement of C_4 plants in greenhouse and growth chamber experiments were attributed to low levels of visible light in growth chambers, resulting in less efficient degree of photorepair mechanisms for plants in a growth chamber as compared to those grown in a greenhouse. It had been suggested that photorepair is an important mechanism for protection of alpine vegetation against

solar UV radiation (Caldwell, 1968). Also soybean and Rumex patientia, when exposed to low levels of visible light and enhanced UV-B radiation, showed more pronounced damage than when plants were under the same dose of UV-B and higher PAR (Sisson et al., 1974). In our greenhouse experiments, UV-B treatment at 2.25 $UV\text{-}B_{seu}$ did show significant depressions of net photosynthesis in sweet corn (Table 6); this effect was also probably partly due to the low level of PAR in this treatment that plants received during the growth period. The possible stimulation of sweet corn net photosynthetic rates at low doses of UV-B radiation either by the UV-B spectrum or by other specific wavelengths emitted by the sun lamp that are responsible for this enhancement cannot be determined or explained.

(3) Hill activity

Hill reaction activities of chloroplast preparations from leaves of control plants and plants irradiated with a UV-B enhancement regime were measured for comparative purposes of the photoreducing capacity of these chloroplasts. The results of these measurements are shown in Table 7 for 'Bragg' soybean and in Table 8 for 'Rutgers' tomatoes. In soybean, the Hill activity in chloroplasts from plants exposed to 2.25 and 1.64 $UV\text{-}B_{seu}$ were significantly reduced as compared to the controls, with inhibition as high as 40% with respect to the control being observed with plants receiving highest doses of UV treatment. In tomatoes, Hill activity was reduced 30% in plants treated with 2.25 $UV\text{-}B_{seu}$. No significant inhibitions were observed in treatments of 1.64 and 1.31 $UV\text{-}B_{seu}$. In both plant species, Hill reaction activities were similar among the control plants. No effect on photoreduction of the dye DCPIP was detected in plants irradiated with 1.31 $UV\text{-}B_{seu}$.

UV-C has been reported to inhibit Hill reaction and photophosphorylation

in chloroplast preparations of several plant species (Holt et al., 1951; Shavit and Avron, 1963; Jones and Kok, 1966; Mantai and Bishop, 1967). Early studies by Holt et al. (1951) with Scenedesmus showed that Hill activity of chloroplast fragments isolated from these green algae was reduced with exposure to 253.7 nm radiation. Similar results were obtained later by Mantai and Bishop (1967) with chloroplasts prepared from this species. Chloroplast preparations from higher plants such as spinach and Swiss chard were also decreased in Hill activity following an exposure to UV-C irradiation (Bishop, 1959; Shavit and Avron, 1963; Jones and Kok, 1966).

Relatively few data have been reported concerning the effects of UV-B on Hill activity and other component reactions of photosynthesis. Studies on chloroplasts isolated from leaves of 'Early Alaska' pea seedlings grown under field conditions with supplemental UV-B radiation showed no significant effects in Hill reaction (Brandle, 1975). However, when 'Little Marvel' peas and 'Flat Dutch' cabbage were grown in growth chambers with enhanced UV-B that simulated a 50% atmospheric ozone depletion, significant inhibition (18%) in the Hill reaction was observed (Thai, 1975). When 'Little Marvel' peas, collard, and peanut were grown under natural greenhouse conditions and chloroplast preparations of these species were irradiated with 298 nm monochromatic radiation, progressive inhibitions in both Hill activity and photophosphorylation were observed with increasing exposure to the radiation. After 2 min of irradiation, Hill activity was inhibited 20% in pea and collard, and 30% in peanut; this inhibition reached 50% after 4 min in all three species. After 10 min of irradiation, inhibition in Hill activity averaged 94% for pea and collard, and 97% for peanut which has been classified as a 'tolerant' crop in respect to UV-B irradiation (Thai, 1975).

At the present time, no clear conclusions have been made on the mechanism or site(s) of inhibition by UV radiation. It has been suggested that UV-C and UV-B radiation would have the same overall effect and share a common mechanism or site(s) with respect to biological activity (Garrard and Brandle, 1975), and that inhibition by UV-B radiation was more closely associated with Photosystem II than with Photosystem I (Brandle et al., 1977). Disruptions of the structural integrity of chloroplast lamellar membranes resulting from exposure of plants to UV-B radiation (Section V) are contributing factors in a decrease in Photosystem II activity and its associated reactions (Mantai et al., 1970; Brandle et al., 1977) and depressions in photosynthesis.

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TABLE 1

EFFECT OF UV-B RADIATION ON CHLOROPHYLL CONTENT[1/]

Species[2/]	Treatment[3/]	Chl. (a + b)[4/]		Chl. a	Chl. b	a/b
'Bragg' soybean	Mylar control	3.48 (100) **	a	2.70 (100)	0.78 (100)	3.46
	1.64 (T_2)	2.61 (75)	b	2.01 (74)	0.60 (77)	3.35
	2.25 (T_3)	2.25 (65)	c	1.69 (63)	0.55 (71)	3.07
'Altona' soybean	Mylar control	3.83 (100) *	a	2.97 (100)	0.86 (100)	3.45
	1.64 (T_2)	3.00 (78)	b	2.35 (79)	0.66 (77)	3.56
	2.25 (T_3)	3.03 (79)	b	2.33 (78)	0.70 (81)	3.33
'Little Marvel' peas	Mylar control	2.06 (100) **	a	1.53 (100)	0.53 (100)	2.89
	1.64 (T_2)	1.71 (83)	b	1.32 (86)	0.40 (75)	3.30
	2.25 (T_3)	1.65 (80)	b	1.23 (80)	0.41 (77)	3.00

1/ Chlorophyll in mg g^{-1} fresh weight. Values in parenthesis are percentages with respect to Mylar controls.

2/ Planted - May 6, 1977; analyzed - June 1, 1977

3/ UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$). Duration of UV-B exposure was 200 hrs.

4/ Values with different letters in the same column are significantly different at the 0.05 level (*) or 0.01 level (**) in a Duncan Multiple Range Test, each cultivar considered separately.

TABLE 2

EFFECT OF UV-B RADIATION ON CAROTENOID CONTENT[1/]

Species[2/]	Treatment[3/]	Total carotenoid[4/]	% of control
'Bragg' soybean	Mylar control	0.638 * a	100
	1.64 (T_2)	0.475 b	74
	2.25 (T_3)	0.426 c	67
'Altona' soybean	Mylar control	0.644 * a	100
	1.64 (T_2)	0.574 b	89
	2.25 (T_3)	0.566 b	88
'Little Marvel pea	Mylar control	0.349 **a	100
	1.64 (T_2)	0.302 b	87
	2.25 (T_3)	0.313 b	90

1/ Carotenoid in mg g^{-1} fresh weight

2/ Planted - May 6, 1977; analyzed - June 1, 1977

3/ UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$). Duration of UV-B exposure was 200 hrs.

4/ Values with different letters in the same column are significantly different at the 0.05 level (*) or 0.01 (**) level in a Duncan Multiple Range Test, each cultivar considered separately.

TABLE 3

EFFECT OF UV-B RADIATION ON NET PHOTOSYNTHESIS IN SOYBEANS[1/]

Plant[1/]	Treatment[2/]	Net photosynthesis[3/] (mg CO_2 dm^{-2} hr^{-1})	% of control
'Bragg' soybean	Mylar control	25.0	100
	1.64 (T_2)	23.3 n.s.	93
	2.25 (T_3)	21.5 n.s.	86
'Altona' soybean	Mylar control	29.2 * a	100
	1.64 (T_2)	22.0 b	75
	2.25 (T_3)	26.6 ab	91

1/ Planted - May 6, 1977; analyzed - June 14-16, 1977.

2/ UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$). Duration of UV-B exposure was 230 hrs.

3/ Photosynthesis was measured at 1400 μE m^{-2} sec^{-1}.

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test, each cultivar considered separately.

n.s. Not significantly different.

TABLE 4

EFFECT OF UV-B RADIATION ON NET PHOTOSYNTHESIS OF 'BRAGG' SOYBEAN[1/]

Treatment[2/]	Net photosynthesis[3/] ($mg\ CO_2\ dm^{-2}\ hr^{-1}$)		% of no UV control
No UV control	5.79 *	a	100
Mylar control for T_1	5.22	ab	90
Mylar control for T_2	4.94	b	85
1.31 (T_1)	4.94	b	85
1.64 (T_2)	3.02	c	52
2.25 (T_3)	4.16	d	72

1/ Planted - June 20, 1977; analyzed - August 22-24, 1977.

2/ Duration of UV-B exposure was 210 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$). No UV control was set up also in greenhouse without any supplemental filtered UV lamps. In Mylar control for T_1 and T_2, the distances between plant apical buds and Mylar filtered lamps were adjusted similarly as for treatments T_1 and T_3, respectively.

3/ Photosynthesis was measured at 700 $\mu E\ m^{-2}\ sec^{-1}$.

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 5

EFFECT OF UV-B RADIATION ON NET PHOTOSYNTHESIS OF 'RUTGERS' TOMATOES

Treatment[2/]	Net photosynthesis[3/] (mg CO_2 dm^{-2} hr^{-1})		% of no UV control
No UV control	5.61 *	a	100
Mylar control for T_1	5.58	a	99
Mylar control for T_3	5.08	ab	91
1.31 (T_1)	4.65	bc	83
1.64 (T_2)	4.13	cd	74
2.25 (T_3)	3.77	d	67

1/ Planted - July 20, 1977; analyzed - August 30-31, 1977

2/ Duration of UV-B exposure was 250 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$).

3/ Photosynthesis was measured at 700 $\mu E\ m^{-2}\ sec^{-1}$

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 6

EFFECT OF UV-B RADIATION ON NET PHOTOSYNTHESIS OF SWEET CORN[1/]

Treatment[2/]	Net photosynthesis[3/] ($mg\ CO_2\ dm^{-2}\ hr^{-1}$)		% of no UV control
No UV control	55.59 *	ab	100
Mylar control for T_2	53.88	bc	97
1.31 (T_1)	59.71	a	107
1.64 (T_2)	55.71	ab	100
2.25 (T_3)	49.79	c	89

1/ Planted - October 4, 1977; analyzed - November 7-8, 1977

2/ Duration of UV-B exposure was 210 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$).

3/ Photosynthesis was measured at 700 $\mu E\ m^{-2}\ sec^{-1}$

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 7

EFFECT OF UV-B RADIATION ON PHOTOREDUCTION OF DCPIP OF CHLOROPLAST PREPARATIONS FROM 'BRAGG' SOYBEAN LEAVES[1/]

Treatment[2/]	Hill activity[3/] (μmoles DCPIP red. mg^{-1} chl hr^{-1})		% of no UV control
No UV control	238.9 *	a	100
Mylar control for T_1	229.9	ab	96
Mylar control for T_3	241.5	a	101
1.31 (T_1)	238.2	a	100
1.64 (T_2)	194.5	b	81
2.25 (T_3)	141.9	c	59

1/ Planted - July 20, 1977; analyzed - September 2, 1977.

2/ Duration of UV-B exposure was 260 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$)

3/ PAR irradiance was 800 $\mu E\ m^{-2}\ sec^{-1}$ at the surface of the reactant.

DCPIP: 2,6-dichlorophenolindophenol.

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 8

EFFECT OF UV-B RADIATION ON PHOTOREDUCTION OF DCPIP OF CHLOROPLAST PREPARATIONS FROM 'RUTGERS' TOMATO LEAVES[1/]

Treatment[2/]	Hill activity[3/] (μmoles DCPIP red. mg^{-1} chl hr^{-1})		% of no UV control
No UV control	172.0 **	a	100
Mylar control for T_1	174.6	a	102
Mylar control for T_3	173.0	a	101
1.31 (T_1)	176.5	a	103
1.64 (T_2)	163.0	a	95
2.25 (T_3)	120.2	b	70

1/ Planted - July 20, 1977; analyzed - September 6, 1977.

2/ Duration of UV-B exposure was 280 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$).

3/ PAR irradiance was 800 μE m^{-2} sec^{-1} at the surface of the reactant.

** Values with different letters in the same column are significantly different at the 0.01 level in a Duncan Multiple Range Test.

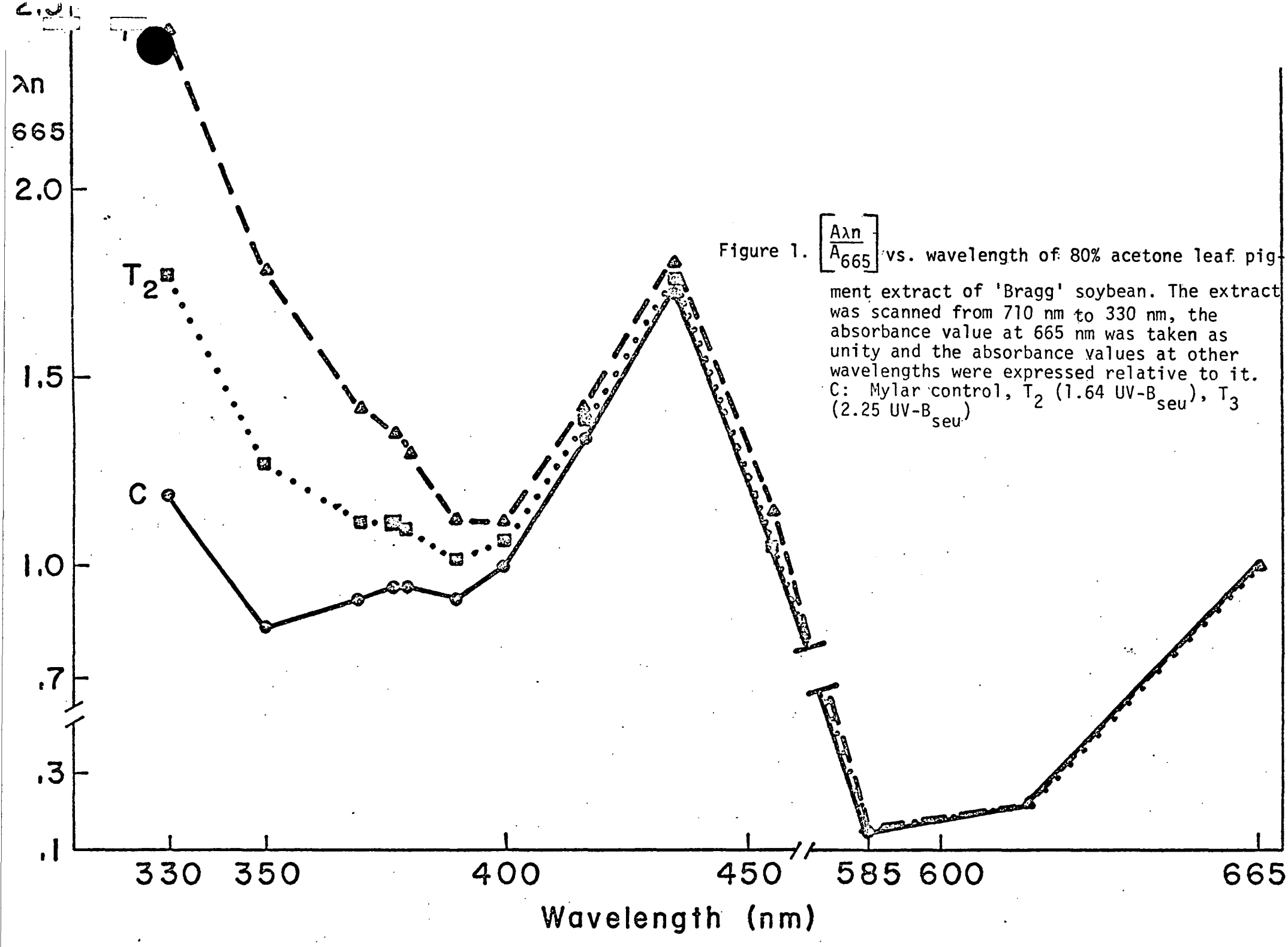

Figure 1. $\left[\frac{A\lambda n}{A_{665}}\right]$ vs. wavelength of 80% acetone leaf pigment extract of 'Bragg' soybean. The extract was scanned from 710 nm to 330 nm, the absorbance value at 665 nm was taken as unity and the absorbance values at other wavelengths were expressed relative to it. C: Mylar control, T_2 (1.64 UV-B_{seu}), T_3 (2.25 UV-B_{seu})

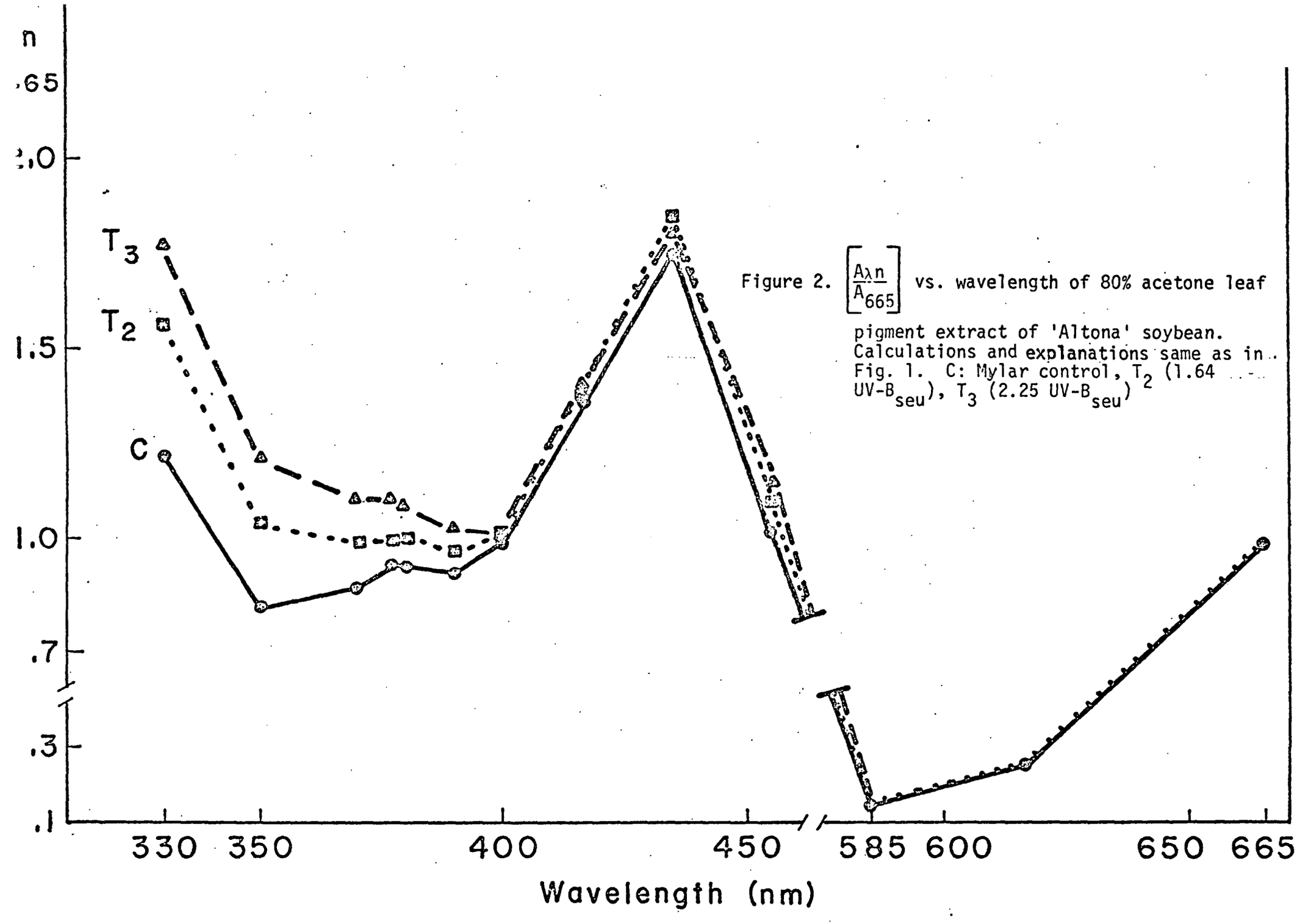

Figure 2. $\left[\frac{A\lambda n}{A_{665}}\right]$ vs. wavelength of 80% acetone leaf pigment extract of 'Altona' soybean. Calculations and explanations same as in Fig. 1. C: Mylar control, T_2 (1.64 $UV\text{-}B_{seu}$), T_3 (2.25 $UV\text{-}B_{seu}$)

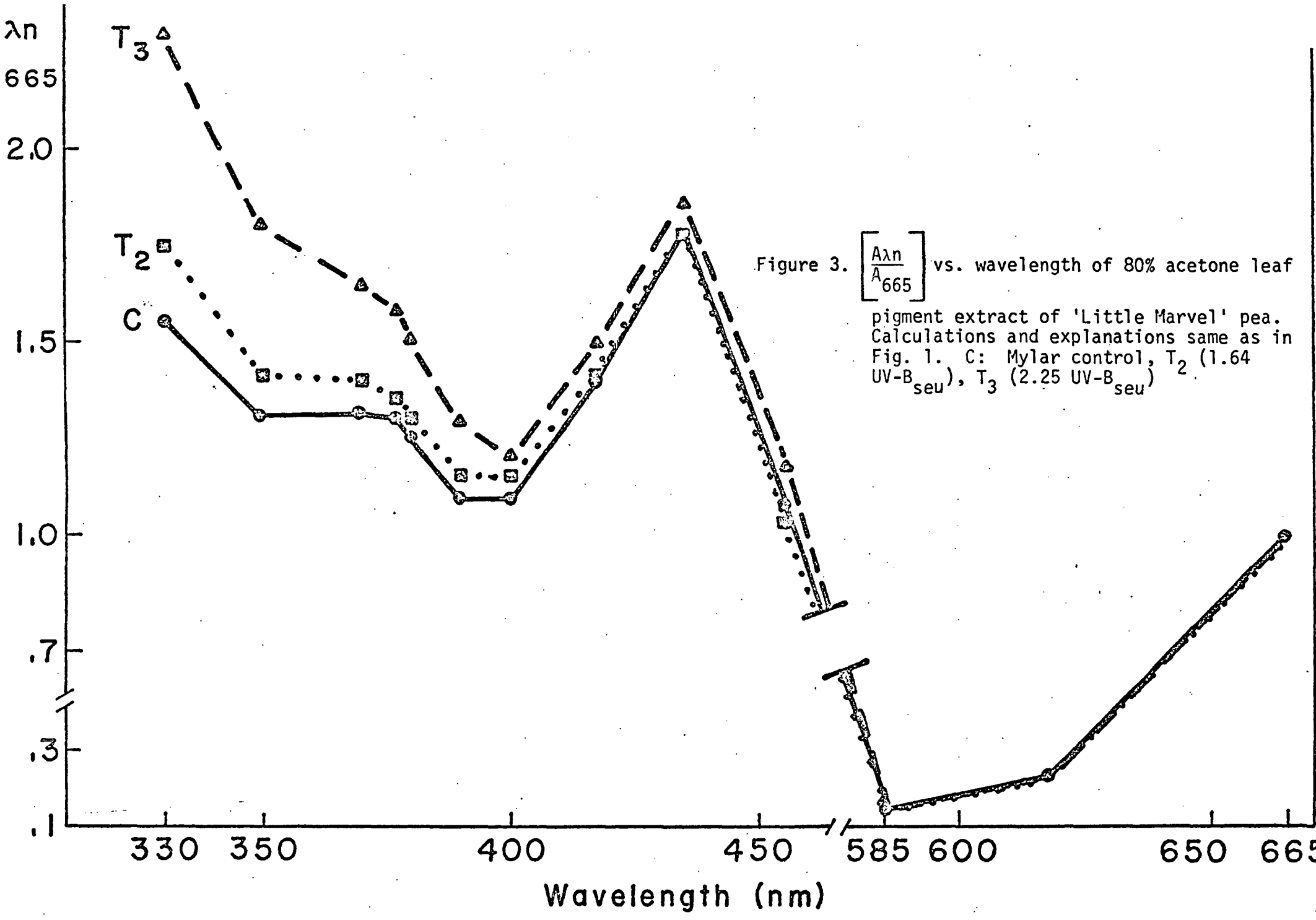

Figure 3. $\left[\frac{A\lambda n}{A_{665}}\right]$ vs. wavelength of 80% acetone leaf pigment extract of 'Little Marvel' pea. Calculations and explanations same as in Fig. 1. C: Mylar control, T_2 (1.64 UV-B_{seu}), T_3 (2.25 UV-B_{seu})

SECTION IV

EFFECTS OF SUPPLEMENTAL UV-B RADIATION ON PRIMARY CARBOXYLATING ENZYMES AND SOLUBLE PROTEINS IN C_3 and C_4 AGRONOMIC CROPS

INTRODUCTION

Basic responses to enhanced UV-B radiation such as inhibitions of photosynthesis, growth, and biomass accumulation have been reported (e.g., Van et al., 1976; Sisson and Caldwell, 1976; Brandle et al., 1977). Less in-depth information is available on the effects of UV-B radiation on different physiological and biochemical processes (Garrard and Brandle, 1975). UV-B radiation is readily absorbed by nucleic acid and protein chromophores. Their involvement in plant responses to UV radiation has been documented (Caldwell, 1971; Murphy, 1975; Giese, 1976). The involvement of these components in biological responses to UV radiation would indicate that protein synthesis and enzyme activities could be affected if biological systems were exposed to UV-B radiation (Garrard and Brandle, 1975). RuDP-carboxylase and PEP-carboxylase are two important enzymes involved primarily in the carbon fixation cycle in C_3 and C_4 plants, respectively. Depression of CO_2 uptake rates in leaves of plants exposed to UV-B radiation (Section III) would suggest the possibility of an effect of this ultraviolet radiation on these enzymes.

In this section, results were reported on investigations of the effects of UV-B radiation on RuDP-carboxylase in soybean and tomato (C_3 plants) and PEP-carboxylase in sweet corn (C_4 plant). Studies included determination of the enzyme activities and the amounts of soluble proteins extracted from leaves of plants which had been exposed to different doses of UV-B radiation throughout their life cycles.

MATERIALS AND METHODS

(1) Extracts and Assays of Ribulose-1,5-diphosphate carboxylase (RuDP-Case) and Phosphoenolpyruvate Carboxylase (PEP-Case)

Experiments on RuDP-Case were performed on leaves of 4-week old 'Bragg' soybeans and 8-week old 'Rutgers' tomatoes. PEP-Case was isolated from 4-week old sweet corn. Crude extracts from whole leaves were prepared and enzyme activities were assayed by measuring the rates of $^{14}CO_2$ incorporation into acid-stable products by a modification of a method described by Bowes and Ogren (1972) and Mbaku (1976). Leaves that were used for experiments were the top 3rd and 4th trifoliates (soybeans), or the top 4th and 5th multifoliate (tomatoes). For sweet corn, the 2nd and 3rd fully developed leaves from the top were used. Approximately 0.8 g of fresh weight leaf samples, with midribs removed, were homogenized with a prechilled mortar and pestle in 5 ml of ice-cold 50 mM Tris (pH 8.0) containing 10 mM $MgCl_2$, 0.1 mM EDTA-Na_2, 5 mM D-isoascorbate, and 5 mM dithiothreitol (DTT). The homogenate was spun in a Sorvall RC-2 automatic refrigerated centrifuge at 35,000 *g* for 15 min and the resultant supernatant was kept in ice bath and used for enzyme activity assays.

For assay of RuDP-Case, the incubation mixture of 2 ml contained 50 mM Tris pH 8.0, 10 mM $MgCl_2$, 0.1 mM EDTA-Na_2, 0.4 mM ribulose-1,5-diphosphate, 5 mM DTT, and 10 mM $NaH^{14}CO_3$ (0.25 μCi/μmole). For PEP-Case assay, 2 ml of incubation mixture contained 50 mM Tris pH 8.0, 10 mM $MgCl_2$, 0.1 mM EDTA-Na_2, 5 mM Na-glutamate, 2 mM phosphoenolpyruvate, and 5 mM $NaH^{14}CO_3$ (0.5 μCi/μmole). The reaction mixtures were placed in pyrex test tubes, sealed with serum caps, flushed with N_2 for 2 min, and gently

shaken in a water bath at 32°C for 3 min. Aliquot of 0.2 ml of crude enzyme extract was then injected through the serum cap into the mixture to initiate the reaction. After 3 min at 32°C, the reaction was stopped by injecting 0.2 ml of 6N glacial acetic acid. Unreacted $^{14}CO_2$ was removed by flushing the reaction mixtures with N_2 for 3 min. Aliquots of 0.3 ml were placed into scintillation vials and 10 ml of scintillation fluid added that was composed of 100 g napthalene, 7 g 2,5-diphenyloxazole (PPO), and 0.3 g 1,4-bis-2-(5-phenyloxazolyl)-benzene (POPOP) in 1 l of 1,4-dioxane. Contents were stirred vigorously with Vortex mixer and samples were counted in a Packard Tri-Carb Liquid Scintillation spectrometer, Model B 2450.

(2) Determination of Soluble Proteins

Soluble proteins in the cell free enzyme extracts were determined by mixing an aliquot of the extract with an equal volume of cold 10% trichloroacetic acid (TCA). The mixtures were shaken and incubated in an ice bath for about 1 hr for complete precipitation of proteins. The protein pellets were sedimented and collected by centrifugation at 2000 *g* for 15 min and were redissolved in 0.1 N NaOH. Colorimetric determination of the protein was based on the method of Lowry et al. (1951). Freshly prepared solutions of crystalline bovine albumin was used as standards.

RESULTS AND DISCUSSION

(1) RuDP-Carboxylase in soybeans and tomatoes

RuDP-carboxylase (D-RuDP-Case) has attracted considerable attention as an enzyme unique to the Calvin cycle (Krogman, 1973). In green plants, the enzyme is found inside the chloroplast, sometimes in crystalline form,

and is probably the most abundant protein on earth (Wildman et al., 1975; Baker et al., 1977). The in vitro activity of isolated RuDP-Case in highly purified crystalline form could be close to that of the enzyme which performs the process of carbon dioxide fixation in vivo (Babajonova et al., 1977). Since the enzyme comprises up to 50% of the soluble protein in green leaves (Kawashima and Wildman, 1970), high activity has been reported even when studies were conducted with crude extracts (Bowes et al., 1972; Mbaku, 1976). In this experiment, crude extracts of RuDP-carboxylase from leaves of control and UV-B treated plants of 'Bragg' soybean and 'Rutgers' tomato were assayed for their capabilities of incorporation of CO_2 into acid stable products.

In soybean all three UV-B doses significantly reduced the activity of the enzyme when it was expressed on the basis of fresh weight (Table 1). Surprisingly, the greatest depression was found in plants that had been exposed to 1.64 UV-B_{seu} (treatment T_2), with approximately 60% inhibition relative to the no UV control. The degree of inhibition decreased to 46% and 28% relative to the no UV control for treatments of 2.25 and 1.31 UV-B_{seu}, respectively. Statistical analyses showed significant differences in enzyme activity among the three UV treatments. Some differences, although not statistically significant, were also noted among the controls. When enzyme activity was expressed on a protein basis, a similar pattern of enzyme inhibition by UV-B was observed, with the greatest inhibition in CO_2 incorporation being found in the 1.64 UV-B_{seu} (T_2) treatment (Table 2). The inhibitions were 44%, 26%, and 20% with respect to the no UV control for the treatment T_2 (1.64 UV-B_{seu}), T_3 (2.25 UV-B_{seu}), and T_1 (1.31 (UV-B_{seu}), respectively.

In tomatoes, enzyme inhibitions by UV-B were similar, although smaller, compared to those in soybeans. Crude enzyme extracts from tomato leaves exposed to 1.64 $UV\text{-}B_{seu}$ also showed the lowest activity when expressed either on a fresh weight basis (Table 3) or on a protein basis (Table 4). Highest RuDP-Case activity was found in the Mylar control for treatment T_3 (Tables 3 and 4), and this activity, when expressed on a protein basis, was significantly different from two other controls (Table 4).

Attempts were made to correlate RuDP-carboxylase activity with photosynthetic rates of both soybeans and tomatoes under UV-B treatment. There is evidence that indicates that differences in leaf CO_2 uptake rates can be accounted for by differences in RuDP-carboxylase activity (Björkman, 1968). Thus, the activity of carboxylase may be a good means of estimating the photosynthesis rates in plants. In Phaseolus vulgaris, increased photosynthetic rates have been attributed to an increase in carboxylase activity (Wareing et al., 1968). Also, in growth chamber-grown soybeans, a good correlation between the activity of this enzyme and photosynthesis was reported (Bowes et al., 1972). By comparing the results of net photosynthetic measurements (Tables 4 and 5, Section III) to those of RuDP-carboxylase (Tables 1-4), some close relationships between the enzyme activity and net photosynthetic capacity were observed. 'Bragg' soybean plants exposed to 1.64 $UV\text{-}B_{seu}$ had the lowest value of photosynthesis and enzyme activity. In other UV treatments and controls, changes in enzyme activity and photosynthetic capacity were found to be roughly parallel. In tomatoes, although net photosynthesis was found to be lowest in 2.25 $UV\text{-}B_{seu}$ treatment, the photosynthetic values at this UV dose was not

statistically different from those plants exposed to 1.64 UV-B_{seu}. In the other treatments and controls, tomato plants also showed some correlation between leaf CO_2 uptake and carboxylase activity.

RuDP-carboxylase catalyzes the reaction of CO_2 with ribulose 1,5-diphosphate (RuDP) and is probably the enzyme responsible for the bulk of CO_2 fixation in most green plants. Little information and work have documented the effects of ultraviolet radiation on this important carboxylating enzyme. Preliminary studies by Thai (1975) showed no reduction in activity of RuDP-carboxylase which was extracted from leaves of growth chamber-grown pea and cabbage plants that had been exposed for 200 hrs and 300 hrs, respectively, to UV-B enhancement that simulated a 50% atmospheric ozone depletion. However, when crude enzyme preparations from pea, collard, and peanut were irradiated with 298 nm monochromatic radiation at a high intensity dose (1.92×10^4 J m^{-2}), inhibitions in enzyme activity of about 30% in pea and 20% in collard and peanut were observed. Also in tomatoes, there was approximately 20% of decrease in RuDP-carboxylase activity when extract from leaves was irradiated for 2 min with 296 nm monochromatic radiation (Thai, 1975).

(2) PEP-carboxylase in sweet corn

The photosynthetic carbon fixation pathway in C_4 plant differs from the conventional Calvin cycle (Hatch and Slack, 1970). C_4 plants utilize PEP-carboxylase for the initial photosynthetic carboxylation before carbon can continue its flow through RuDP-carboxylase to carbohydrates. Crude extracts from leaves of C_4 species showed that the activity of PEP-carboxylase was several times higher than that of RuDP-carboxylase (about 14-fold higher in corn on a protein basis, Bowes et al., 1972, and 40-fold

higher in slenderstem digitgrass on a chlorophyll basis, Mbaku, 1976). Therefore, from a biochemical and physiological point of view, studies of PEP-carboxylase are worthwhile and might help to explain why C_4 plants generally seem to be more 'resistant' to UV-B radiation than C_3 plants.

The effects of UV-B radiation on CO_2 incorporation by PEP-carboxylase in crude extracts from sweet corn leaves were presented in Tables 5 and 6. The activity of the enzyme was significantly suppressed with respect to the no UV control when plants were exposed to UV-B radiation at the two highest doses, 2.25 $UV\text{-}B_{seu}$ (T_3) and 1.64 $UV\text{-}B_{seu}$ (T_2). The differences in PEP-carboxylase were greater when expressed on a fresh weight basis (Table 5) than on a protein basis (Table 6). Plants exposed to 1.31 $UV\text{-}B_{seu}$ (T_1) had highest enzyme activities and also had highest values of photosynthetic rates (Table 6, Section III). For some unknown reasons, plants growing under the Mylar control were significantly lowest in enzyme activity on fresh weight basis (Table 5); the enzyme activity per unit protein was also low and consequently so was the photosynthetic rate. In general, data of PEP-carboxylase (Tables 5 and 6) and photosynthetic capacity (Table 6, Section III) indicated that corn plants (C_4 species) were more 'resistant' to UV-B radiation than soybeans and tomatoes (C_3 species).

(3) Soluble proteins

Since RuDP-carboxylase, and possibly PEP-carboxylase, can be expected to account for a large fraction of the total leaf protein, a substantial part of the difference in protein content among UV-B treated and control plants may be attributed to the different levels of this enzyme. Tables 7, 8, and 9 show the protein content in leaves of plants that had been exposed to different doses of UV-B enhancement. In 'Bragg' soybeans, UV-B

caused a significant decrease in soluble proteins as compared to those of the control plants (Table 7). Inhibitions with respect to the no UV control, were 25% at the high (2.25 UV-B_{seu}) and medium (1.64 UV-B_{seu}) dose, and 10% at the low dose (1.31 UV-B_{seu}). In both Mylar controls, increases in protein content relative to the no UV control, although not statistically different, were observed. Tomato plants behave quite differently under UV-B radiation in terms of protein content (Table 8). Plants exposed to UV-B radiation were higher in soluble protein contents per unit fresh weight than those of the controls; consequently, these data were in contrast to the results appearing in Tables 3 and 4 for RuDP-carboxylase and those in Table 5 of Section III for photosynthesis.

In leaves of sweet corn, only UV-B at the high dose (2.25 UV-B_{seu}) significantly reduced the soluble protein content. The low level of proteins in the Mylar control was closely correlated to the lowest activity of PEP-carboxylase as compared to other treatments and controls (Table 5). No significant reduction in proteins was observed in other treatments.

Ultraviolet radiation in general is well recognized as an effective agent for denaturing proteins (Giese, 1976). It has been found that ultraviolet radiation damages cells by interfering with syntheses of macromolecules, among which nucleic acid synthesis is the prime target (Murphy, 1975; Giese, 1976). Synthesis of proteins may also be reduced or stopped by high doses of UV radiation (Giese, 1976).

Higher plants have been known to be damaged when exposed to ultraviolet irradiation. The alteration of nucleic acids by UV radiation would ultimately lead to changes in enzymic and structural proteins

which themselves absorb UV radiation and could therefore be directly affected (McLaren and Luse, 1961). Since about 75% of proteins in green leaves is located in the chloroplasts, leaves cannot suffer much protein loss without harm to their photosynthetic organelles (Campbell, 1975). In wheat leaves and cucumber cotyledons, changes in chloroplast ultrastructure were correlated with loss in protein and photosynthetic pigments. This protein loss might account for the damaged chloroplasts observed in microscopic preparations from leaves of UV-irradiated plants (Shaw and Manocha, 1965; Butler, 1967). In 'Bragg' soybean, continued exposure of plants to UV-B radiation caused development of visual bronzed areas in leaves (Section V). In addition, bronzed areas frequently showed completely collapsed palisade regions where cells closest to the adaxial epidermis were almost or completely collapsed and/or degraded. Electron microscopic studies revealed that the organelles of the bronzed areas, including nuclei, mitochondria and chloroplasts, were at various stages of breakdown and degradation, with disruption of chloroplast being observed as severe damage induced by UV-B radiation (Section V). This would have a significant importance on plant growth and development since the thylakoid membrane or grana contains essentially all the photosynthetic pigments and enzymes required for the primary light-dependent reactions; the stroma, on the other hand, contains the enzymes of the carbon cycle. Since the photosynthetic activity is closely related to membrane integrity of the chloroplast, a disruption of this organelle as a result of UV-B radiation will partly destroy the components required for both light and dark reactions and thus reduce the rate of CO_2 fixation.

Inhibition of enzyme activity by UV radiation has been suggested to be

due to protein destruction or enzyme inactivation (McLaren and Luse, 1961; Piras and Vallee, 1966; Giese, 1976). Since the most important biochemical property of an enzyme is its catalytic activity, a slight alteration of its steric configuration is sufficient to make it inactive and incapable of combining with the substrate molecule. Since inactivation always involves some type of molecular damage to the enzyme, its quantitative and qualitative appraisal would be a means of assessment of the damage.

Low doses of UV-B radiation appeared to enhance the catalytic activity of PEP-carboxylase and photosynthesis in sweet corn, larger doses, however, inactivate the same enzyme. This phenomenon could possibly be a case of radiation-induced creation of an active catalytic site that did not exist before, or a case of increased reactivity of a previously existing active site (Arena, 1971). Obviously, more studies are required before satisfactory answers can be obtained.

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TABLE 1

EFFECT OF UV-B RADIATION ON RATE OF $^{14}CO_2$ INCORPORATION BY RIBULOSE-1,5-DI-P CARBOXYLASE IN EXTRACTS OF 'BRAGG' SOYBEAN LEAVES[1/]

Treatment[2/]	Enzyme Activity (μmoles CO_2 hr^{-1} g^{-1} fresh wt)		% Incorporation
No UV Control	434.3 *	a	100
Mylar control for T_1	404.8	a	93
Mylar control for T_3	393.1	a	91
1.31 (T_1)	312.0	b	72
1.64 (T_2)	180.8	c	42
2.25 (T_3)	234.0	d	54

1/ Planted - July 20, 1977; analyzed - August 19, 1977.

2/ Duration of UV-B exposure was 180 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$).

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 2

EFFECT OF UV-B RADIATION ON RATE OF $^{14}CO_2$ INCORPORATION BY RIBULOSE-1,5-DI-P CARBOXYLASE IN EXTRACTS OF 'BRAGG' SOYBEAN LEAVES[1/]

Treatment[2/]	Enzyme Activity (μmoles CO_2 hr^{-1} mg^{-1} protein)		% of Incorporation
No UV Control	27.72 *	a	100
Mylar Control for T_1	23.40	b	84
Mylar Control for T_3	23.88	ab	86
1.31 (T_1)	22.24	b	80
1.64 (T_2)	15.52	c	56
2.25 (T_3)	20.63	b	74

1/ Planted - July 20, 1977; analyzed - August 19, 1977.

2/ Duration of UV-B exposure was 180 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$).

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 3

EFFECT OF UV-B RADIATION ON RATE OF $^{14}CO_2$ INCORPORATION BY RIBULOSE-1,5-DI-P CARBOXYLASE IN EXTRACTS OF 'RUTGERS' TOMATO LEAVES[1/]

Treatment[2/]	Enzyme Activity (μmoles CO_2 hr^{-1} g^{-1} fresh wt)		% Incorporation
No UV Control	280.0 *	ab	100
Mylar Control for T_1	276.8	ab	99
Mylar Control for T_3	281.7	a	101
1.31 (T_1)	254.2	bc	91
1.64 (T_2)	222.0	d	79
2.25 (T_3)	242.6	cd	87

1/ Planted - July 20, 1977; analyzed - September 15, 1977.

2/ Duration of UV-B exposure was 335 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$).

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 4

EFFECT OF UV-B RADIATION ON RATE OF $^{14}CO_2$ INCORPORATION BY RIBULOSE-1,5-DI-P CARBOXYLASE IN EXTRACTS OF 'RUTGERS' TOMATO LEAVES[1/]

Treatment[2/]	Enzyme Activity (μmoles CO_2 hr^{-1} mg^{-1} protein)		% Incorporation
No UV Control	16.83 *	c	100
Mylar Control for T_1	17.61	bc	105
Mylar Control for T_3	19.57	a	116
1.31 (T_1)	13.06	de	78
1.64 (T_2)	10.29	f	61
2.25 (T_3)	12.00	e	71

1/ Planted - July 20, 1977; analyzed - September 15, 1977.

2/ Duration of UV-B exposure was 335 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$).

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 5

EFFECT OF UV-B RADIATION ON RATE OF $^{14}CO_2$ INCORPORATION BY PEP CARBOXYLASE IN EXTRACTS OF SWEET CORN LEAVES[1/]

Treatment[2/]	Enzyme Activity (μmoles CO_2 hr^{-1} g^{-1} fresh wt)		% Incorporation
No UV Control	867.6 *	a	100
Mylar Control for T_2	653.1	b	75
1.31 (T_1)	902.8	a	104
1.64 (T_2)	734.0	cd	85
2.25 (T_3)	710.5	d	82

1/ Planted - October 4, 1977; analyzed - November 3, 1977.

2/ Duration of UV-B exposure was 180 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$).

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 6

EFFECT OF UV-B RADIATION ON RATE OF $^{14}CO_2$ INCORPORATION BY PEP CARBOXYLASE IN EXTRACTS OF SWEET CORN LEAVES[1/]

Treatment[2/]	Enzyme Activity (μmoles CO_2 hr^{-1} mg^{-1} protein)		% Incorporation
No UV Control	76.36 *	a	100
Mylar Control for T_2	68.20	b	89
1.31 (T_1)	81.35	a	107
1.64 (T_2)	67.84	b	89
2.25 (T_3)	70.94	b	93

1/ Planted - October 4, 1977; analyzed - November 3, 1977.

2/ Duration of UV-B exposure was 180 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$).

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 7

EFFECT OF UV-B RADIATION ON SOLUBLE PROTEINS OF 'BRAGG' SOYBEAN LEAVES[1/]

Treatment[2/]	Proteins[3/] (mg g^{-1} fresh wt)		% of No UV control
No UV Control	15.74 *	a	100
Mylar Control for T_1	17.04	a	108
Mylar Control for T_3	16.41	a	104
1.31 (T_1)	14.13	ab	90
1.64 (T_2)	11.74	b	75
2.25 (T_3)	11.62	b	74

1/ Planted - July 20, 1977; analyzed - August 19, 1977.

2/ Duration of UV-B exposure was 180 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$).

3/ Soluble proteins from crude enzyme extract in Tris buffer pH 8.0.

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 8

EFFECT OF UV-B RADIATION ON SOLUBLE PROTEINS OF 'RUTGERS' TOMATO LEAVES[1/]

Treatment[2/]	Proteins[3/] (mg g^{-1} fresh wt)		% of No UV control
No UV Control	16.83 *	cd	100
Mylar Control for T_1	15.77	de	94
Mylar Control for T_3	14.39	e	86
1.31 (T_1)	19.44	b	116
1.64 (T_2)	21.58	a	128
2.25 (T_3)	20.21	ab	120

1/ Planted - July 20, 1977; analyzed - September 15, 1977.

2/ Duration of UV-B exposure was 335 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$).

3/ Soluble proteins from crude enzyme extract in Tris buffer pH 8.0.

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

TABLE 9

EFFECT OF UV-B RADIATION ON SOLUBLE PROTEINS OF SWEET CORN LEAVES[1/]

Treatment[2/]	Proteins[3/] (mg g^{-1} fresh wt)		% of No UV Control
No UV Control	11.38 *	a	100
Mylar Control for T_2	9.80	b	86
1.31 (T_1)	11.10	a	98
1.64 (T_2)	10.83	ab	95
2.25 (T_3)	10.02	b	88

1/ Planted - October 4, 1977; analyzed - November 3, 1977.

2/ Duration of UV-B exposure was 180 hrs. UV-B enhancement in sun equivalent units ($UV\text{-}B_{seu}$).

3/ Soluble proteins from crude enzyme extract in Tris buffer pH 8.0.

* Values with different letters in the same column are significantly different at the 0.05 level in a Duncan Multiple Range Test.

SECTION V

UV-B EFFECTS ON ULTRASTRUCTURE OF CROP PLANTS

INTRODUCTION

Ultraviolet enhancement (280-320 nm, or UV-B) of plant growth regimes frequently results in an inhibition of photosynthesis. Mantai (1970), Mantai et al. (1970), and Thai (1975) suggested that the multiplicity of biological events affected by UV-B irradiation of plant tissue may be due to a disruption in the lamellar structure of chloroplasts. Brandle et al. (1977) suggested that the decrease in net photosynthesis caused by UV-B radiation was due to both the destruction of chloroplast lamellae and the inhibition of electron transport at the reaction center chlorophyll of Photosystem II, PS II (Okada et al., 1976). Berg and Garrard (1976) found UV-B irradiation (monochromatic, 298 nm) of haploid tobacco leaf mesophyll tissue to cause a general alteration of chloroplast membrane structure, including a swollen and undulating membrane profile in the chloroplast envelope and in the grana and stromal lamellae. In order to interpret the results of physiology studies reported herein, an examination was made of the effect of UV-B enhanced regimes on the structure of leaf mesophyll tissue.

MATERIALS AND METHODS

A description of the UV-B-enhancement regime appears in Section I of this report. In the following discussion: T_c represents the control tissue (grown under Mylar), T_1 represents tissue grown under a UV-B equivalent of 1.31 sun equivalent units, T_2

represents tissue grown under a UV-B equivalent of 1.64 sun equivalent units, and T_3 represents tissue grown under a UV-B equivalent of 2.25 sun equivalent units.

Both soybean (Glycine max, cv. 'Bragg') and corn (Zea mays cv. 'Golden Cross Bantam') leaf mesophyll tissue were sampled. Samples from one-month-old plants were taken both at the beginning of the day (to make observations on tissue depleted of starch) and the end of the day (to observe the quantity of starch formation). With soybean tissue, areas of leaf bronzing and yellowing occurred in certain UV-B treatments; these areas were sampled and analyzed separately. Three soybean UV-B experiments were conducted in 1977. Tissue samples from the third experiment were taken six weeks after emergence. With corn leaves, the tissue was sampled from the central regions of the youngest fully-expanded blade.

Tissue was fixed for electron microscopy in glutaraldehyde and osmium tetroxide and embedded in Spurr's epoxy resin as previously described (Berg and Garrard, 1976). Thick sections of this material were made for light microscopy.

Citrus leaves exposed to enhanced UV-B in the field were sampled and scanning EM, air dried over desiccant and sputtercoated with gold-palladium.

RESULTS

Increased levels of UV-B irradiance caused increased areas and degrees of chlorosis of leaves. These areas would first develop as vein-limited areas of whitish-yellow pigmentation (chlorosis) and, as

the length of time under UV-B irradiance increased, bronzed areas would develop within some of the chlorotic areas. Bronzing pigmentation appeared as brown-to-rust-colored areas.

A photographic record was made of soybean leaf development on two-week-old plants under the various treatments. Two trifoliate leaves per treatment were observed from emergence through 15 days of growth. The results of these observations are presented in Table 1. The control leaves (T_c) developed normal green leaves without any sign of chlorosis. All leaves grown under enhanced UV-B irradiance developed chlorosis after four days of growth. The degree of chlorosis and the leaf area affected generally depended on the intensity of UV-B treatment ($T_3 > T_2 > T_1$). The highest level of UV-B irradiance caused chlorosis to occur over the longest period of time (around seven days), and produced the greatest area and degree of chlorosis. As UV-B irradiance decreased in intensity, the duration and severity of chlorosis correspondingly decreased. In all cases, the leaf (and the plant) reached an age after which no further chlorosis occurred (around three to four weeks). This was a phenomenon associated with the whole plant rather than on an individual leaf basis. Most chlorosis and bronzing occurred on the plant before this stage. There was no apparent difference in the occurrence of chlorosis among the three leaflets comprising a trifoliate leaf. In general, the leaflets receiving the most intense UV-B irradiance (T_3) were smaller compared to the other treatments.

A comparison of trifoliate leaves of soybean grown under various UV-B enhancement regimes is given in Figures 1-4. The leaves were two weeks old. Compared to the control leaf grown under Mylar

(T_c, Figure 2) there was a slight chlorosis in the terminal leaflet of the leaf from T_1 (Figure 1). There was considerably more chlorosis in the leaf of T_2 (Figure 3). This chlorosis appeared in all three leaflets and obviously occurred in regions demarcated by vascular tissue. The leaf shown in Figure 4 was grown under the highest UV-B irradiance (T_3). A high degree of epinasty, as well as chlorosis and bronzing, was evident; these leaflets were smaller than those in the more moderate UV-B treatments.

Areas of chlorosis and bronzing were delimited by vascular tissue as is shown in Figures 5-7. The chlorosis in the soybean leaf of Figure 5 was extensive, and in the more intensely chlorotic areas bronzing occurred. Vascular tissue defines regions where there was a sharp border between green tissue and chlorotic tissue. The close-up photograph in Figure 6 shows the surface of a soybean leaf in a region where bronzing occurred within chlorotic areas, both are spatially defined by regions of vascular tissue. This is shown by the light microscope photograph in Figure 7 that showed tissue of a region similar to Figure 6 (upper surface view). The bronzed palisade cells were shrunk in size and were separated from green tissue by vascular tissue, some of which contain the reddish-brown pigmentation associated with bronzing. Limitation of chlorosis and bronzing to areas bordered by vascular tissue indicated that these pigmentation changes (and, as will be shown later, cell structure changes) may be associated with (and/or be enhanced by) the production of a translocatable substance causing lysis. Siegel and Corn (1974) found UV-C irradiation of red beet to cause the production of a translocatable factor causing membrane

lysis.

Light micrographs of transverse sections of soybean leaf mesophyll grown under UV-B enhancement are presented in Figures 8-10. The control tissue in Figure 8 showed a vacuolate adaxial epidermal cell layer subtended by several layers of palisade cells that contained a majority of the well-developed green chloroplasts of the leaf. Below the palisade layer, in the region where the vascular tissue occurs, a vein is seen in cross-section. Subtending this region is the spongy mesophyll tissue that also contained well-developed green chloroplasts. This was subtended by a vacuolate layer of abaxial epidermal cells. The tissue in Figure 9 was from a chlorotic region of soybean leaf tissue grown under UV-B enhancement. An abaxial trichome was present as well as a vein in this cross-section. The most evident difference between this tissue and the control was in the palisade layers, where there was a substantial reduction in chloroplast volume and chlorophyll content. This indicated that chlorosis due to UV-B irradiation was not only restricted in the area across the leaf surface by vascular tissue, but that it was also primarily restricted to the upper half of the leaf by the same tissue. Areas of more severe leaf chlorosis became bronzed. Figure 10 is a transverse section of a bronzed region. (Note that this micrograph is presented upside down due to our printer's error). Again, the most severe damage was located in the upper half of the leaf and was delimited by the vascular tissue appearing in the section shown. The adaxial epidermal cells were severely desiccated and the walls of these cells gave rise to bronzing pigmentation. This pigmentation was also located in the walls of cells in the palisade cell layer. The

palisade layer cells in bronzed regions undergo degradative changes that result in the appearance shown in Figure 10. The cells were desiccated, as in the adaxial epidermis, and the amount of cellular material (especially chloroplasts) was greatly reduced. The vascular tissue subtending the palisade layers (Figure 10) displayed a sort of "resistance" in that the cellular structure was affected to a much lesser extent. The phloem parenchyma contained chloroplasts. The spongy mesophyll was likewise less affected, though the chloroplasts in this tissue were smaller in size compared to the control tissue. The abaxial tissue was intact and much more typical than the adaxial epidermis.

Ultrastructure of UV-B-irradiated tissue

The fine structure of cells in leaf mesophyll tissue grown under UV-B enhancement regimes showed distinct features, the quality of which depended upon the pigmentation of the tissue sampled. Although the amount of chlorosis and bronzing that occurred in UV-B-irradiated plants increased with increasing levels of UV-B radiation, the ultrastructure of a given type of pigmentation appeared similar, regardless of the treatment level.

Samples from green control tissue showed the same fine structure found in green tissue of UV-B-irradiated plants. After an overnight period of darkness the chloroplasts were depleted in starch. Samples taken at the end of the daylight period showed chloroplasts to form several starch grains, as presented in Figure 11, that show green palisade tissue from T_3 (highest level of UV-B-irradiance. As in the control tissue, this tissue appeared healthy.

Samples from chlorotic tissue showed a substantial reduction in

the amount of chloroplast lamellae in palisade cells, seen in Figure 12. Most of the chloroplasts in chlorotic regions have one or two starch grains, an amount lower than in green tissue. Spongy mesophyll chloroplasts from chlorotic regions contain three to five starch grains per chloroplast. The lower levels of starch in chlorotic palisade tissues may be due to the generally lower amount of chloroplast lamellae found in this tissue as well as a smaller chloroplast volume. This was verified by light microscopy, which showed chlorosis to be restricted to palisade tissue (Figure 9), and the chloroplasts to be smaller in size. Spongy mesophyll tissue in chlorotic regions contained green chloroplasts of normal size (Figure 9). Organelles other than chloroplasts occurring in chlorotic regions appeared similar in variety and appearance to those in the controls. Chloroplasts contain ribosomes and nucleoids.

As indicated earlier, bronzing pigmentation occurred in the walls of the adaxial epidermal cells as well as the walls of palisade cells. The appearance of these bronzed walls on the ultrastructural level was distinctive, as shown in Figures 13 and 14. In Figure 13 are shown two bronzed adaxial epidermal cells subtended by a bronzed palisade cell. The electron-dense areas in the wall were found in regions of bronze pigmentation. The bronzing phenomenon caused the walls to weaken, as evidenced by the collapsed wall separating the two epidermal cells. As a result, the volume of the epidermal cells was greatly reduced. Note that the contents of these cells are destroyed, probably as a result of the bronzing reaction (see section under "Lytic Cells"). Figure 14 shows the collapsed

wall and degraded cytoplasm contained in bronzed epidermal cells. Within the wall, the heaviest concentration of the electron-dense pockets appeared in the region of the middle lamella and primary wall. Note that the electron-dense pockets appeared to have moved into the cell compartment and are mixed with the remnants of the cytoplasm, where there are no recognizable organelles. However, remnants of membranes may be seen. In Figures 13 and 14 can be seen the lack of any electron-dense pockets in the cuticle.

Another distinctive feature of bronzed leaf mesophyll tissue was the quality of plastids in the palisade cells. Control tissue contained one basic type of palisade cell whereas a variety of cell types, based primarily on the ultrastructure of their plastids, were found in bronzed palisade tissue. These cell types are occasionally found in the margins of chlorotic leaf regions near the interface between chlorotic and bronzed regions. The types are referred to as "vesiculate", "lamellate", "alamellate", and "lytic" cell types and will now be discussed individually.

(1) Vesiculate cells

Vesiculate cells are characterized by having plastids whose lamellae are in various stages of vesiculation. Many of these cells had a degree of bronzing-associated structures in their cell walls. Figure 15 shows a typical vesiculate cell. The prominent nucleus was bounded by an intact nuclear envelope which contained a mitochondrion within an invagination. The several mitochondria present varied in size from (normal) ovoid to elongate. Most mitochondria in vesiculate cells had reduced numbers of cristae, which were somewhat vesiculated.

Several dictysomes were present. Rough endoplasmic reticulum and polysomes may be seen in the cytoplasm. The vacuole was intact and bronzing-associated electron-opaqueness was located within some of the cell wall.

As illustrated in Figure 15 the plastid populations of vesiculate cell types were generally found to contain only vesiculate-type plastids, apparently at various developmental stages. However, vesiculate plastids were also found in cells with mixed plastid populations, as described in the section on "alamellate" cell types. Vesiculate plastids are generally circular-to-ovoid in transverse sections.

The development of the vesiculate plastid is difficult to follow, given the fact that they occurred in bronzed regions. No clear developmental zones occurred within bronzed regions and it is not possible to sample a given chlorotic leaf region with the knowledge that bronzing is about to occur therein. However, in the vesiculate type of plastid, aberrant structures were found. This suggests that chloroplasts (of previously green tissue) had degenerated.

The grana in vesiculate plastids contained thylakoids of a diameter considerably greater than those in normal grana. These are referred to as "macrograna" (Bechmann et al., 1969). Macrograna may be seen in the vesiculate plastids of Figure 15. The formation of macrograna, rather than grana, in vesiculate plastids indicates aberrant plastid structure.

Plastoglobuli in vesiculate plastids were generally found in the stroma as clusters. Seen in Figure 16 is an invagination of a vesiculate plastid, a feature occasionally found in all plastid types

of bronzed regions. Also seen in the plastid in Figure 16 are a starch grain and ribosomes, both of which are sometimes found in vesiculate plastids. Phytoferritin was another plastid component found in vesiculate plastids (Figures 17 and 19).

As seen in Figure 16, there was a conspicuous lack of stromal lamellae in vesiculate plastids. Instead, vesicles were dispersed throughout the plastid, and appeared as shortened and swollen thylakoids. Stacks of two shortened thylakoids, termed "thylakoid pairs", commonly became swollen into vesicles (Figure 16) and often were more numerous than single vesicles. Both single vesicles and thylakoid pairs may sometimes originate from the inner membrane of the plastid envelope (Figure 17). The degenerated plastid in Figure 17 had a conspicuous cluster of plastoglobuli closely associated with linear arrays of segmented lamellae apparently derived from the inner membrane of the plastid envelope. In other cells these were found to swell into vesicles.

Evident in Figures 18 and 19 are large vesicles derived from dilation of thylakoids in various locations within macrograna. Attached at the periphery of these vesicles were smaller vesicles (perhaps derived from segmented thylakoids) separated during the swelling of the larger vesicle. In the vesiculate plastids of Figure 19, all of the thylakoids had some degree of swelling. In Figure 18, the double arrows point to a region in a macrogranum where several vesicles (and a thylakoid pair) are at one time fused with a thylakoid. This is further evidence for an error in the assembly of the plastid lamellar system. At the other end of this thylakoid a thylakoid pair was attached (single arrow). The other

end of the thylakoid pair adjoined the large vesicle of the adjacent macrogranum. There was a conspicuous absence of stromal lamellae in vesiculate plastids.

(2) Lamellate Cells

In certain palisade cells chloroplasts contained unusual stroma lamellae (Figure 20). These lamellae were of uniform spacing in transverse section and a relatively large proportion of these stromal lamellae interconnect granal stacks. These plastids (and cells) may develop into the "lamellate" cell types. As seen in Figure 21 lamellate cells contained an obviously unhealthy cytoplasm. The nucleus in this cell (see also inset) was virtually void of contents except for remnants of chromatin adhering to the envelope. Nuclear pores persist. There were no ribosomes in the free form or attached to the swollen endoplasmic reticulum (Figure 27). Dictysomes were aberrant in structure. Both the tonoplast and plasmalemma were ruptured and large areas of the cell were filled with vesicles (Figure 21). The mitochondrial matrix varied in density, eventually becoming void of contents. Cristae were rudimentary, often semicircular or swollen in transverse section (Figure 23). Some of these organelles occurred in invaginations of plastids in the lamellate cell type as in other cell types found in bronzed regions. Bronzing-associated electron-opaque deposits were found in lamellate cells (Figures 23-25).

The distinct plastids found in lamellate cells appeared to persist compared to other organelles any may contain phytoferritin, clusters of plastoglobuli, and an intact plastid envelope. No starch or plastid ribosomes were found, though nucleoids may be present

(Figure 25). Lamellate cells were so named because of the structure of the lamellar system in their plastids. There were no mixed lamellate cells, i.e., all plastids were of the lamellate type. These plastids were generally lenticular or amoeboid in transverse section and probably resulted from degeneration of chloroplasts. Lamellate plastids commonly contained primary thylakoids in which layers of thylakoids were arranged in a regular spacing in transverse section (Figures 22-26). Single, irregular lamellae may also occur in these plastids (Figure 23). In Figure 23, the primary thylakoids appeared to adhere in forming a macrogranum. Vesicles derived from the inner membrane of the plastid envelope were often found in the lamellate plastid (Figures 23-25 and 27). Normal chloroplast lamellar systems did not occur in lamellate plastids. Degeneration in some was arrested at the primary thylakoids (Figures 22 and 24); many contained tightly appressed granum (Figures 23-27). In some lamellate plastids only tightly appressed macrogranum occurred along with single lamellae (Figure 27). In these, the formation of macrogranum by primary thylakoids was complete. In Figure 26, projections between the regular layers of primary thylakoids may be seen. These also occurred in regions bounded by stroma (Figure 26).

(3) Alamellate Cells

The term "alamellate cell" comes from the unique structure of plastids in this cell type. The nuclei alamellate cells appeared intact. Ribosomes and polyribosomes occurred in the cytoplasm and the presence of rough endoplasmic reticulum is not uncommon. Dictysomes are present. The tonoplast is intact; vesicles often appear

in the vacuole, derived from the cytoplasm and invaginations of the plasmalemma (Figure 28). While typical mitochondria were found (Figure 29), other of these organelles were elongated (Figure 29).

Alamellate plastids were found to have no typical thylakoids or lamellae and appeared to result from degeneration of chloroplasts (of previously green tissue). While phytoferritin occasionally occurred (Figure 28, inset), no starch or plastid ribosomes were found. Though not easily detected against the generally light stroma, there was some indication of the presence of large plastid nucleiods (Figure 31). Alamellate plastids were generally circular-to-ovoid in transverse section. As seen in Figure 29, the lamellar system was generally disoriented with no typical thylakoids occurring in the plastid. However, a closer examination of Figure 29 showed the presence of a very small "granum" (single arrow) from which "lamellae" extends (double arrow). The transverse section showed the "lamellae" to be entirely enclosed, as in a thylakoid. However, the matrix of this very atypical "thylakoid" is similar in appearance to the stroma and the nature of the other "thylakoids" in the plastid indicates they are at least partially open to the stroma. These "lamellate" are derived from invaginations of the inner membrane of the (intact) plastid envelope (triple arrows). The alamellate plastid of Figure 30 contains a variety of membrane configurations. Plastoglobuli are common either as clusters or singly in alamellate plastids. There is virtually no internal membrane system within the plastid of Figure 31. The stroma is of a very low density with some indication of fibrillar plastid DNA being present, interspersed throughout the stroma.

The vesicle within the plastid did not appear to be an invagination of the plastid. Along with the absence of normal thylakoids in alamellate plastids there was the occasional presence of abnormal grana. As previously seen, these grana contained tightly appressed lamellar membranes (Figure 29). The serial sections of Figures 32-34 transected a semicircular granum composed of tightly appressed membranes derived from a tubular structure that dominated the stroma. The granum partially enclosed a myelin-like membrane structure in Figure 32. Plastoglobuli were subsequently shown to be adjacent to the myelin structure in later sections (Figures 33 and 34). The semi-circular granum in Figure 35 surrounded a vesicle. The membranes comprising the granum were continuous, and were tightly appressed in one region to form the granum. The circular granum in Figure 36 may be a culmination of membrane appression processes that apparently occurred as shown in Figures 32-35.

Structures only occasionally found in alamellate plastids included the larger vesicles in Figure 37.

Alamellate plastids may also occur in cells with mixed plastid populations. The vesiculate plastid in Figure 38 was one type found to occur with alamellate plastids. In Figure 39 several vesiculate plastids and chloroplasts are seen in a cell containing an alamellate plastid. This was not termed a vesiculate cell because the two plastid types did not appear to be developmentally related, i.e., purely vesiculate cells appear to have a developmental pattern that does not include alamellate structures. The chloroplast of Figure 40 was from a cell with alamellate plastids as the sole other type of

plastid. This chloroplast was functional (has starch) and ribosomes were present in the stroma. The alamellate plastid in Figure 30 is adjacent to a chloroplast. A chloroplast is adjacent to an alamellate plastid in Figure 41. This alamellate plastid was inside an invagination of another organelle (serial section Figure 42). This was evidenced by the presence of cytoplasmic ribosomes between the two organelles (Figure 41, arrow) and the continuity of the outer organelle around the plastid. The outer organelle may be a mitochondrion because it was bounded by a double membrane (circle) and the density of its matrix is of the same order as the adjacent mitochondrion.

(4) Lytic Cells

As was mentioned earlier, electron-dense "pockets" occurred in the cell wall of adaxial epidermal cells that had bronze pigmentation. These pockets are inferred to have a role in the breakdown of adjacent cell contents. This was the case in the degraded cells of the palisade region of bronzed leaf tissue. These cells are termed lytic cells. Lytic cells were the most commonly found cell types in the palisade layers of bronzed regions. Indeed, the large volume of air space in the palisade layers of bronzed regions was due to the removal of palisade cells by degradation.

In Figure 45 the pockets have not penetrated the plasmalemma of the cell on the right whereas they are seen to have moved into the cytoplasm of the cell on the left. This suggests that a cell-mediated response was occurring. In Figure 46 a similar directionality was evident. On one side of the cell wall appears healthy cytoplasm while the adajacent cell no longer has an intact plasmalemma, the electron-

dense pockets permeating the cytoplasm except for a few vacuoles. Normal cytoplasm is no longer recognizable. Certain organelles were still recognizable in the "pocket-invaded" cell of Figure 47. The plastid remnants indicate that this was formally a lamellate type of plastid (arrow). Fragments of the plasmalemma were interspersed with fragments of the cell wall. Similar degradation occurred in the cell of Figure 48; remnants of a plastid macrogranum may also be seen (arrow).

(5) Other tissue types

The foregoing description of cell types that occurred in palisade layers of bronzed leaf tissue indicates the diversity of cellular reactions to increased levels of UV-B. A dramatic reversal of this trend occurred just below the palisade layers. The delimiting vascular tissue that demarcated the zone of severe UV-B-triggered damage was relatively unaffected, as seen in the chloroplast of Figure 43, from a phloem parenchyma cell (morning sample from a one-month-old plant). The chief structural aberration found in these chloroplasts occurred in plants sampled six weeks after emergence. In this case there was an accumulation of starch, even in morning samples, in phloem chloroplasts.

The same trend was found in spongy mesophyll tissue of bronzed regions. Chloroplasts from one-month-old plants had little or no starch and extensive grana and stroma lamellae, as well as few ribosomes (Figure 44, morning sample). However, in contrast to the chloroplast in Figure 43 and those in the control tissue, the stroma lamellae was wavy which indicated an unhealthy condition. As in the phloem parenchyma chloroplasts the spongy mesophyll chloroplasts were filled

with starch insamples from six-week-old plants.

Effect of UV-B Enhancement on Corn Leaf Ultrastructure

On the ultrastructural level, corn leaf tissue was unaffected by UV-B enhancement. No deleterious affects were found in the structure of cell organelles in bundle sheath and mesophyll cells.

The lamellar system shown in Figure 49 was from a mesophyll chloroplast sampled in the afternoon that was grown under treatment T_3 (highest level of UV-B irradiance). There was no difference in the structures seen here as compared to the control tissue. Note the abundance of chloroplast ribosomes.

The bundle sheath chloroplast shown in Figure 50 was from the same treatment (T_3), sampled in the morning. The agranal structure of the chloroplast lamellae is well known and appeared to be no different from the control tissue. In Figure 51 is shown the corresponding tissue in an afternoon sample. The bundle sheath chloroplasts contained an abundance of starch whereas the adajacent mesophyll chloroplast was void of starch. Again, this was typical of corn leaf tissue and may be said to no different from the control tissue.

SEM of Citrus

No significant difference between exposed and non-exposed citrus leaf surfaces were found. The abaxial surface of grapefruit on trifoliate rootstock is shown in Figures 52 and 43 (control tissue) and in Figures 53 and 55 (UV-B-treated tissue). There appeared to be no significant differences in treatments. The adaxial leaf surfaces of some of the same cultivars are shown in Figures 56 and 57. The control tissue (Figure 56) contained surface waxes, the uneven distribution probably due to weathering. As seen in Figure 57 the UV-B-treated tissue is also capable of surface wax deposition.

DISCUSSION

This study dealt with structural analyses of leaf tissue placed under UV-B stress. The analyses correlated light and electron microscopy data and the tissue of interest was that of the mesophyll region. Photosynthesis, and hence the productivity of agricultural systems, is primarily dependent upon processes that occur within this region. There is uncertainty and disagreement as to the effect of certain trace gases on atmospheric ozone levels, the effect of ozone on the terrestrial levels of UV-B, and the effects of UV-B on biological systems. The UV-B enhancement growth regimes used in this investigation cover a wide range (1.31 $UV\text{-}B_{seu}$ to 2.25 $UV\text{-}B_{seu}$). The effects produced by this stress are qualitatively similar in all treatment levels and may be a general response to UV-B stress in soybeans, as well as other plants.

The following discussion contains several references to investigations utilizing UV-C (200-280 nm). It should be kept in mind that plant responses to UV-C may be different than their responses to UV-B (Caldwell, 1971).

The evidence accumulated during this study confirms the findings of Van et al. (1976) that soybean is a species sensitive to enhanced UV-B irradiance. Along with several other species they found soybean to sustain a loss of fresh and dry weight as well as a reduction in photosynthesis (as net CO_2 uptake) when subjected to UV-B stress.

The most prominent symptomology of UV-B stress in soybean leaves was the development of chlorosis. While green tissue of irradiated leaves showed no abnormal structures, the fine structure of chlorotic chloroplasts showed a reduced lamellar system, reduced levels of starch and a reduction in chloroplast size. These characteristics would

understandably contribute to a reduction in photosynthesis.

Plants grown under high light intensities characteristically develop reduced chloroplast lamellar systems compared to the lamellar systems they develop under shade conditions (Lyttleton et al., 1971; Björkman et al., 1972). Whether the reduced lamellar system we found in chlorotic soybean chloroplasts was due to high levels of UV-B or rather to reduced levels of chlorophyll (chl) is not clear. The development of chloroplast lamellar systems is dependent upon a complex relationship between lamellar protein synthesis and chl synthesis (Anderson, 1975).

Ballantine and Forde (1970) studied the effect of high and low temperature and light treatments on soybean leaf ultrastructure. They found a reduced lamellar system in chloroplasts grown under high light intensities (400-700 nm) correlated with reduced levels of chl.

Campbell (1975) studied ultrastructural changes in field-grown soybean leaf meosphyll tissue under enhanced UV-B. Interestingly, he made no mention of abnormal pigmentations. This may be due to the presence of relatively high amounts of photoreactivating radiation in the field. Tanada and Hendrix (1953) found the accelerated chlorosis induced by UV-C irradiation of soybean to be photoreactivatable. Campbell's micrographs give no indication of structures we have found to be associated with abnormal leaf pigmentation. He more commonly found vesiculation apparently due to the disruption of the tonoplast and, in a few cells, chloroplasts had disrupted envelopes. He attributed this damage to senescence that was accelerated by UV-B

treatment. However, we feel "accelerated senescence" to be a nebulous term used by many authors when damage to stressed tissue cannot be better described.

In a study of enhanced UV-B effects of greenhouse-grown pea Brandle et al. (1977) found up to 26% of leaf mesophyll cells to exhibit damage after 16 days of treatment. In chloroplasts, this progressed from a dilation of thylakoids to a disruption of the envelope and, in the most severe cases, vesiculations of the thylakoids. Again, no mention was made of abnormal pigmentation. These workers attributed an inhibition of PS II and damaged chloroplasts to the depressed photosynthetic rates they found in irradiated plants.

Berg and Garrard (1976) irradiated haploid tobacco plant leaves with monochromatic UV-B (298 nm) at a total dose of 19200 Jm^{-2} (32 Wm^{-2} for 10 min). No photoreactivating wavelengths were involved, the tissue was kept in the dark for an induction period. In an examination of the ultrastructure of leaf mesophyll tissue, they found a dilation of thylakoids and stromal lamellae as well as an undulating membrane profile throughout the chloroplast lamellar system. No pigmentation changes were found.

Sisson and Caldwell (1976) found UV-B irradiation of Rumex (UV-B-sensitive) to produce no changes in chl levels in the field or in a controled environment, though treatment caused an inhibition of photosynthesis. Alternatively, Garrard et al. (1976) found a reduction in chl levels of bean and cabbage irradiated with enhanced UV-B in a growth chamber. These workers also found decreased levels of the major carbohydrate components of several irradiated species.

In general, one of the most commonly documented detrimental effects of UV-B stress in plants if the effect on photosynthesis, and this was manifested in altered chloroplast structure for most dicotyledonous species examined.

In an interesting series of papers (Wu, 1971; Wu et al. 1973; Skokut et al., 1977) Wu and coworkers examined the effect of UV-C (254 nm) on detached leaves of tobacco. They found an accelerated leaf chlorosis to be accompanied by degradation of chloroplast lamellae though high doses seemed to inhibit degradation enzymes. The UV effect could be eliminated by removing the irradiated epidermis or by floating irradiated tissue on water. These investigators suggested that accelerated chlorosis was due to an indirect effect of the (irradiated) epidermis possibly mediated by some toxic substance(s) released from the epidermal cells. Siegel and Corn (1974) found evidence for a translocatable factor causing membrane lysis in UV-C-irradiated beet.

The production of such a factor may be a defense mechanism of the plant in response to UV (Caldwell, 1971). Lautenschlager-Fleury (1955) found the production of a UV-absorbing compound in bean to be water-soluble. Caldwell (1968) found a UV-induced UV-absorber to be soluble in methanol/water/HCl and indicated these substances to be flavonoids and related phenolics. Both of these workers found a correlation between increased levels of UV radiation and decreased epidermal transmission of UV, probably due to the production of these substances. Shibata (1915) determined that the epidermal and underlying mesophyll cells of UV-irradiated leaves contained large quantities of

UV-absorbing flavone derivatives. Caldwell (1971) indicated that UV absorption in the outer leaf tissues offers plant protection from UV-induced damage and that flavonoids and related phenolic compounds (including the anthocyanin group) were probably some of the most important compounds in the extinction of UV in epidermal and subepidermal layers of plant tissue.

The production of bronzed pigmentation in soybean leaves irradiated with UV-B shown to occur in this study was probably due to the presence of similar groups of phenolic compounds. Krizek and coworkers (Ambler et al., 1975; Krizek, 1975) found UV-B enhanced growth regimes to induce bronzing in cotyledons of soybean and other species. Cline and Salisbury (1966) suggested the bronzing found in Xanthium leaves irradiated with UV-C to be due to the formation of oxidized polymerized phenolic products subsequent to UV-caused cell damage. The vein-limitation of these areas, as well as their restriction to the adaxial epidermis and palisade layers indicated these factors to be mobile and water soluble.

Bridge and Klarman (1973) have shown UV-C to cause bronzing in soybean seedlings and they showed the bronzing to be due to production of hydroxyphaseollin, a phenolic compound known to be component of hypersensitivity reactions. Inoculation of bronzed areas of susceptible plants with pathogenic fungi (Phytophthora megasperma var. sojae) showed bronzing to confer a degree of resistance to infection. Similarly, Hadwiger and Schwochau (1971) induced phenylalanine ammonia lyase (PAL) and biosynthesis of pisatin in pea irradiated with UV-C. These are phenolic components of the hypersensitivity reaction of pea plants and the reaction appears to be dependent on new RNA and protein synthesis.

The authors proposed that the control of these responses occurs at the gene transcription level and depends on the conformational state of the double-stranded DNA. They indicated the UV-treatment to cause a change in the conformation of DNA which induces PAL and pisatin formation.

Our authors showed that the most extensive bronzing first occurred in tissue within the leaf closest to the UV source (i.e., the adaxial epidermis). At later stages bronzing appeared in the palisade layers. It was not clear whether or not damage to the epidermis induced bronzing in the palisade lauers. It may be that damaging of epidermal layers allowed UV penetration to the palisade layers and the concomitant b bronzing reaction there. In addition, the bronzing reaction in the epidermal cells could cause a release of a mobile factor that in turn effects the bronzing reaction in palisade layers. The latter interpretation would better explain the restriction within the leaf of the reaction, i.e., a mobile factor would be mobilized in the phloem before it could reach the lower part of the leaf.

That come unknown compound may become mobile in vascular tissue is evidenced by the pattern of chlorosis and bronzing found in UV-B-irradiated leaves. The diffuse "outer" edge of this pigmentation occurs in a region of minor veins, whereas the sharp edges occur at major veins. This we hypothesize to be due to a preferential unloading by phloem tissue of a mobile compound which elicits chlorosis and bronzing in leaf tissue. Produced as a response to enhanced UV-B radiation, after a few day's growth this material has become mobilized and translocated to several leaves wherein symptoms are produced. We are presently studying the effect of this (hypothesized) compound on phenolic compounds in the cell wall

compartment. The observed effects may result from altered phenolic metabolism in the cell wall (lignin synthesis may be disturbed) that results in a heavy concentration of relatively simple phenols. We are using TLC and colorimetric histochemistry in our studies. Preliminary results indicate to us that a major response in plants irradiated with enhanced UV-B is that of increased production of phenolic compounds.

Our micrographs showed the bronzing reaction not to occur in the spongy mesophyll. Although the chloroplasts in this region appear normal during early growth of the plant, there was a persistence of starch in samples from older plants which indicated that these cells may eventually be adversely affected by UV-B stress.

Phenolic compounds are capable of cell damage (e.g., their effect in the hypersensitivity reaction). The large reduction in numbers of palisade cells in bronzed regions was due to cell degradation. On the ultrastructural level, we associated the electron-dense areas of bronzed cell walls with phenolic compounds that eventually moved into the cytoplasm and caused cell death.

Cellular degradation observed in the lytic cell type is associated with these electron-dense pockets and degradation is probably effected by phenols.

The variety of unusual cell types we found in bronzed regions of UV-B-irradiated tissue have not previously been reported in association with UV damage. Brandle et al. (1977) did not find abnormal structures (except for a slight dilation of thylakoids) in intact chloroplasts from pea leaf tissue irradiated with UV-B. Similarly, Skokut et al.

(1977), using UV-C, reported only "wavy" stroma and high numbers of plastoglobuli in intact chloroplasts of irradiated tobacco leaves. The paucity of reports in the literature on UV effects on plant ultrastructure would explain this lack of corroboration of our data.

Caldwell (1971) stressed the significance of the UV-B absorption spectra of nucleic acids and proteins (which are very similar in the UV-B region) in describing the action spectrum of plant response to UV-B. UV absorption by membrane proteins could possibly alter their structure and, concomitantly, membrane structure. This would explain the effect of UV on the quality of membranes (e.g., permeability, undulating profiles, lack of thylakoid appression, incongrous channeling of excitation energy in photosynthesis). We propose that the altered cellular structure found with UV-B-enhanced irradiation of soybean leaf tissue to be primarily due to damage incurred by nucleic acids and proteins with absorption of this radiation. This proposal is based upon evidence gathered from published studies of the effects of chloroplast ribosomes (versus cytoplasmic ribosome) inhibitors and from mutant studies. Mutations cause alterations in physiology which often are manifested in cell fine structure. This alteration in physiology forms the basis for our comparison with mutation studies.

We are presented with an unusual situation in interpretation of the atypical cell types. They developed in apparently normal green leaves a few days after emergence. The green appearance of the leaves indicated the presence of healthy chloroplasts. The appearance of chlorosis and bronzing was accompanied by development of the cell types. This would indicate the cell types to be a result of degeneration of healthy cells and this is what we suggest is occurring.

The noteworthy occurrence here is that the degenerated structures are similar in apperance to structures found in incompletely developed plastids, though our samples were made of fully expanded (mature) leaves.

In vesiculate cell types organelles other than plastids and mitochondria appear normal. Though aberrations in the metabolism of mitochondria may cause plastid degeneration (Wettstein and Eriksson, 1965) this is probably not the case here because of the occurrence of vesiculate plastids in mixed cells with chloroplasts. Indeed, it appears that the metabolic processes responsible are within the plastid.

Thompson and Ellis (1972) treated greening pea leaves with the antibiotic lincomycin which is a specific inhibitor of 70 S (plastid) ribosomes. They found this treatment to interfere with the formation of normal lamellar systems in chloroplasts and that treated chloroplasts contained vesiculated lamellae interspersed with macrogranum, i.e., similar structures to those found in vesiculate plastids. Heslop-Harrison (1962) treated hemp plants with the pyrimidine analogue, 2-thiouracil, which interferes with chloroplast protein synthesis, and found this to cause a vesiculation of chloroplast lamellae. Machold (1971) treated bean leaves with the 70 S ribosome inhibitors streptomycin and chloramphenicol and found this to cause an inhibition of the synthesis of four lamellar proteins in chloroplasts. The ultrastructure of chloramphenicol-treated bean leaves was studied by Bradbeer et al. (1974) and they found vesiculation in the stroma of chloroplasts accompanied by larger

and fewer grana as compared to the control tissue. It is evident from the above studies that alteration of chloroplast ribosome metabolism (i.e., chloroplast protein systhesis) causes an increase of granum size (macrograna) and a loss of stromal lamellae. The latter appears to be replaced by numerous small vesicles in the stroma. Chloramphenicol binds specifically to plastid ribosomes (Kung, 1977). Proteins synthesized on plastid ribosomes are essential in the formation of a functional thylakoid membrane (Eytan and Ohad, 1970; Anderson, 1975). Thus, it appears that the aberrant lamellar system of vesiculate plastids is due to dysfunction of plastid ribosomes in these plastids. This may be due to dimerization of component nucleic acids by enhanced UV-B levels. It cannot be ruled out that the effect could be on plastid DNA, which codes for plastid r-RNA (Kung, 1977). There appears to be plastid ribosomes present in our micrographs of vesiculate plastids (Figure 16).

It is interesting to note that chloramphenicol causes an inhibition of the synthesis of the large subunit of Fraction 1 Protein (Kung, 1977) and that we found a corresponding decrease in RuDP carboxylase activity (Section IV) as well as a lack of starch in vesiculate plastids. Again, we emphasize the occurrence of the plastids in mixed cells to show that the vesiculate plastid is not due to aberrations in nuclear or cytoplasmic metabolism (Wildman et al., 1973; Wong-Staal and Wildman, 1973; Kirk and Tilney-Bassett, 1967). A plastid mutant in mixed cells of variegated leaves of Tradescantia was shown by Gyurjan et al. (1977) to contain macrograna, some of the thylakoids of these macrograna were dilated, as is found in some vesiculate plastids.

Macrograna are found in both vesiculate and lamellate cell types. There are many published micrographs of macrograna. They appear in rust-infected tissue of flax (Coffey et al., 1972) and in virus-infected leaf tissue of tomato (Arnott et al., 1969). They are found in mutants of barley (Wettstein, 1960), corn (Bachmann et al., 1967; Orsenigo and Marziani, 1971), and tobacco (Schmid et al., 1966). Bachmann et al. (1969) considered macrogranum in a pastel mutant of corn to be true grana, i.e., composed of chl-containing thylakoids with an intrathylakoid space and with adjacent thylakoids appressed. Smith and Sjolund (1975), using tissue cultures of Streptanthus tortuosua that contained chloroplasts having macrogranum, showed that no PS II activity occurred in macrograna although PS I activity was present. Macrogranum formation in this case was due to the presence of viruslike particles in nucleoli. It is of interest to note that PS II activity is inhibited by UV-B. Macrogranum in the xantha-15 mutant of barley contain chl (Wettstein, 1961). When Walles (1963) grew the xantha-23 mutant of barley on minimal media supplemented with leucine, he was able to eliminate macrograna formation and the chloroplasts developed normal lamellae. These structures seem to be common in plastids located in tissue with disturbed metabolism.

Since the atypical cell types found in this investigation appeared in previously healthy tissue, we feel the unusual structures to be degenerative in nature. While this is perhaps not so obvious in the vesiculate cell type, it is much more so in the lamellate cell type. All organelles and membranes appear dysfunctional in this type. Interestingly, the plastids often persist over the other organelles. However, judging by plastid structure, these organelles are hardly

photosynthesizing. Lamellate plastids are not found in mixed cells and their structure is probably due to the irregular nature of the rest of the cell.

Lamellate plastids commonly contain closely grouped aggregates of thylakoids in regular spacing. Termed primary thylakoids, they are not appressed though they often contain tightly appressed grana in their arrays. Bachmann et al. (1969) termed these structures "parallel thylakoids" and found them to occur in several corn mutants, especially when they were grown under dim light. They appeared to result from incomplete development of the lamellar system. These workers attributed this atypical structure to suboptimal conditions, either genetic or environmental, and did not consider them to be true grana. We attribute them to the abnormal condition of enhanced UV-B radiation. Primary thylakoids are found in other nuclear mutants of barley (Wettstein et al., 1971), corn (Orsenigo and Marziani, 1971), and tobacco (Schmid et al., 1966). Stacking of thylakoids is apparently under nuclear control (Anderson, 1975). In the lamellate cell type, the obvious condition of the nucleus would explain the aberrant plastid lamellar structure. Note that no plastid ribosomes are found in these plastids.

Of the three anomalous cell types found in bronzed regions, the plastids in alamellate cells appear most like degenerating plastids. Mitochondria are the only other abnormal organelles in this type. It is doubtful that mitochondria of these cells influence the plastid structures since these plastids occur also in mixed cells along with chloroplasts and vesiculate plastids. Their occurrence in mixed cells implied that the causal mechanisms for the alamellate plastid

structure resides in the individual plastid. These plastids have no typical lamellar structure (i.e., thylakoids) and no apparent ribosomes. The stroma is homogenous. Similar features were found by Walles (1965) in non-allelic carotene-less mutant of sunflower. Grown under dim light, the mutant contained lamellae and chl *a* and *b* which became photooxidized with increased levels of light. This was accompanied by a degeneration of the plastids which formed loose membranes and a homogenous stroma. Corn mutants grown under similar conditions also produced degenerated plastids similar to alamellate plastids (Bachmann *et al.*, 1969). The circular grana found in some alamellate plastids have been reported in the *xantha-b*^{18} mutant of barley (Sager, 1972) and a mutant of corn (Orsenigo and Marziani, 1971). Again, the similarity of alamellate plastid structure to those reported in various mutants indicates a response via altered cell physiology probably due to lesions in nucleic acids or proteins caused by UV-B absorption. That these plastids occur in mixed cells indicates the altered metabolism occurs within individual plastids. The presence of a true plastid mutation cannot be determined easily in this situation because of the need for propagation of the cells in question.

Our finding of degenerate plastids (vesiculate and alamellate) in cells containing chloroplasts indicated that this degeneration is under plastid control to some extent, and that plastids may respond to enhanced UV-B on an individual basis.

A feature common to all atypical cell types (and chlorotic cells) is the occasional occurrence of mitochondria within invaginations of plastids. This phenomena was noted to occur in soybean leaves

grown under low light intensities by Ballantine and Forde (1970). Montes and Bradbeer (1976) also reported this effect as a response to low light conditions in corn and Hyptis. They suggested this association allows for energy compounds (produced by mitochondria) to be utilized by chloroplasts in maintaining their basal metabolism with low light conditions. Wildman et al. (1973) suggested that this close association occurred in their mutant tobacco plants (plastid mutant), as observed by phase microscopy of living cells.

Phytoferritin and plastoglobuli found in atypical plastids are presumed to result from accumulation during the degeneration of these plastids (Thompson, 1974).

The data presented here, taken with data presented elsewhere in this report, implicates UV-B-enhanced growth regimes in the development of detrimental cell structure of soybean leaves.

The apparent lack of detrimental effect of UV-B stress on corn leaf ultrastructure is interesting and may have some basis in this species being widely separated from soybean and in the erect habitat of the corn plant.

The apparent lack of effect of UV-B-enhancement on citrus leaf surfaces also indicates the variation in species resistance to this stress.

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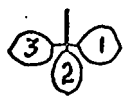
TABLE 1

DEVELOPMENT OF LEAF CHLOROSIS IN SOYBEAN WITH DIFFERENT LEVELS OF UV-B IRRADIATION[1/]

	T_3[2/]		T_2		T_1		T_c	
Leaf number	1	2	3	4	5	6	7	8
Leaf age								
3 days	G[3/]	G	G	G	G	G	G	G
4 days	p	p	p	G	p	p	NC	NC
7 days	IP	IP	IP	p	IP	IP	NC	NC
9 days	I	Ip	i	Ip	NC	NC	NC	NC
11 days	NC	NC	NC	NC	NC	NC	NC	NC
15 dyas	NC	NC	NC	NC	NC	NC	NC	NC
Leaf size[4/] (cm)								
width	2.8	2.8	4.1	3.1	3.4	4.5	4.6	4.1
length	5.8	5.0	6.7	6.8	6.4	6.7	6.4	7.2
Order of increasing pigmentation[5/]	2	2	3	1	2	1	-	-
	3	1	2	2	1	2	-	-
	1	3	1	3	3	3	-	-
Severity across treatments[6/]	5	6	4	3	3	2	1	1

[1/] *Glycine max* cv. 'Bragg'; development on two-week-old plants of two trifoliate leaves per treatment was followed from emergence to 15 days' growth; chlorosis as presence of yellow-white pigment areas.

[2/] See text for explanation of irradiance levels.

[3/] Grading symbols: G=green, p-slight pigmentation area, P=substantial pigmentation area, i=slight increase in degree of pigmentation, I= substantial increase in degree of pigmentation, NC=No change.

[4/] Terminal trifoliate leaflet.

[5/] Within each leaf, leaflet number order illustrated; no difference in the controls.

[6/] Severity of non-green pigmentation, 6=most severe.

LIST OF FIGURES

All electron micrographs are of soybean leaf mesophyll unless otherwise stated.

Plate III

Figure 11	Chloroplast from green region of soybean leaf irradiated with UV-B (22,400 X).
Figure 12	Chloroplasts from chlorotic leaf region (26,000 X).
Figure 13	Bronzed adaxial epidermal and palisade cells (7,300 X).
Figure 14	Collapsed bronzed adaxial epidermal cells (18,000 X).

Plate IV

Figure 15	Vesiculate cell from bronzed leaf region (13,000 X).
Figures 16-17	Vesiculate plastids. Figure 16 - 18,000 X. Figure 17 - 16,000 X.

Plate V

Figures 18-19	Vesiculate plastids. Figure 18 - 36,000 X. Figure 19 - 9,000 X.
Figure 20	Palisade chloroplast with lamellate-type stromal lamellae (16,000 X).

Plate VI

Figure 21 — Lamellate cell (6,200 X; inset - 12,000 X).

Figures 22-23 — Lamellate plastids. Figure 22 - 12,000 X. Figure 23 - 23,000 X.

Plate VII

Figures 24-27 — Lamellate plastids. Figure 24 - 25,000 X; Figure 25 - 28,000 X; Figure 26 - 77,000 X; Figure 27 - 69,000 X.

Plate VIII

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Figure 55 - 5,000 X; Figure 56 - 2,000 X;

Figure 57 - 5,000 X.

PLATE I

PLATE II

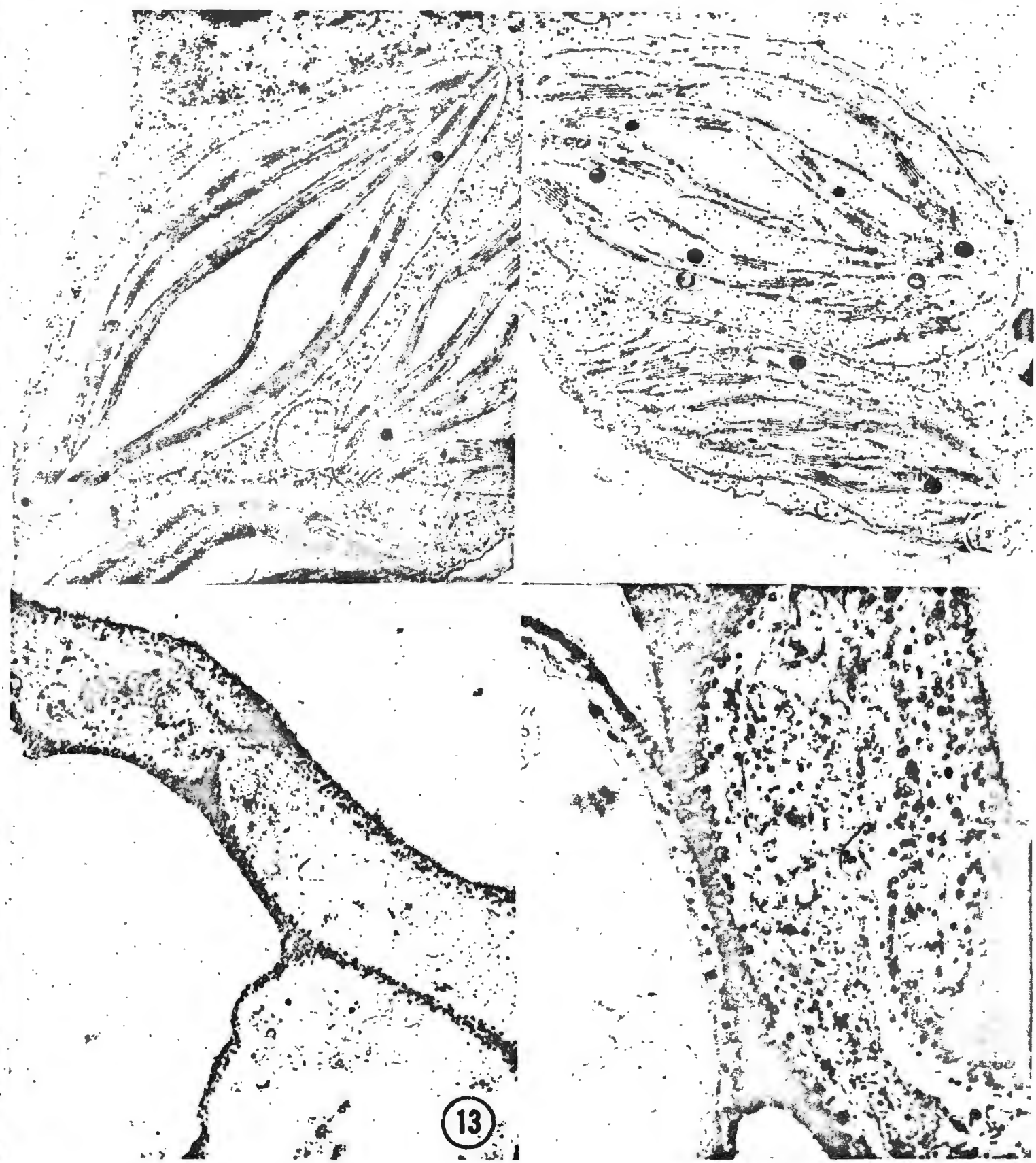


PLATE III

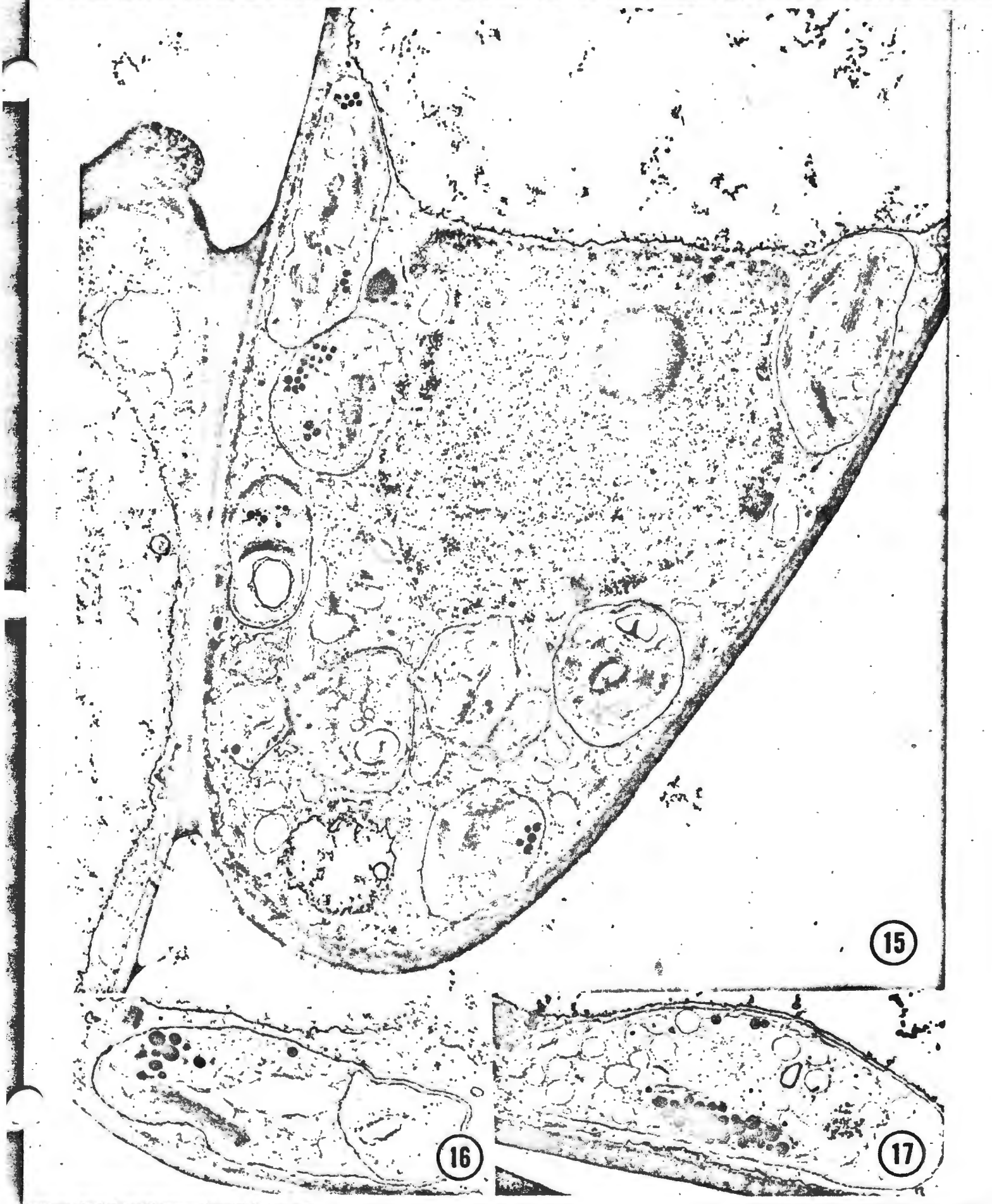
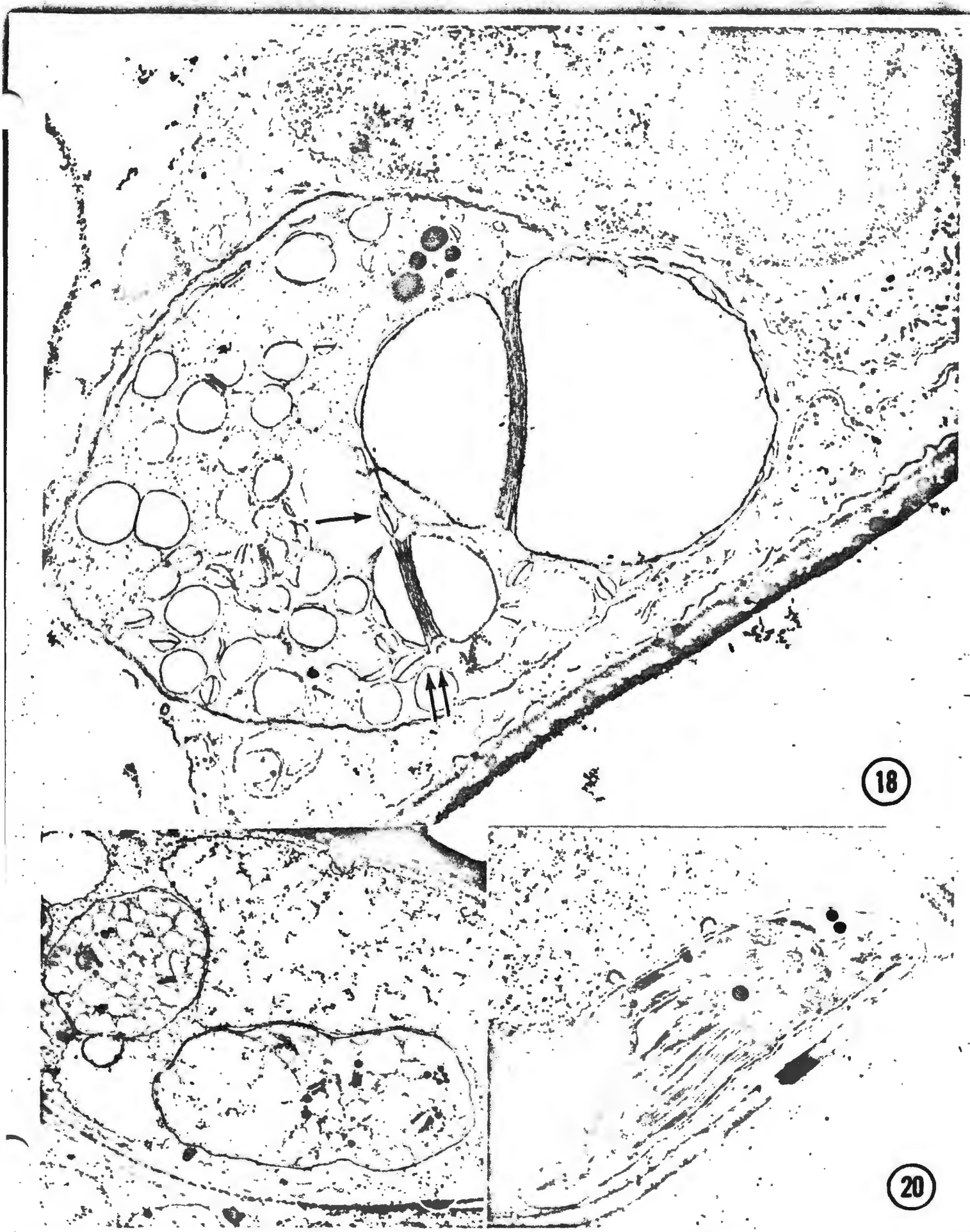


PLATE IV



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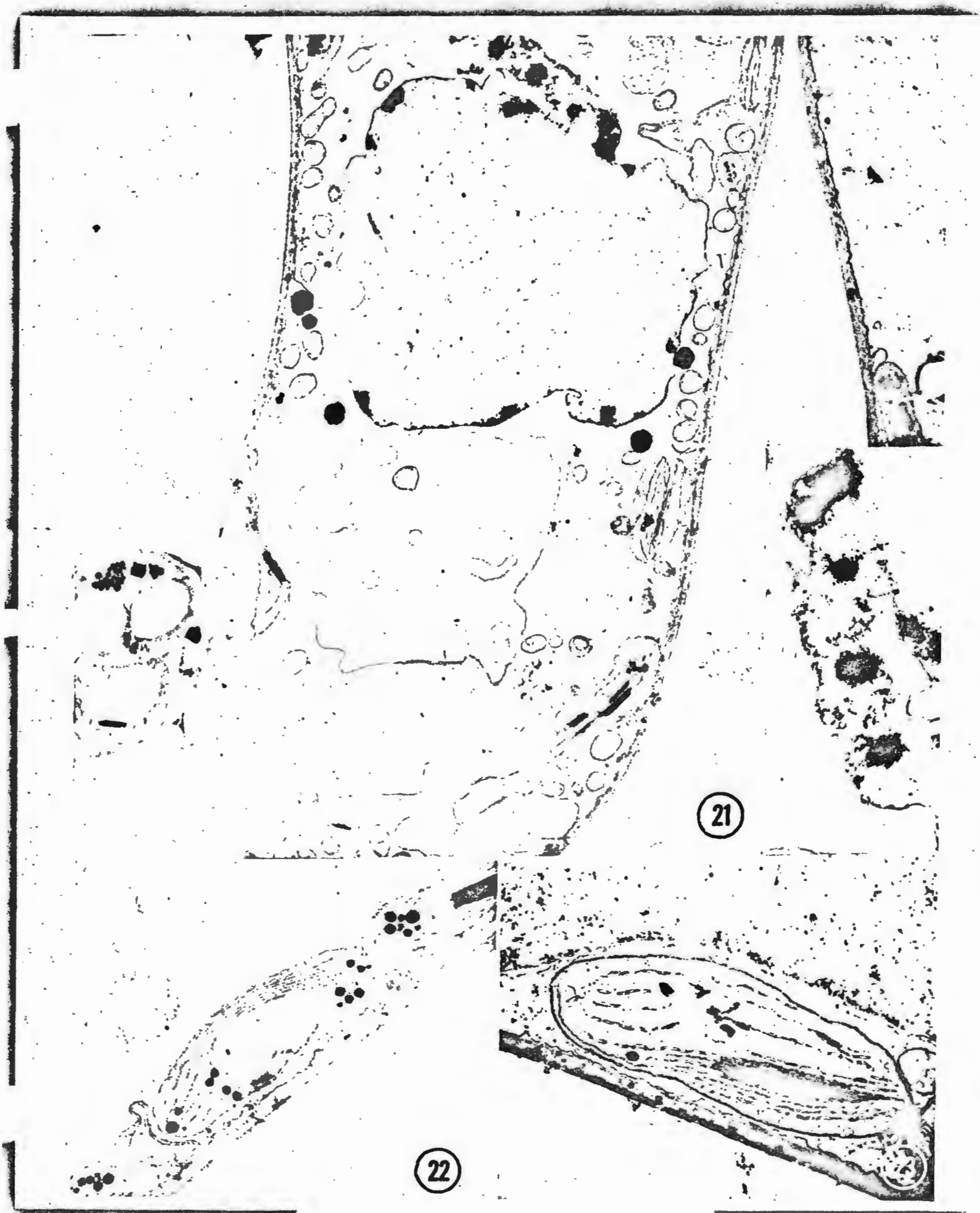

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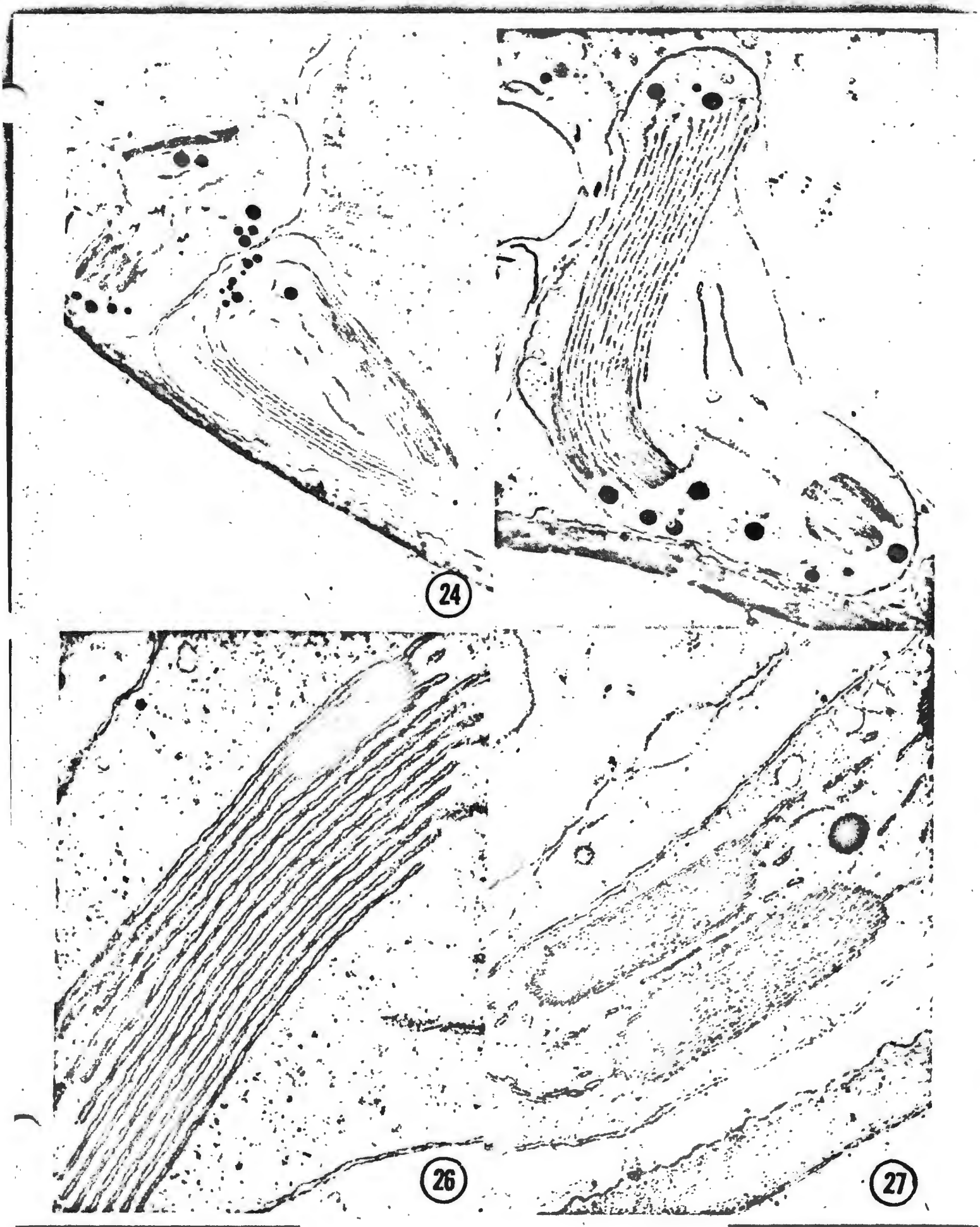

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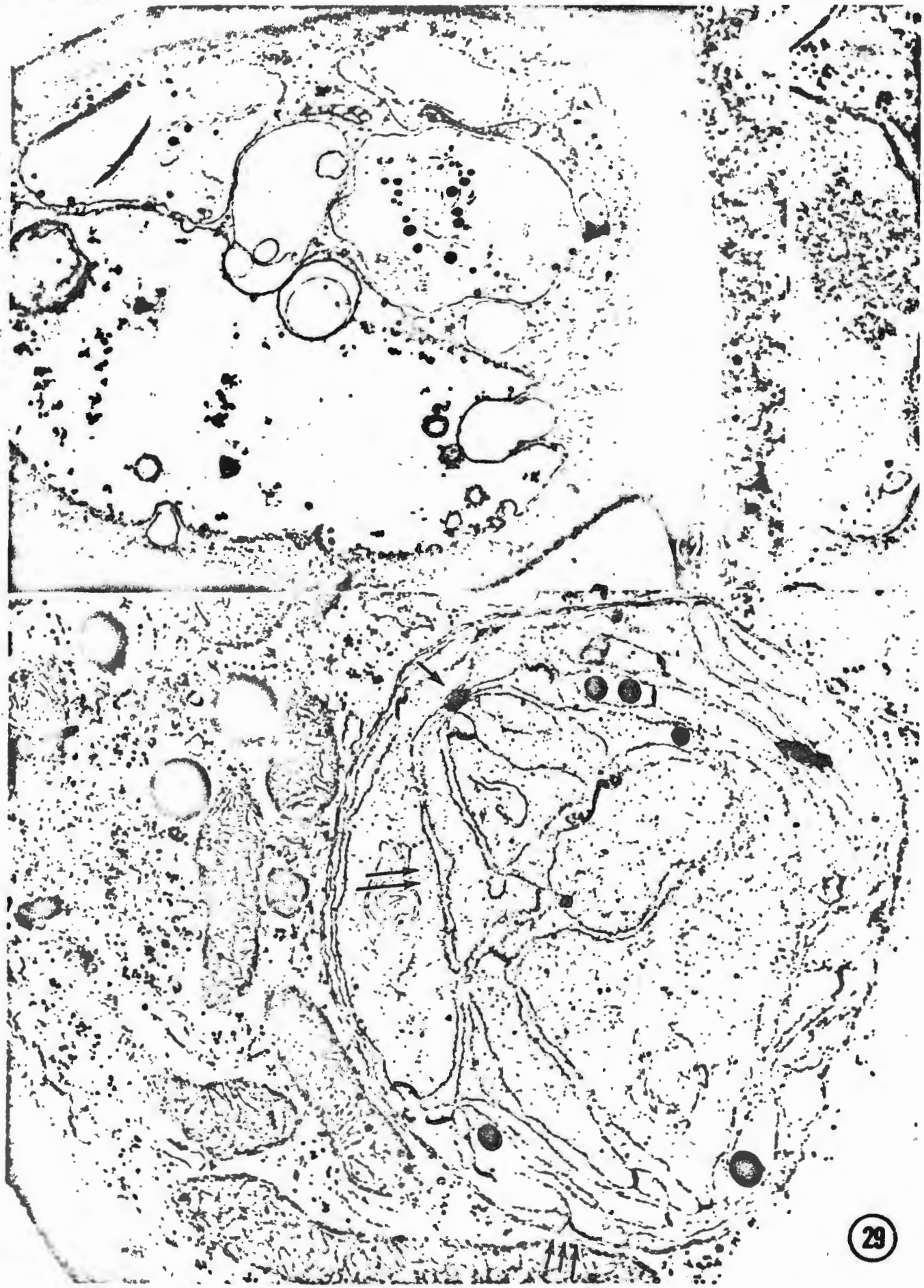

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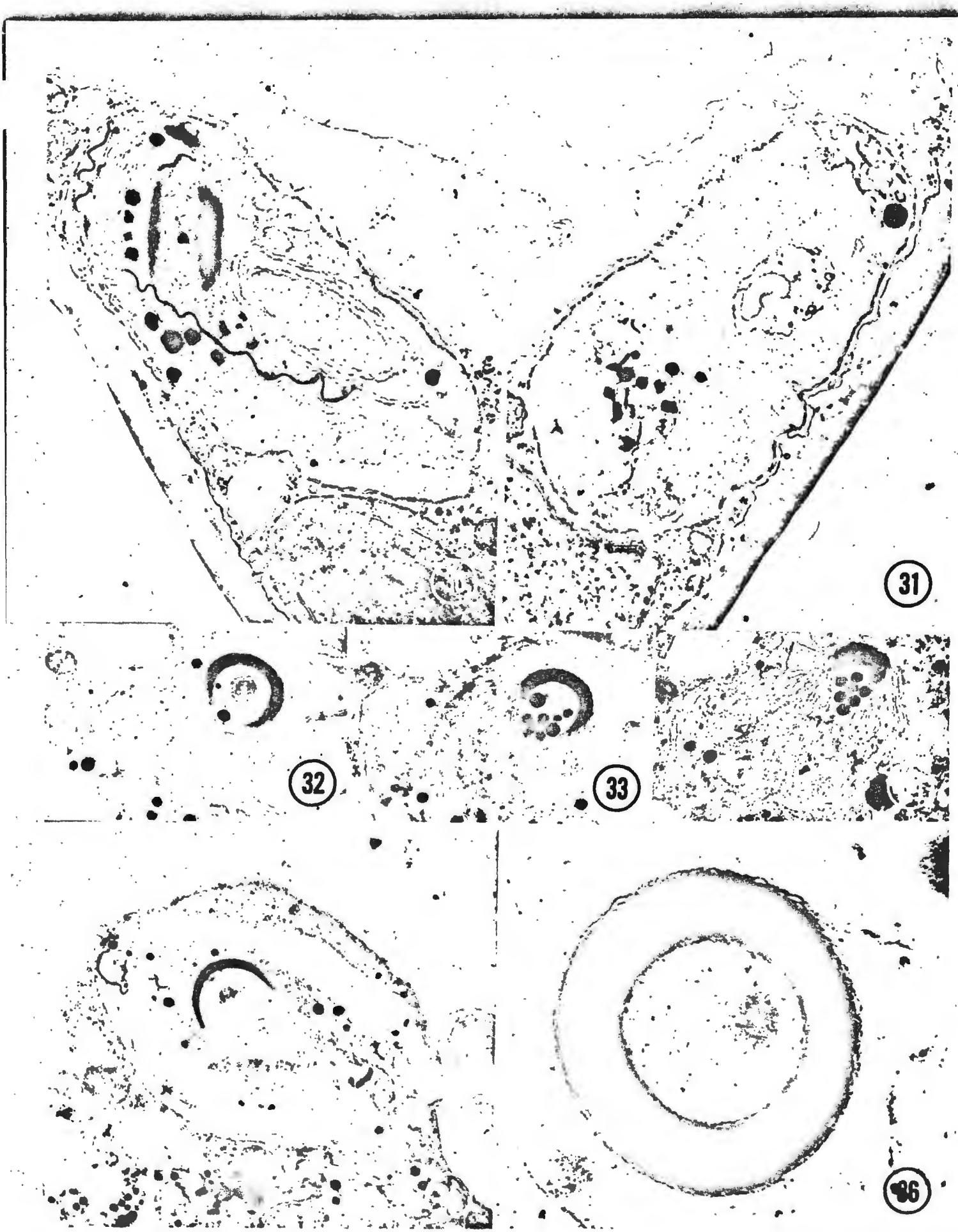
PLATE VIII



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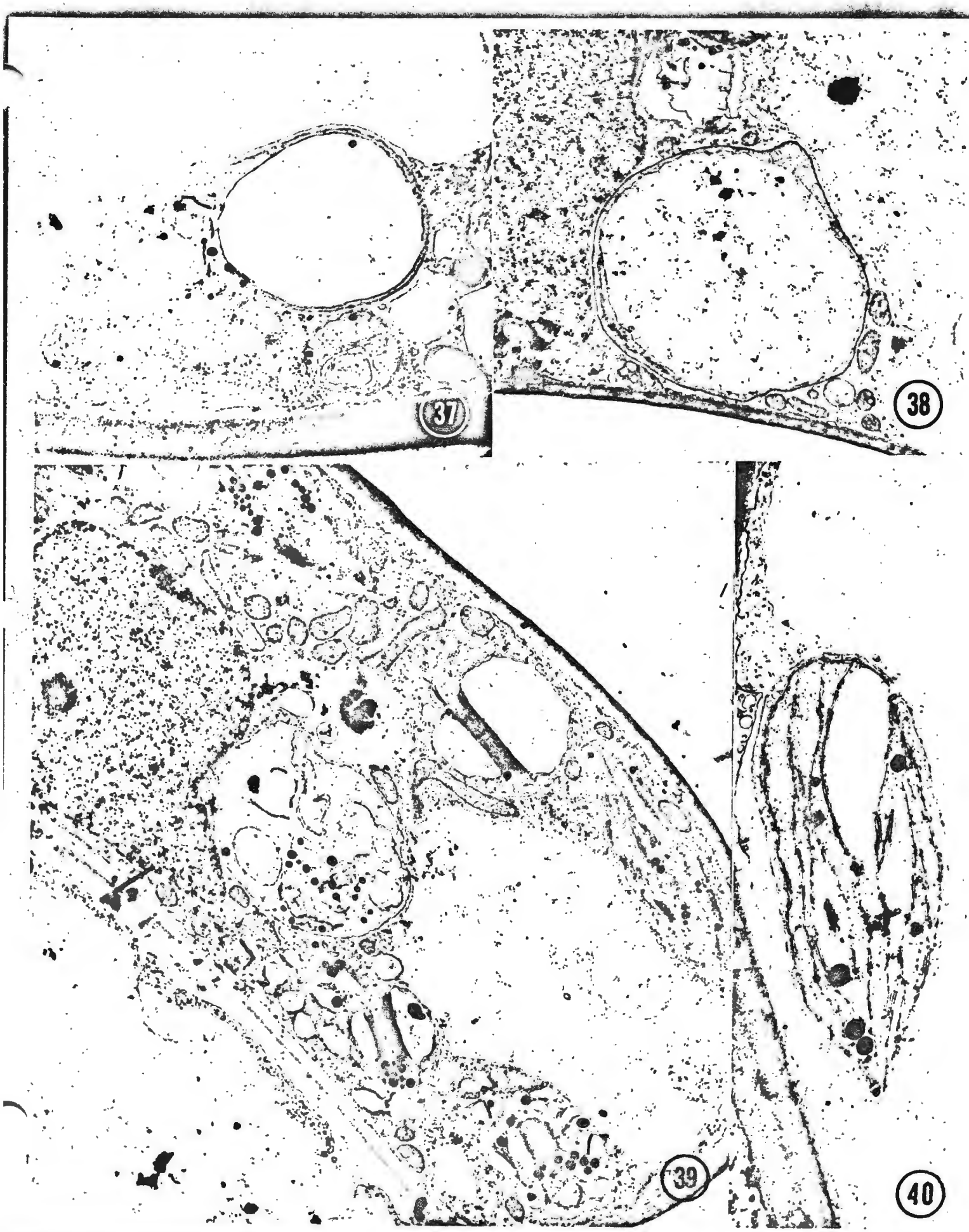


PLATE X

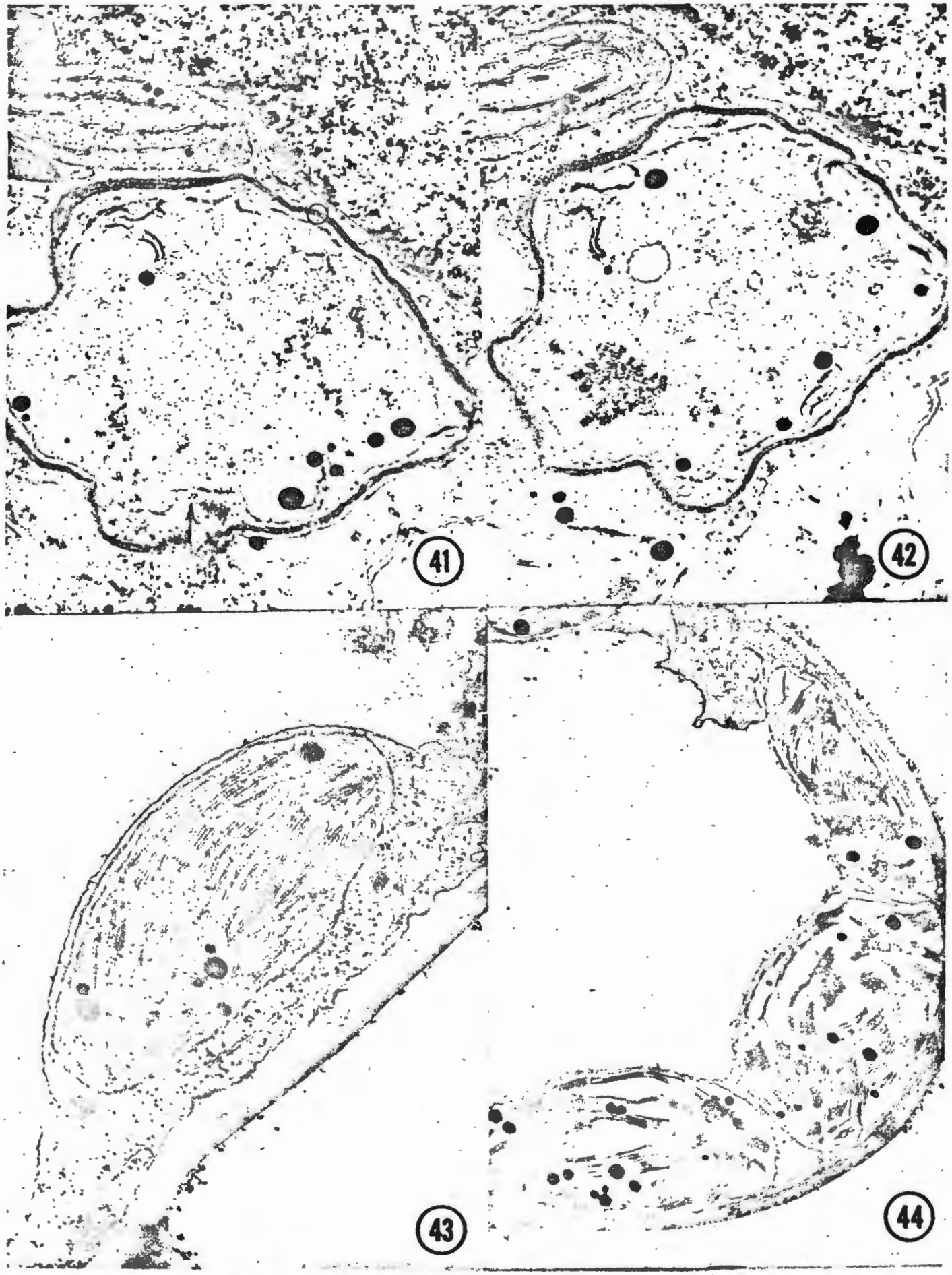
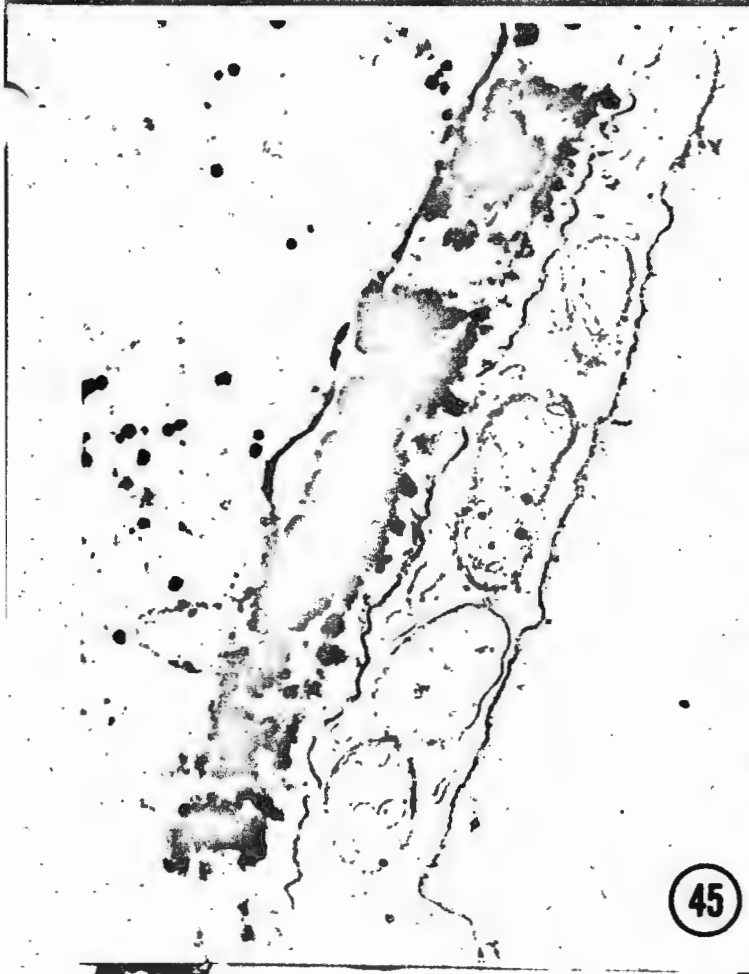


PLATE XI



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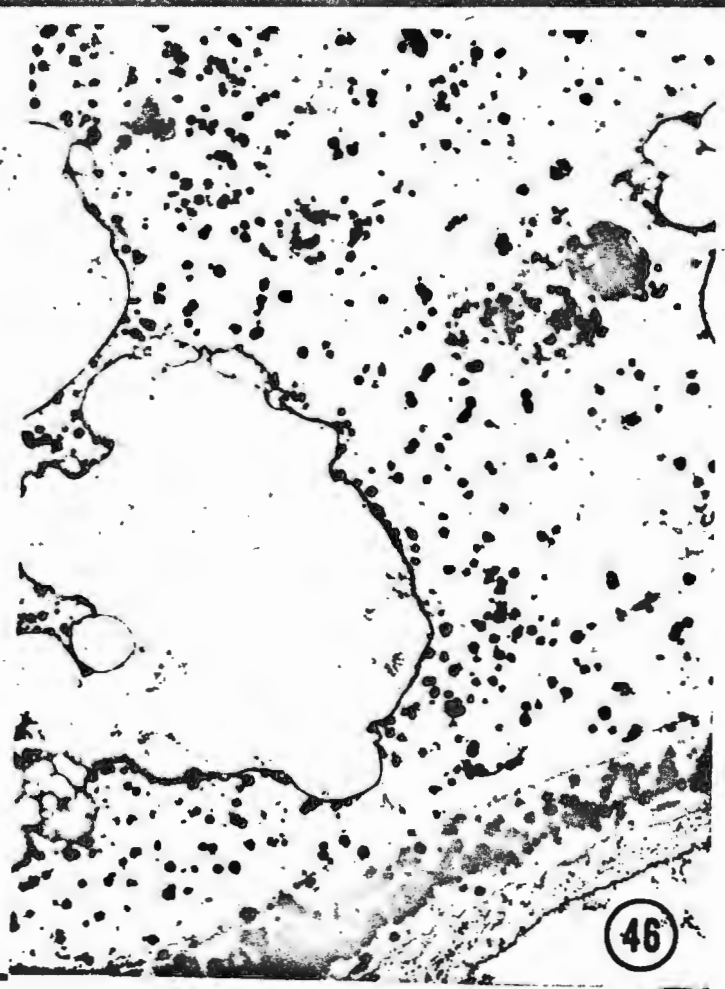

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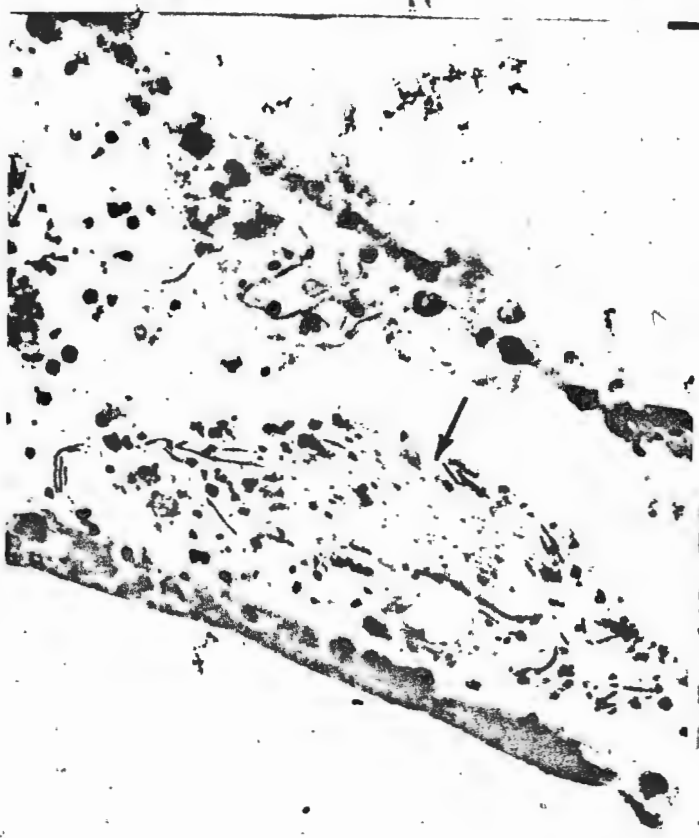

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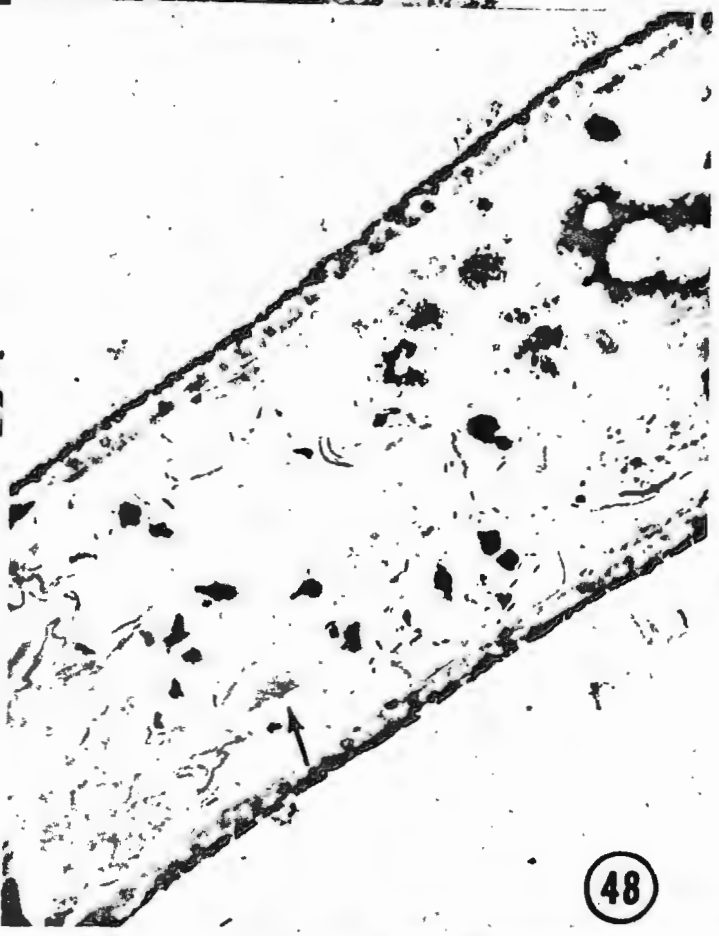

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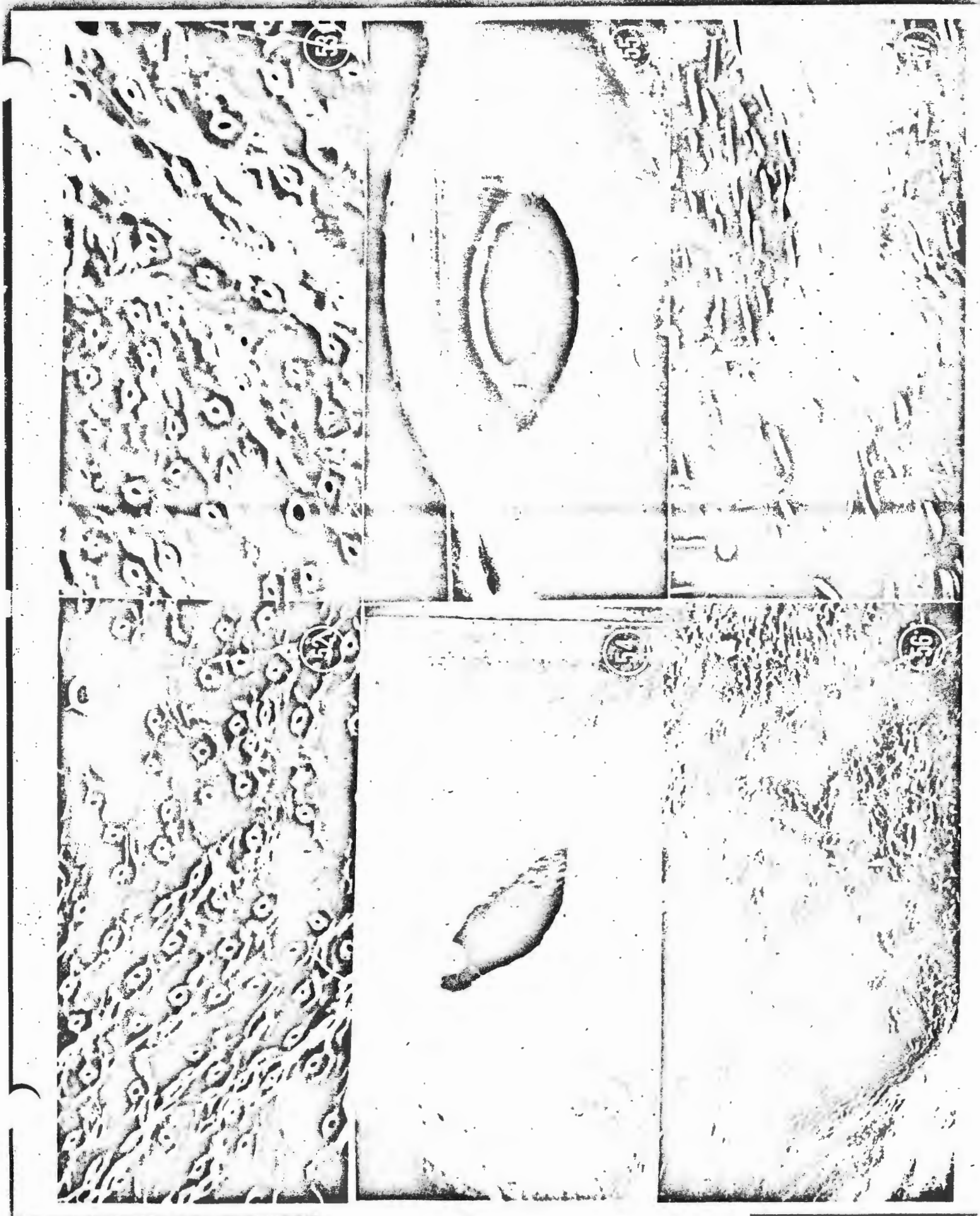
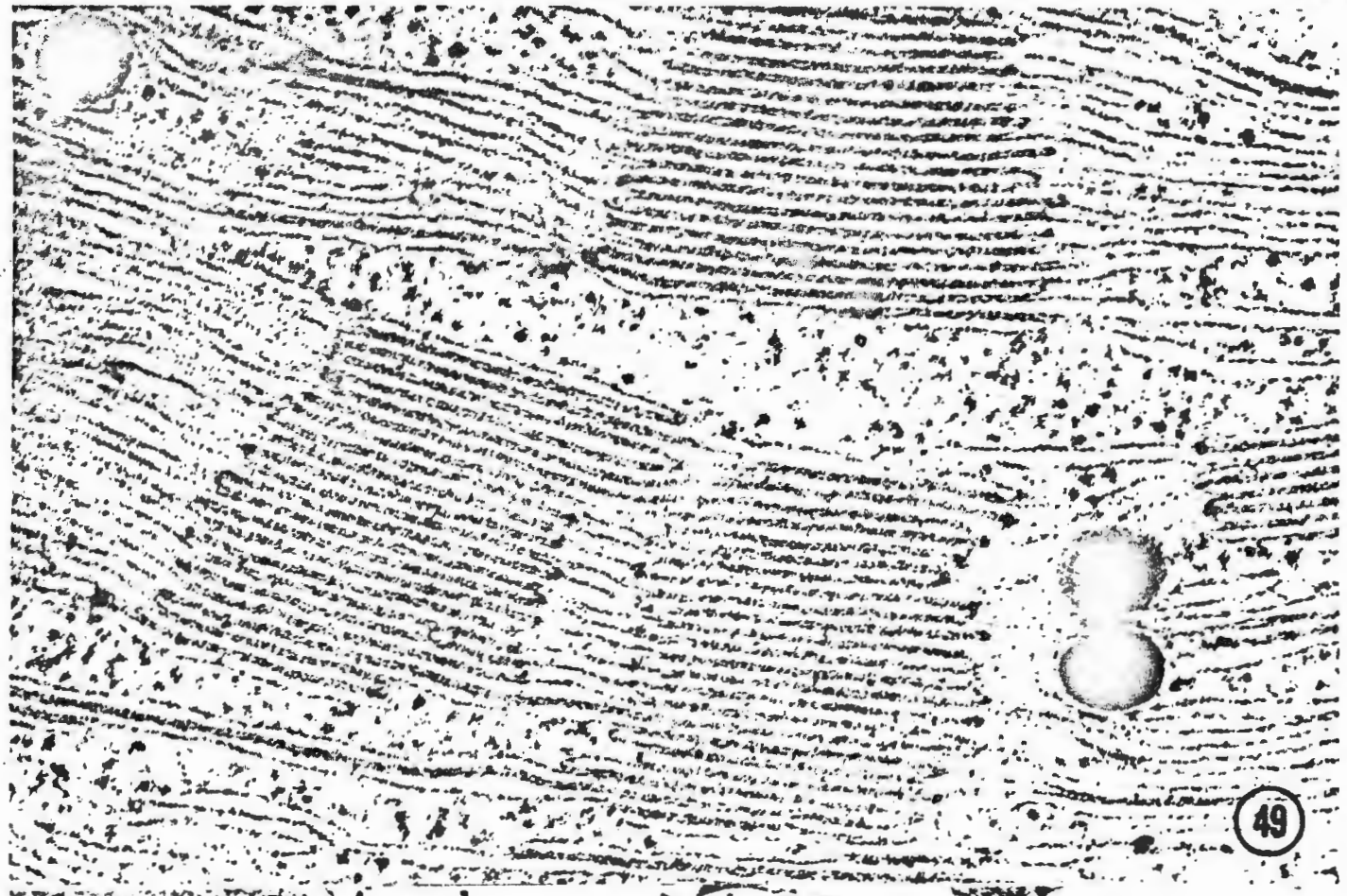
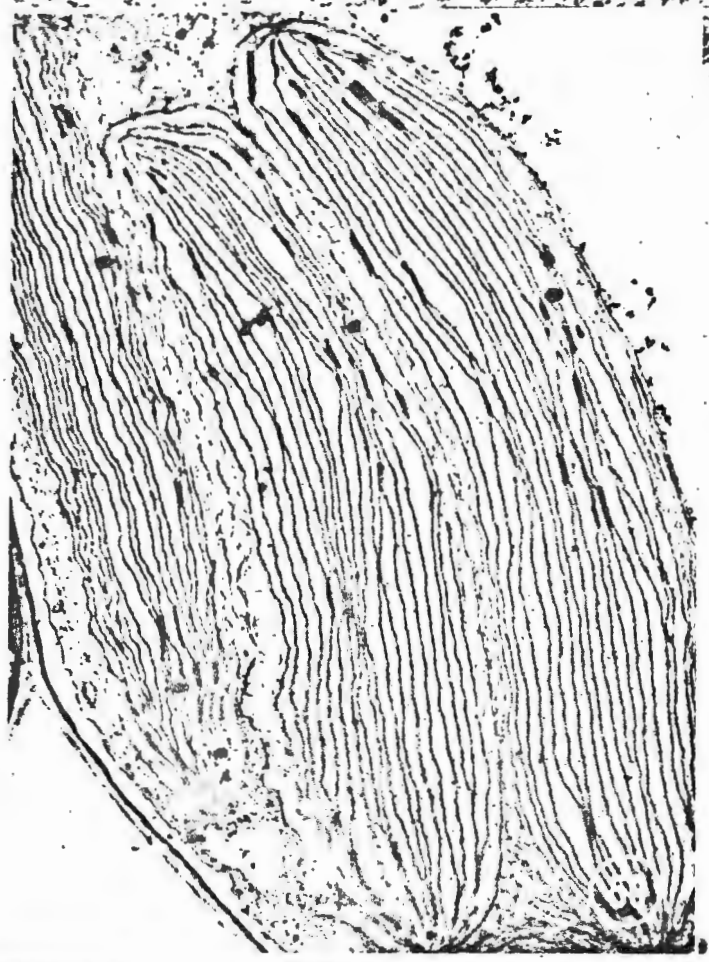


PLATE XIV





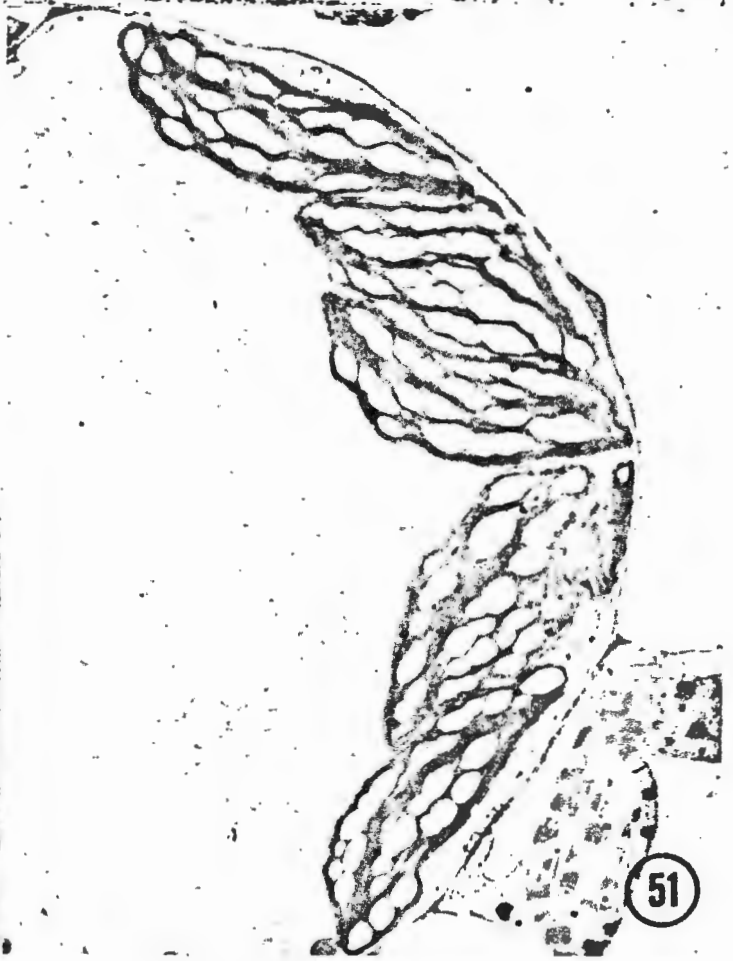


PLATE XIII

FINAL REPORT

HIGH ALTITUDE STUDIES OF NATURAL, SUPPLEMENTAL AND DELETION OF UV-B ON VEGETABLES AND WHEAT

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FORWARD

Decisions having great impact must be made with regard to inadvertent modification of the upper stratosphere. It will be difficult to make such decisions due to insufficient hard data. Man's sustenance is at stake and thorough and rapid investigation is necessary.

There is need to know whether man's traditional food crops are adapted to enhanced levels of UV-B radiation which will result from stratospheric ozone depletion. The Colorado State University Horticulture group contributed to this interdisciplinary effort through research focused on enhancement of solar UV-B by means of filtered sunlamps as well as exclusion methods. These studies were conducted at high altitude with four crop species of international importance.

ABSTRACT

Our research was initiated in order to determine the influence of solar UV-B and solar supplemented UV-B radiation on wheat, Triticum aestivum; potato, Solanum tuberosum; radish, Raphanus sativus; pea, Pisum sativum and also to develop dose-response information including threshold UV-B levels for injury.

A field program was initiated at a site at 3000 m elevation, 39°11'N latitude and 106°56'W longitude located 43 km W of the Continental Divide and 11 km from the nearest highway.

Filtered sunlamps were employed in one experiment and UV-B transmitting films, a UV-B absorbing film, and 26% shade were used as treatments in another experiment. Plants were grown in containers in an artificial medium. Exposure began at emergence, June 23 and ended on August 13.

The only significant response by plants exposed to UV-B simulating at least a 20% reduction in ozone was that of stature reduction in wheat. It was discovered in the experiment where solar UV-B was supplemented with lamp UV-B that various factors associated with the technique preclude any rigid interpretation of the data.

Technical information regarding Aclar^{R}, a UV-B transmitting film; lamp output relative to temperature; lamp variability; was gathered and a new approach to UV-B studies was suggested.

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FIGURES

FIGURES (cont.)

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

UV-B	--irradiance in the 280-320 nm range
CA	--cellulose acetate film transmitting UV-B
AC	--Aclar film, transmitting UV-B
M	--Mylar film, does not transmit UV-B
U NL	--unlit or non-lamp, no emmission of energy
+UVB	--designation for treatments permitting UV-B
-UVB	--designation for treatments preventing UV-B
UV-A	--irradiance in the 320-400 nm range
PAR	--photosynthetically active radiation 400-700 nm range
AST	--apparent solar time
MDT	--mountain daylight time
BARC	--Beltsville Agricultural Research Center
UVBSE	--UV-B sun equivalents, a function of weighted (action spectrum applied) irradiance in the UV-B range - developed by BARC, UVBSE x 3.06 = weighted $mW.m^{-2}$ (280-320nm)
Aξ9	--refers to actual equation $y = [0.25\ (\lambda/228.178)^{9.0}\ ]\ \exp.\ [4-(\lambda/228.178)^{9.0}]$ and weights for biological effectiveness $\lambda<320$ nm, developed by BARC
FW	--fresh weight, not dried
DW	--dry weight - obtained by drying tissue in a forced draft oven at 70^{o} C for 48 hrs
14-14-14	--slow release fertilizer, 14% nitrogen + 14% phosphate + 14% potash

FS40	--Westinghouse sunlamp designation
nm	--nanometers
$mW.m^{-2}$	--milliwatts per meter squared
Error a	--whole plot error used to test $\pm$ UVB effect
Error b	--subplot error used to test irradiance and $\pm$ UVB x irradiance interaction
df	--degrees of freedom
MS	--mean square
LSD	--least significant difference, refers to mean separation
CdS	--cadmium sulfide
mmhos/cm	--a measure of conductivity and related to soluble salt concentration
pH	--$\log_{10}$ of the reciprocal of the H ion concentration, a measure of active acidity
mil	--2.54 mm 0.254 mm or 0.001 inches
bar	--750 mmHg or 99998 $N.m^{-2}$

SYMBOLS

R^2	--coefficient of determination, percent indicates the extent of variability in the dependent variable accounted for by the model
$Y = aX^b$	--general form for power model
$\bar{x}$	--arithmetic mean
*	--significant at 5% level
**	--significant at 1% level

P	--phosphorus
K	--potassium
Fe	--iron
Zn	--zinc
Cu	--copper
Mn	--manganese
Mo	--molybdenum
S	--sulfur
NO_3 - N	--nitrate nitrogen
$Ca(H_2PO_4)_2 \cdot H_2O$	--triple super phosphate
KNO_3	--potassium nitrate
$(NH_4)_2SO_4$	--ammonium sulfate
$NiSO_4 + CoSO_4$	--nickel sulfate plus cobalt sulfate, a liquid filter

ACKNOWLEDGEMENTS

We wish to acknowledge the continued cooperation of Aspen Skiing Corporation. Among other things, they provided the 3000 m site at the Snowmass Mountain Facility. We are particularly indebted to Mr. James Snobble, Mountain manager, and Mr. Robert Clark, Supervisor for their help including "emergency" type decisions made on the mountain. Ms. Ann McSay, Senior Research Technician in Horticulture deserves praise for her dedicated involvement in the project from beginning to end. We are happy to take the opportunity to thank the students both graduate and undergraduate who helped as they learned. They are Joseph Freeman, Debora Stevens, Tracy Sulzbach, Phoebe McCoy, C. Rajashekar and Robert Morris as well as Daniel Pskowski, Laurie Maxwell, Cheryl Hoffman and Douglas Drake. We also acknowledge the help of Thomas Knoblock a former student and resident of Aspen who provided handyman expertise when we needed it and Karen Hulse for data collection and analyses. A special note of appreciation goes to Dr. Frank Ronco of the U.S. Forest Service, former project leader of the spruce-pine investigation at the site. We wish to thank Dr. Ronco in particular for his design of the waterproof lamp fixtures and lamp structures and for the aid of his staff, Mr. Nelson and Mr. Ross.

Dr. Harry R. Carns, Chairman, Plant Physiology Institute USDA, ARS and his staff including Dr. Krizek and Mr. Rowan are acknowledged for their help particularly with the actual measurement of the UV-B irradiance on the mountain. Mr. Daniel Rowan actually spent a week with the IRL

Spec. D making measurements on the mountain. Mr. Michael Becwar, Ph.D. candidate and one of the authors of this report is to be congratulated for assuming full responsibility at the site so soon after he arrived from Oregon State University. Many thanks to Mrs. Jonilyn Hall for careful typing of the manuscript.

The Pitkin County Commissioners representing the most forward thinking community in the United States are hereby thanked for granting funds for research which was a prelude to the research carried out as described in the following pages of this report.

INTRODUCTION

Destruction of the stratospheric ozone due to increased concentration of halocarbons and nitrogen oxides could have serious impact. A problem is predicting this impact on food crops. Our study measured the magnitude of the impact caused by a realistic increase in solar UV-B radiation under natural outdoor conditions.

The study was unique in that the research took advantage of the naturally higher levels of solar UV-B radiation at high altitude. This was a primary method for increasing natural UV-B radiation levels. There are many difficulties in reproducing the natural levels of UV-B radiation using artificial light and some of these difficulties are reviewed by Sisson and Caldwell (1975). They point out that many of the difficulties are due in part to the increased effectiveness of shorter wavelengths of radiation which are present at such low levels. Artificial UV-B radiation generally has the wrong spectral distribution and intensity and therefore is not comparable to the natural solar radiation.

Radish and pea were chosen for this study because they originate at low altitude and because of this, we anticipated little innate UV-B radiation tolerance. Cline and Salisbury (1966) investigated the UV (254 nm) sensitivity of these two crops and found them to be sensitive and very sensitive, respectively. They were used for UV-B sensitive plants. Radish and pea have additional advantages in that they adapt well to the cool climate and short growing season at our high altitude research plot. Ergasheve et al (1971) reported photosynthetic impairment in pea seedlings

attributable to high elevation UV. Potato was chosen because it may be naturally more UV-B tolerant. Potato orginates in high elevation equatorial regions such as the high valleys and plateaus of Peru and Bolivia (approximately 4300 m elevation) and as such may be conditioned to higher levels of UV-B radiation. Although potato is not commercially grown at northern latitudes at 3000 m elevation it does well under wide diurnal temperature conditions. In the summer of 1976 reasonable yield for experimental purposes was obtained at 3200 m in Colorado. A potato leaf abnormality was noted at 2800 and 3200 m, possibly due to high irradiance levels. Wheat was chosen because it might also be UV-B resistant (Krizek, 1975) and because of its considerable importance as a major food crop.

The elevated site at approximately 3000 m above sea level was chosen for several reasons. Estimates by Becker and Boyd (1957) would indicate a 26% increase in insolation while Caldwell's (1968) work suggested an increase in global biologically effective UV-B irradiance of 2.5% to 12.6%, depending on the sun's zenith angle and air mass. Sauberer (Caldwell, 1968) would predict an increase of 34% UV-B irradiance of undetermined biological effectiveness. Tousey (1966) and Koller (1965) demonstrated the presence of the spectral lines 288.1 nm and 286.3 nm, respectively, at high elevations in the Alps. The anticipated high UV-B radiant flux density and shorter wavelength UV-B was seen as a natural way to simulate the effect of ozone depletion.

CONCLUSIONS

1. Solar UV-B irradiance at levels above those equivalent to a 20% reduction in stratospheric ozone reduced wheat plant stature.
2. Further investigation of solar UV-B by means of filtered lamps is needed prior to any future field experimentation.
3. Undue concern regarding detrimental effects on biomass resulting from 20% depletion of stratospheric ozone appear not warranted according to our investigation of wheat, potato, radish, and possibly pea.

RECOMMENDATIONS

1. Future research at high altitude should employ neutral density filtration of the UV-A and PAR regions.
2. The solar UV-B collector and irradiator concept should be investigated.
3. In any field studies, the UV-B, UV-A and PAR should be monitored continuously on classified days, so that true dosages may be ascertained.
4. The photographic technique of Tousey (1966) might be employed in high altitude studies so that evidence of <280 nm radiation might be gathered.
5. Photo-dosimetry should be investigated as a technique to determine dosages applied to whole plants. This technique would compensate for individual leaf positioning in relation to the UV-B source.

6. We suggest a workshop be held on solar UV-B manipulation techniques.

MATERIALS AND METHODS

Crop species and cultivars tested were: pea, Pisum sativum 'Alaska'; wheat, Triticum aestivum 'Inia 66'; potato, Solanum tuberosum, 'Kennebec'; and radish, Raphanus sativus, 'Cherry Belle'. All species were grown in steel containers of 2.4 liter (potato) and 1.2 liter capacity with drainage provided, Figure 1. An "artificial" medium was used TABLE 1.

The site chosen was at 3000 m elevation, 39° 11' N latitude (BARC is 39° 01' N latitude) and 106° 56' W longitude located 43 km W of the Continental Divide and 11 km from the nearest highway. The surface was level and water and electrical power (110 v and 220 v) were available.

During the course of these studies all plants received 10 to 11 hours of direct sunlight per day. The site indicated in Figure 2 is mountainous and heavily forested, however, the site was chosen so that the horizon in all directions was not higher than 18° from the horizontal plane.

Two studies were conducted. The first was an exclusion study involving both reduction and filtering of overall insolation including UV-B radiation. This approach takes advantage of the naturally high levels of UV-B radiation occurring at 3000 m elevation. The high levels of natural UV-B radiation were reduced using various filters. Thus, in this experiment the extra UV-B radiation was reduced with filters in such a way as to simulate stratospheric ozone depletion relative to sea level.

TABLE 1. GROWING MEDIUM PROPERTIES USED IN LAMP AND EXCLUSION STUDIES

1. 40% peat, 30% vermiculite, and 30% sand by volume.

2. Chemical properties.

pH	5.2
Texture	loamy sand
Organic matter	5.4%
Conductivity	2.5 mmhos/cm
NO_3-N	158 ppm
P	71 ppm
K	345 ppm
Fe	63.4 ppm
Zn	8.7 ppm
Cu	0.5 ppm
Mn	20.4 ppm

Nutrients added per liter of medium.

0.536 g $Ca(H_2PO_4)_2 \cdot H_2O$

0.357 g KNO_3

0.179 g $(NH_4)_2SO_4$

0.179 g slow release 14-14-14

0.005 g soluble trace element mix

inert	60.15%
Mn	8.15%
Fe	7.50%
Cu	3.20%
Zn	4.50%
B	1.45%
Mo	0.05%
S	15.00%

3. Water holding properties.

$\%H_2O$/DW	bars
100.0	0.0
49.2	- 0.1
24.0	- 0.3
21.0	- 0.5
18.0	- 1.0

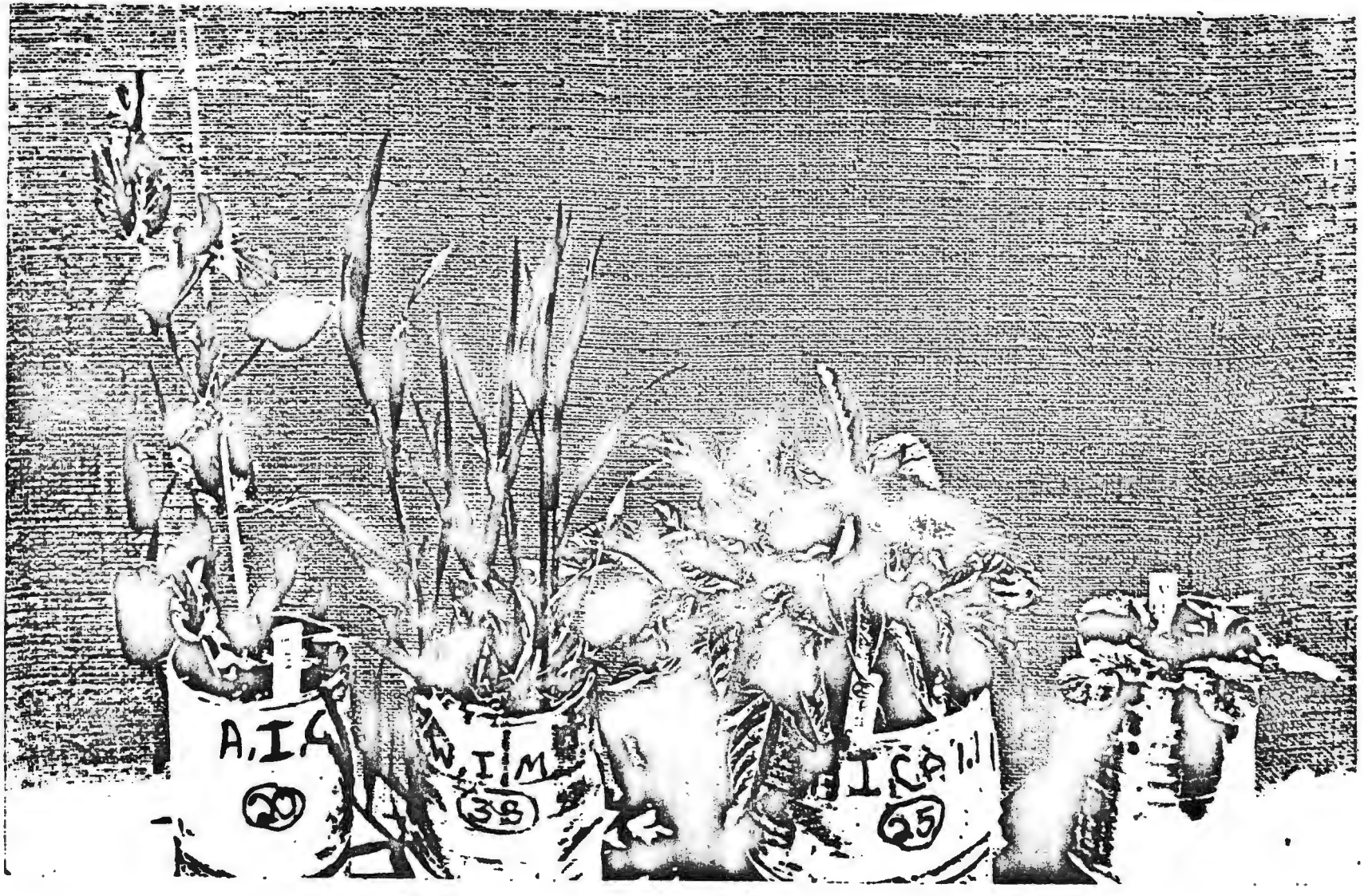

Figure 1. Container - artificial medium culture of pea, wheat, potato, and radish used in the exclusion and lamp studies.

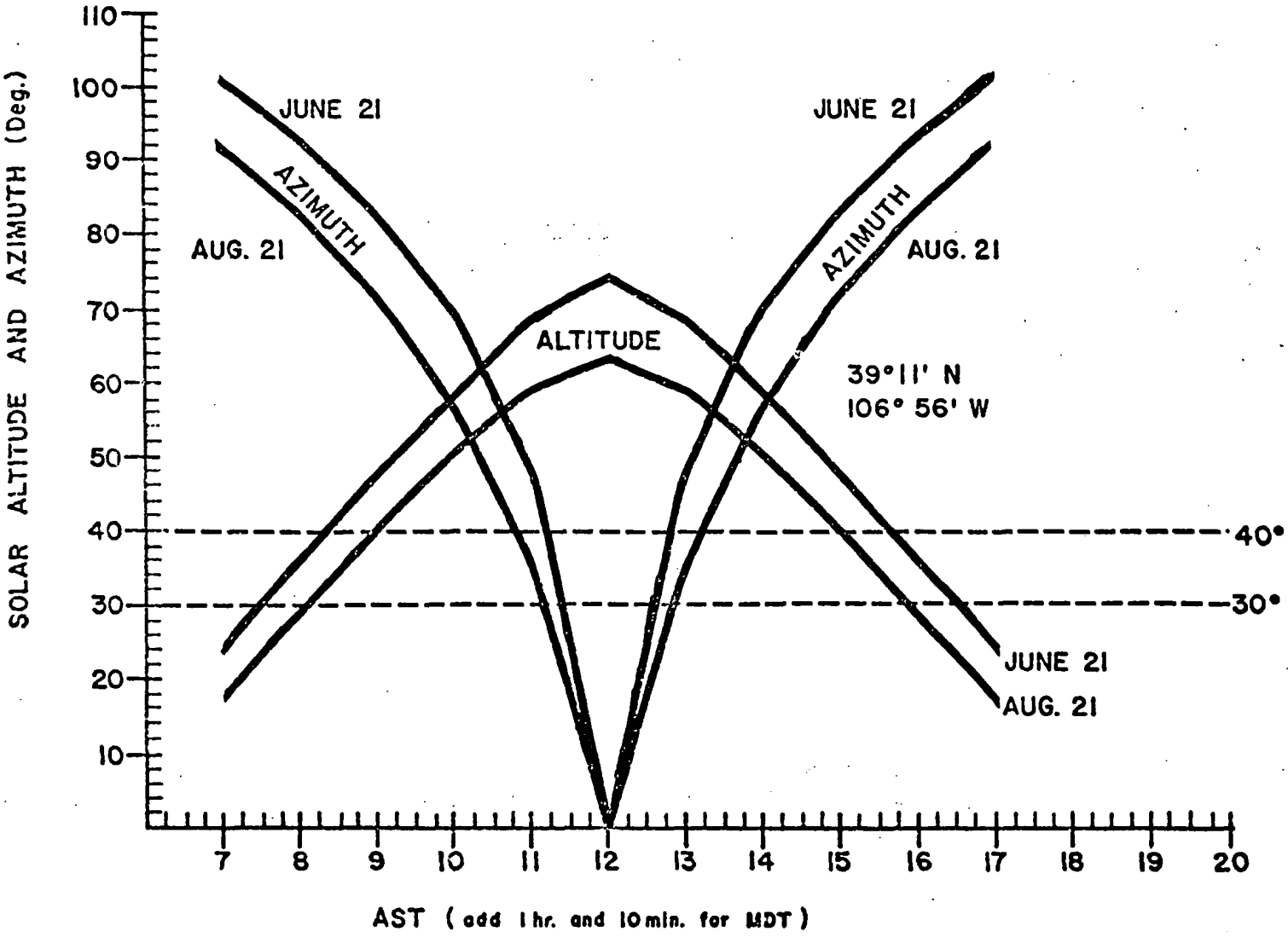

Figure 2. Graphic analysis of the sun position at the Colorado site during the exposure period, June 23 - August 13.

Treatments involved were: 1) an open control 2) a 26% insolation reduction using lath shading to simulate sea level insolation 3) cellulose acetate filtering to reduce UV-B radiation levels without substantial reduction in visible radiation 4) Mylar filtering to essentially eliminate UV-B radiation without substantial reduction in visible radiation and 5) Aclar filtering to reproduce the microclimate under the above filters without significant reduction of UV-B or visible radiation. The structures are illustrated in Figure 3. The transmission properties of Mylar and cellulose acetate are well understood and the transmission spectrum of Aclar is in Figure A-1 (Appendix). Aclar has no significant absorption above 230 nm through the visible region. Filter thicknesses were: cellulose acetate and Mylar, 5 mil; and Aclar, 1.5 mil. The experimental design employed was a randomized complete block with three replications per plant species. Treatment differences were tested by using the F test and if differences were significant, means were then separated using LSD procedures at the 5% level.

Spectral evaluation of the films in situ, as well as thermal analysis and total insolation measurements, were made with the BARC IRL Spec D spectroradiometer, an ISCO spectroradiometer, an Optronics radiometer, a Barnes IR thermometer, pyranographs, and a Leeds and Northrup recording potentiometer. Data are presented in Figure 4 and 5 and TABLE 2 and TABLE A-1 (appendix).

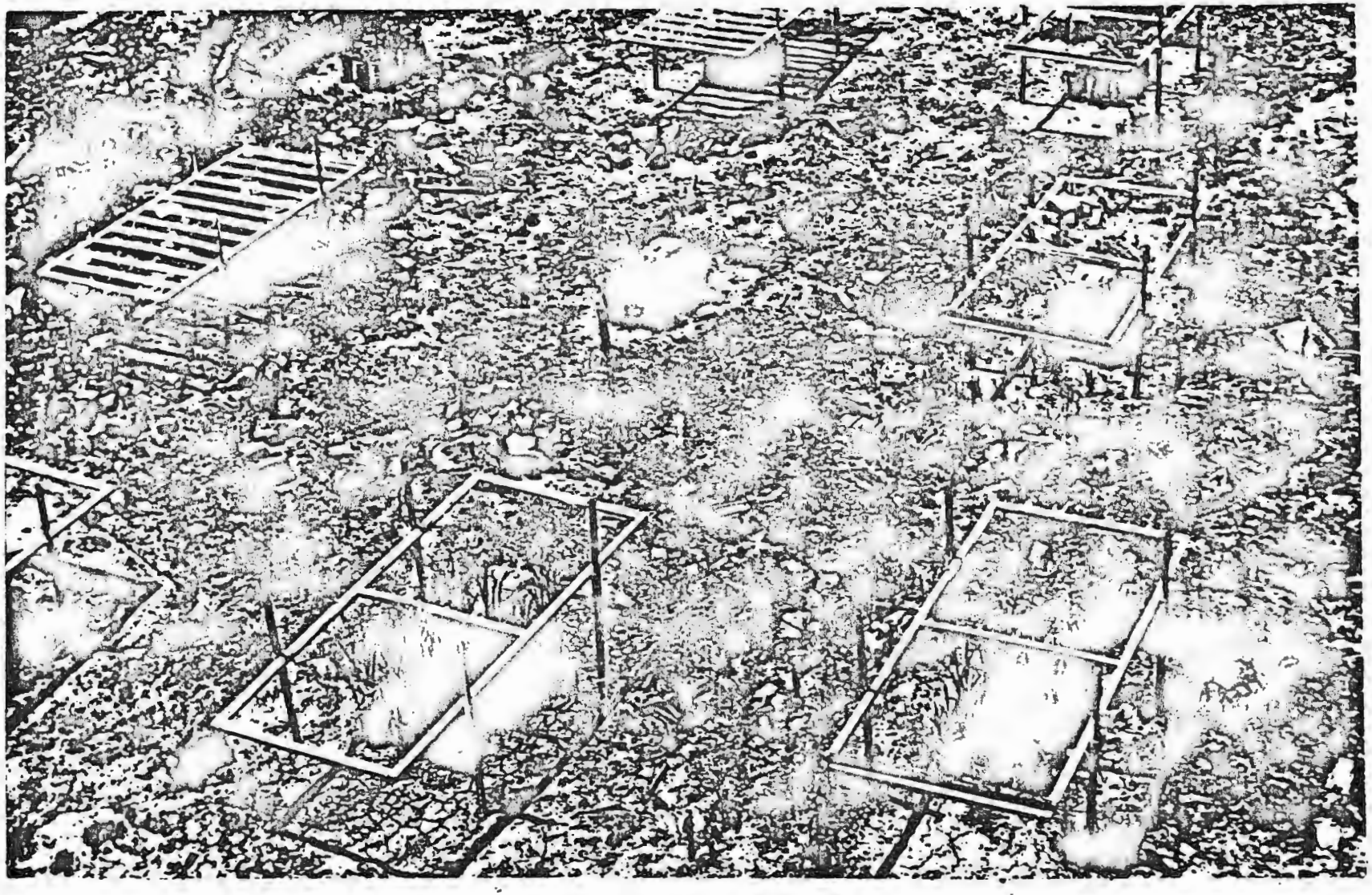

Figure 3. Exclusion study frames 91.5 x 213.5 cm, angle steel with adjustable steel pipe legs.

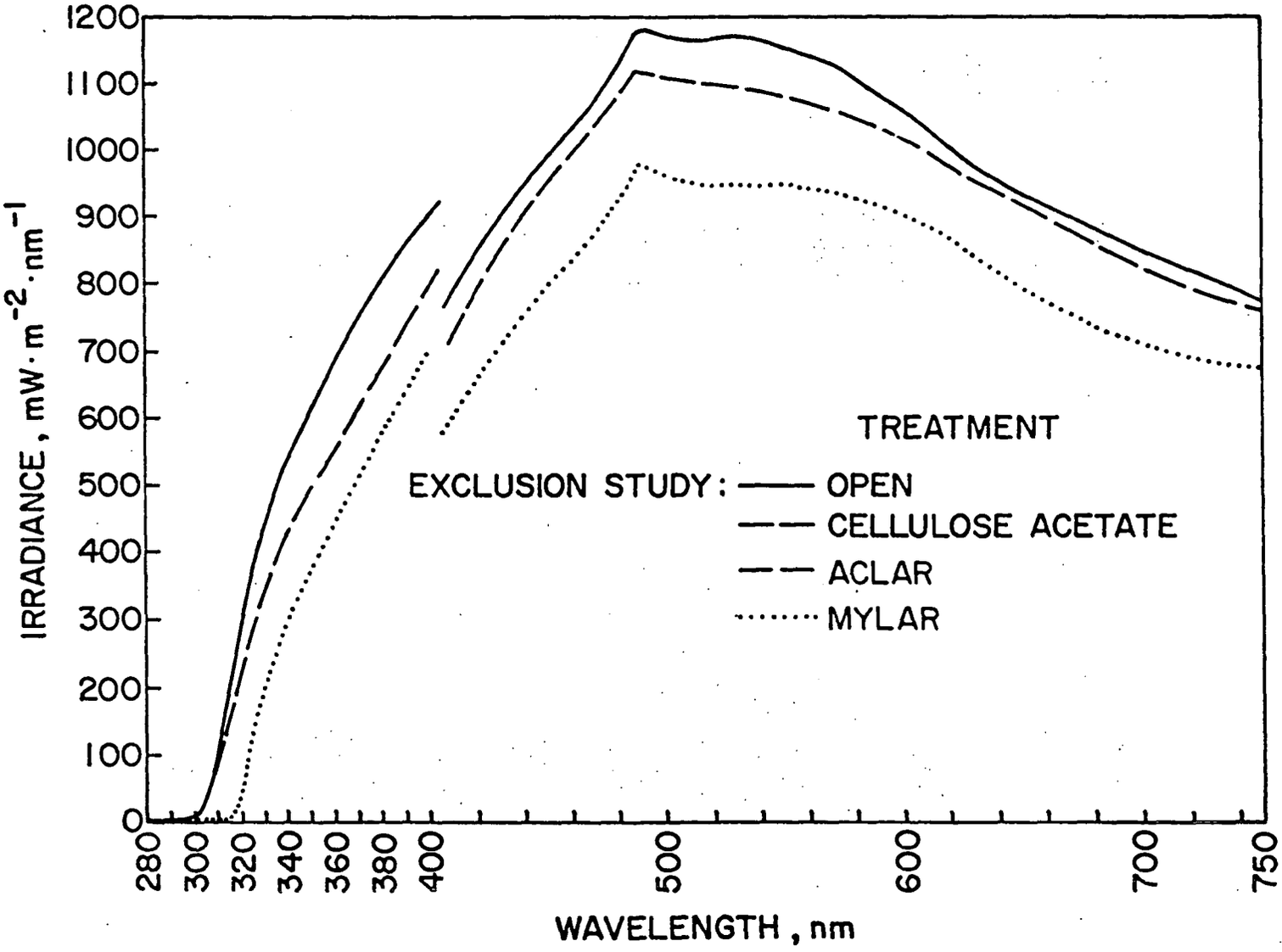

Figure 4. Sun spectra measured with the BARC Instrumentation Laboratory IRL Spec. D Spectroradiometer and an ISCO spectroradiometer.

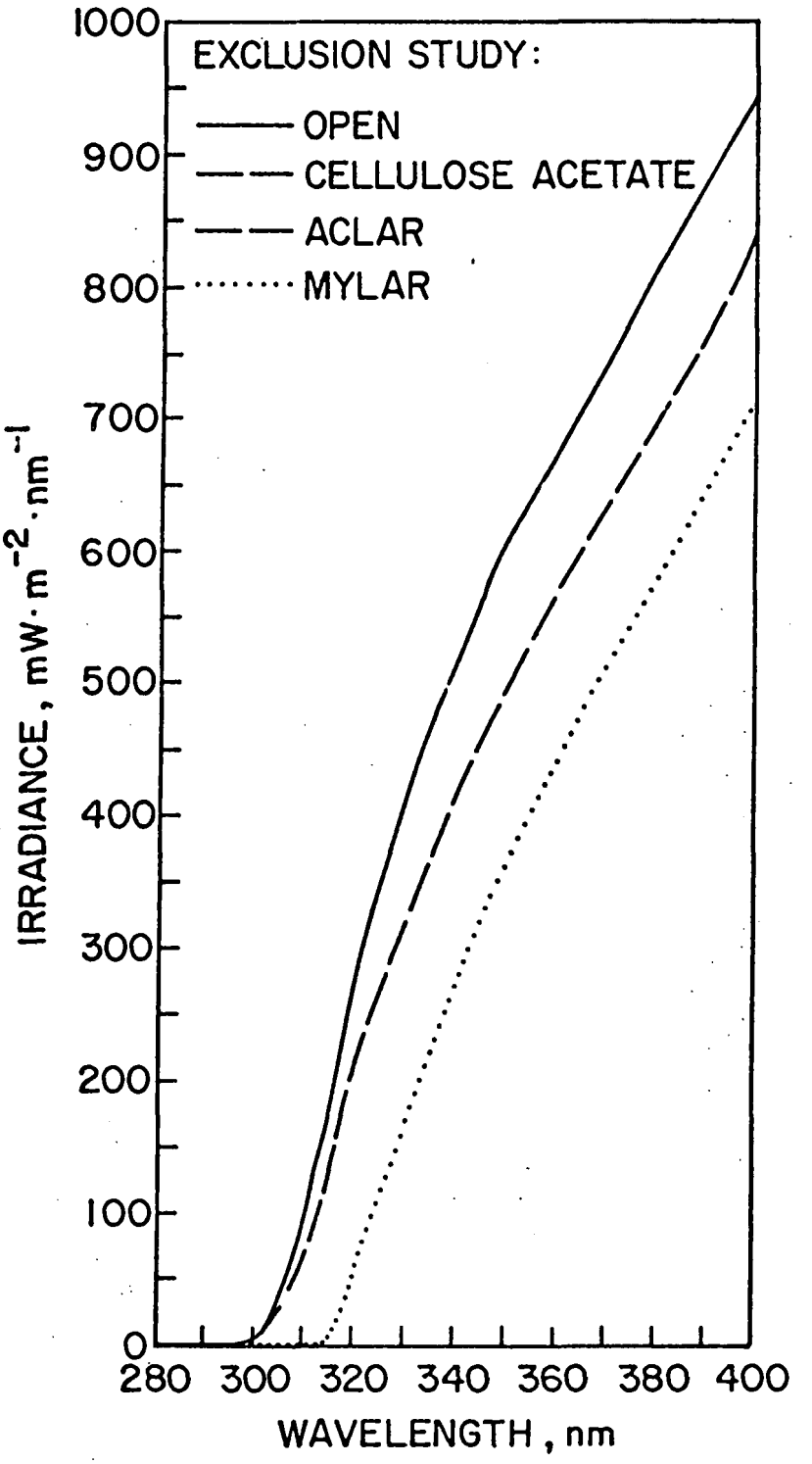

Figure 5. Sun spectra measured with the BARC Instrumentation Laboratory IRL Spec. D spectroradiometer.

Figure 6. Lamp study conduit frames with a 96 x 127 cm structure suspending 2 fixtures, 4 FS40 sunlamps, 110 cm above plants.

TABLE 2. EXCLUSION STUDY, ENVIRONMENTAL PARAMETERS, POTATO

SOLAR FILTER	HOURLY MEAN TEMPERATURE (^{o}C)			SOLAR RADIATION ($W/_{m}2$)
	AIR	PLANT	NATIVE SOIL	SOLAR NOON
NONE(OPEN)	12.9	12.7	16.2	803
Cellulose Acetate	(+0.7)[1]	(+1.4)	(+2.6)	(-63)
Aclar	(0.0)	(+1.5)	(+1.1)	(-21)
Mylar	(+0.2)	(+1.6)	(+2.7)	(-84)
Shade	(-0.2)	(0.0)	(-0.2)	(-208)

[1]Numbers in brackets indicate deviation from plants growing in the open.

The second study involved supplemental lighting in the field with Westinghouse FS40 sunlamps. The filtered sunlamps were operated for 6 hours each day (3 hours before and after solar noon) at a distance of 110 cm above the plants. Procedural protocol used with regard to lamps, lamp filters, lamp reflectors, lighting configuration, filter and lamp ageing, and filter changing was according to the instrumentation laboratory BARC. Figure 6 illustrates the basic four-lamp configuration employed. There were three treatments used. The first was lamps filtered with 5 mil cellulose acetate. Two control treatments were lamps filtered with Mylar which transmitted no UV-B radiation and reflectors without lamps to reproduce the microclimate of the lamp fixtures without adding radiation. Spectral evaluation of the filtered lamps *in situ* is presented in Figures 7 and 8. A split plot design was used in the lamp study with whole plots

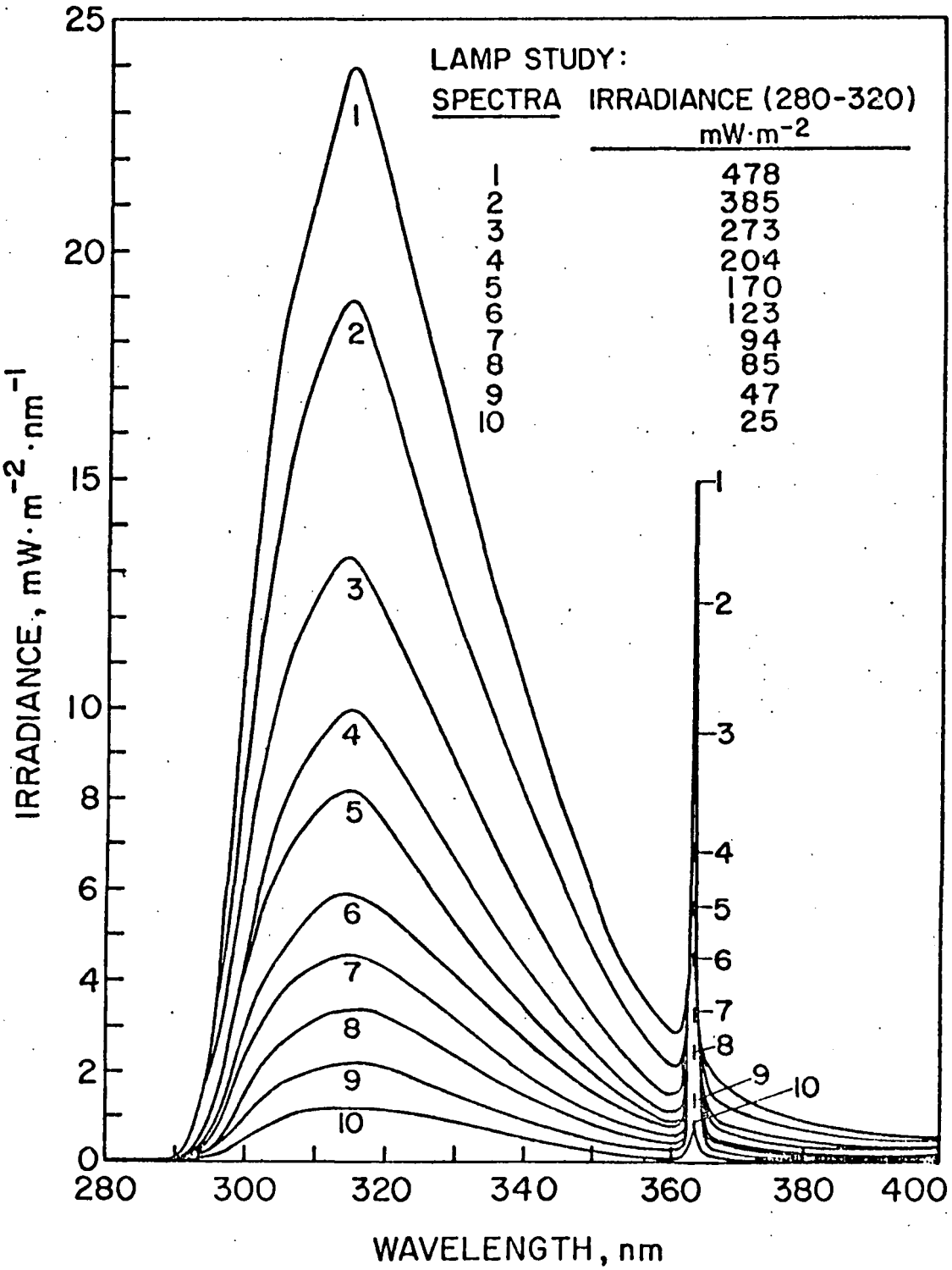

Figure 7. Cellulose acetate filtered FS40 lamp spectra and broad band summation measured with the BARC IRL Spec. D spectroradiometer at night.
Number 1 indicates a plant position directly under the center of the fixture. Number 10 indicates a plant position 212 cm from number 1 and in the same plane as number 1.

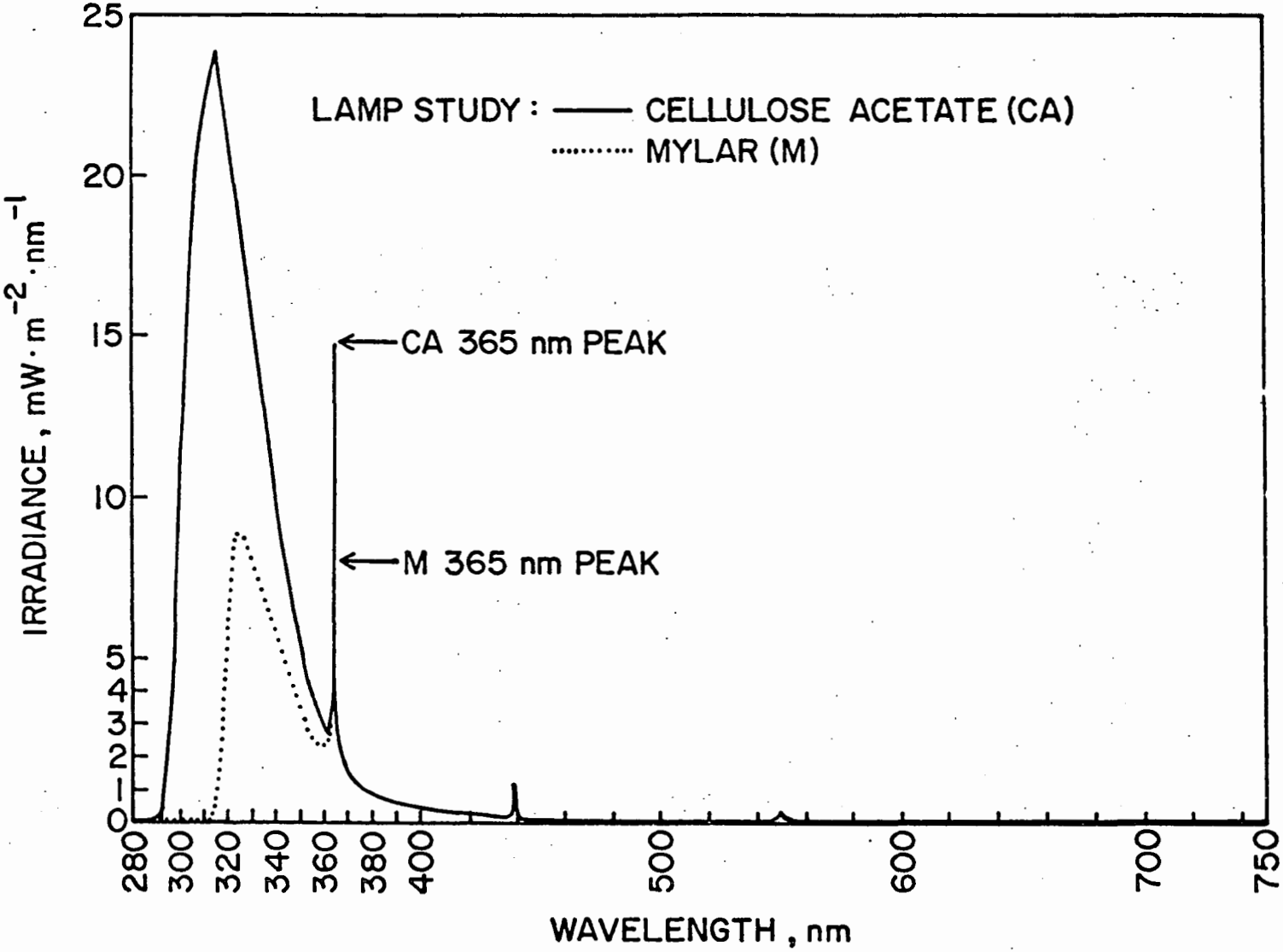

Figure 8. Comparison of cellulose acetate filtered and Mylar filtered FS40 lamp spectra. Measurements made with the BARC Instrumentation Laboratory IRL Spec. D spectroradiometer and ISCO spectroradiometer at night.

consisting of lamps filtered with cellulose acetate, lamps filtered with Mylar and lamp reflectors without lamps. Each plot was split into subplots of UV-B irradiance levels and/or position depending on the distance of the subplot from the lamps or reflectors. There were two replications of each of the three treatments for each of the four species. Regression analyses were performed on the interaction means when the interaction was found significant at the 5% level of probability.

Potato tubers were planted on June 6, wheat on June 18, radish and peas on June 29. Tuber "seed" consisted of whole potatoes each of which weighed 55 g $\pm$ 5 g. Containers were moved under lamp or exclusion structures just prior to emergence which occurred for all species during the last week of June and the first week in July. Duration of exposure and parameters measured are in the appendix. Over 15,000 individual plant measurements were made, including 71 parameters. The last plant observations were made on August 13. A diagram of the entire plot area is in Figure 9.

RESULTS AND DISCUSSION

Exclusion Study - The solar UV-B spectra of Beltsville (BARC) at 31 m elevation and the Colorado 3000 m site are compared in Figure 10. There was a marked increase in irradiance over the entire UV-B range in Colorado relative to Beltsville. These preliminary sepctra suggest that the Colorado site compared to the Beltsville site may have 2.7 times more biologically effective UV-B radiation. The weighted irradiance values were 8.3 and 3.1 mW/M^2 for Colorado and Beltsville, respectively. If these high UV-B

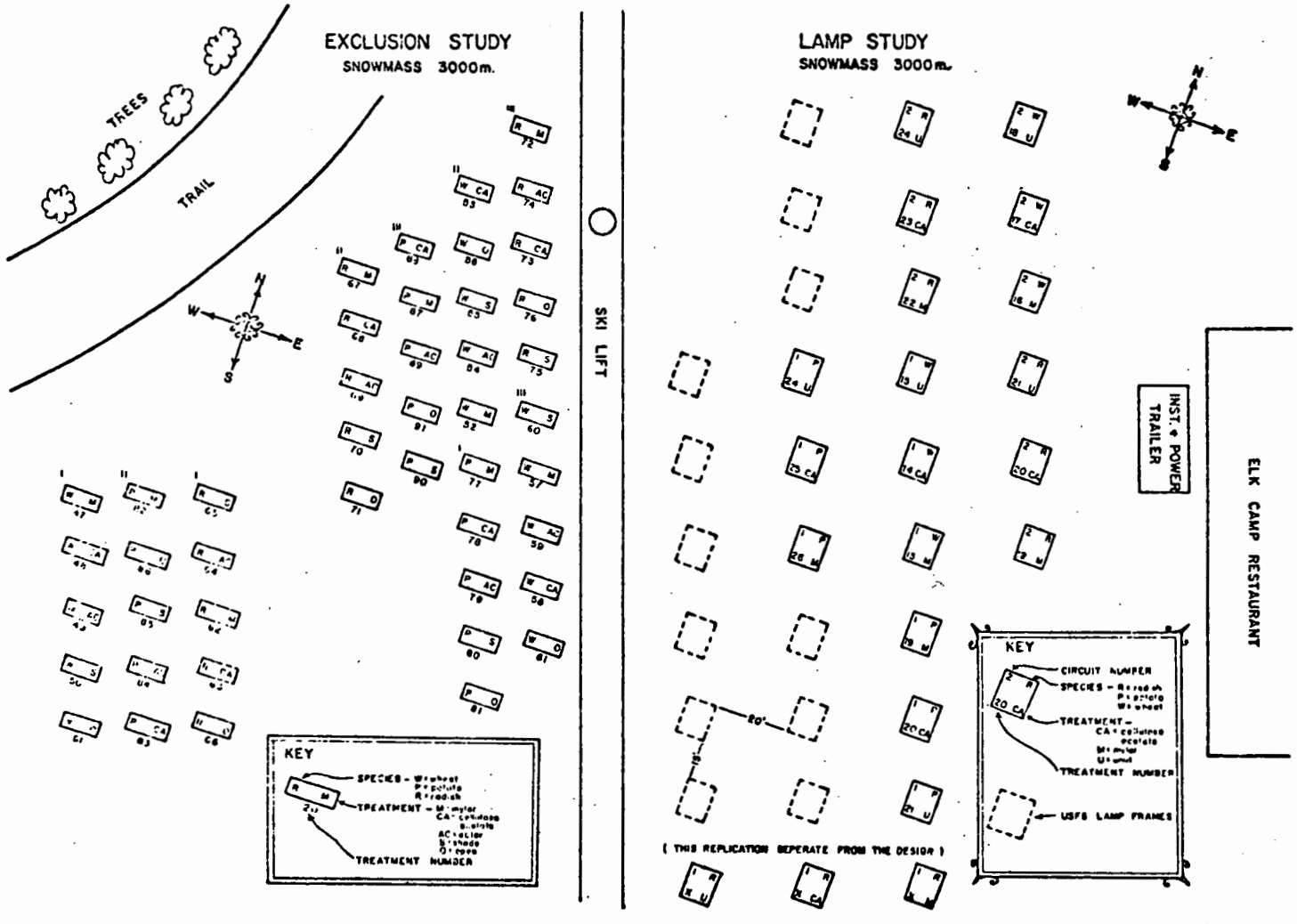

Figure 9. Experimental area depicting lamp and exclusion structure positioning at 3000 m elevation.

radiation levels can be verified in planned future study then exclusion experiments employing filters like cellulose acetate, Mylar and Aclar can easily be used to simulate 20% reductions in stratospheric ozone for low elevation regions.

In the exclusion study comparisons between cellulose acetate, Aclar and Mylar were made. In such an experiment effects which are to be attributed to UV-B radiation must be evident under cellulose acetate and Aclar filtration where natural UV-B radiation is present. Such UV-B radiation effects should not appear under Mylar filtration where no UV-B radiation was present. The only result showing a difference between the two types of filter treatments which could be attributed to UV-B radiation was wheat plant height indicated in Figure 11. All other measurements on wheat and other crops showed no significant difference attributable to UV-B radiation level. In general, sample homogeniety was good with little variability yet there was little detectable difference among the three filter treatments whether attributable to UV-B radiation or not (see appendix for more detail on other crops and parameters). Note that wheat, having increased UV-B radiation under cellulose acetate or Aclar, tended to be shorter in stature relative to the zero UV-B radiation control plants under Mylar. This effect was observed only in the wheat growth at 14 and 31 days. Mixed results not wholly attributable to UV-B radiation level were obtained after 50 days. Comparison of open and 26% shade treatments also showed a relative stunting of growth in the open for wheat. This effect was clear throughout the growth of the plants Figure 12.

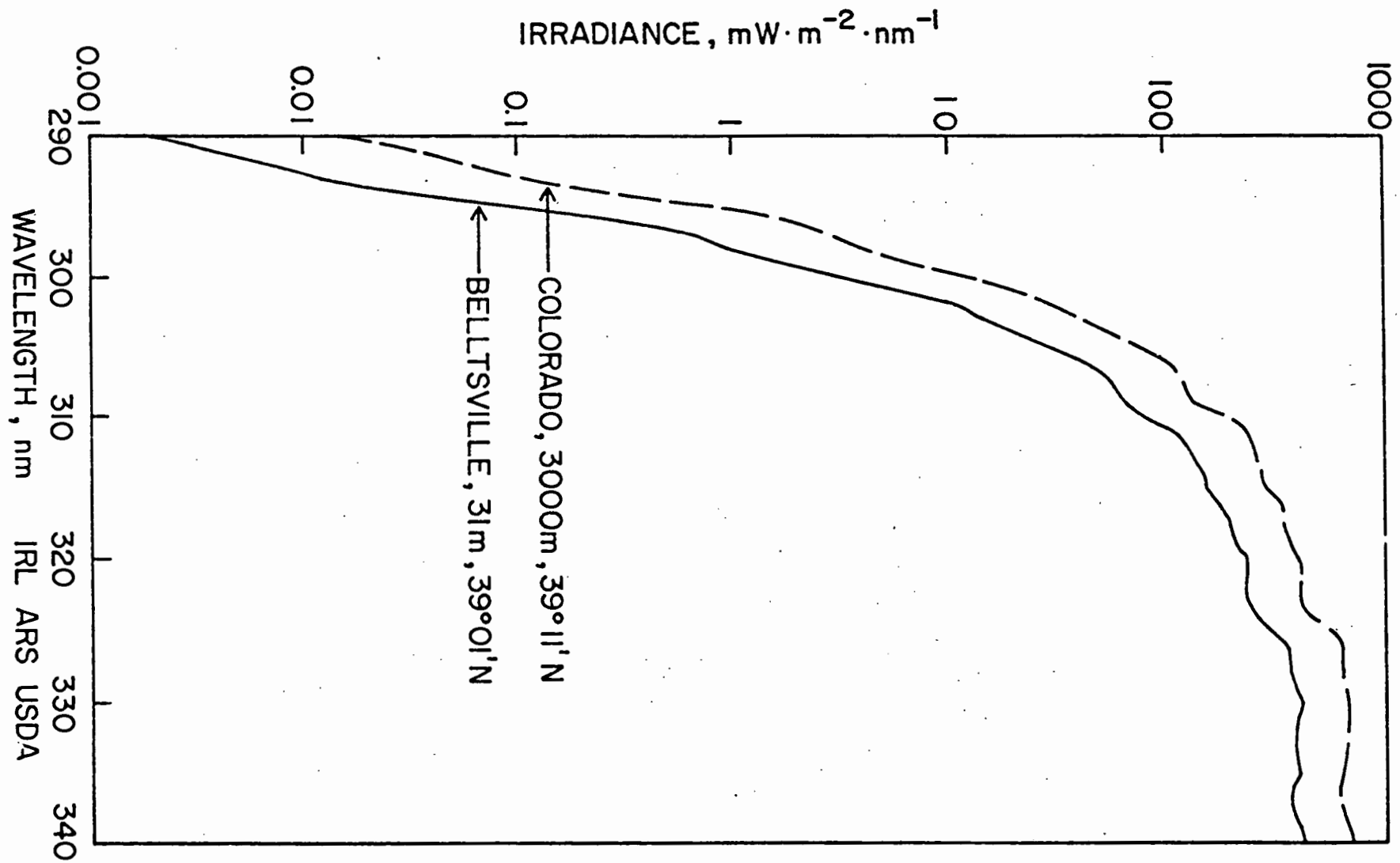

Figure 10. Comparison of solar UV-B spectra on two different "bright" days in August at Beltsville and the Colorado site measured with the same IRL Spec. D spectroradiometer.

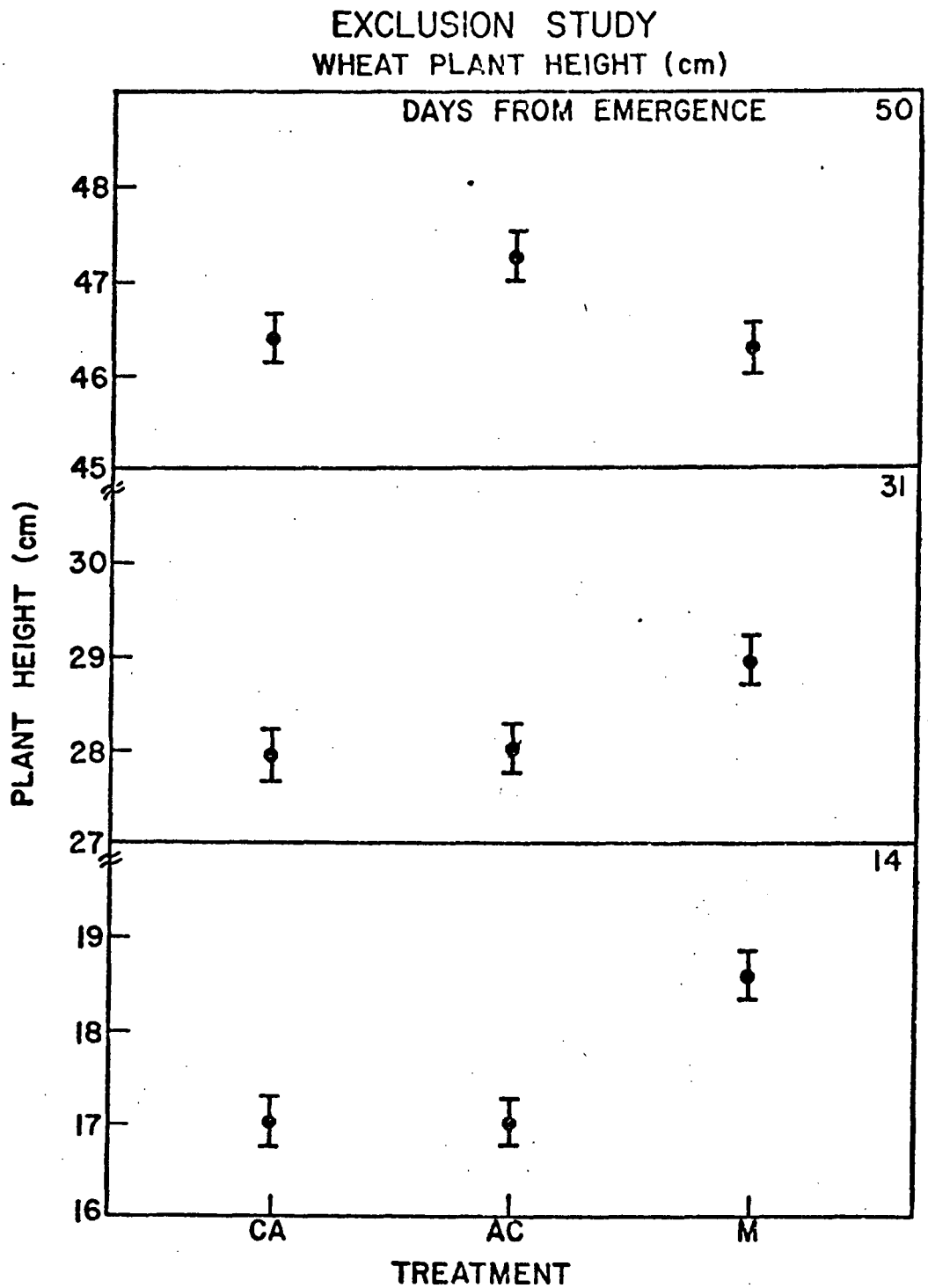

Figure 11. Wheat plant height as a function of UV-B exclusion (M = Mylar) and UV-B transmission (CA = cellulose acetate and AC = Aclar).

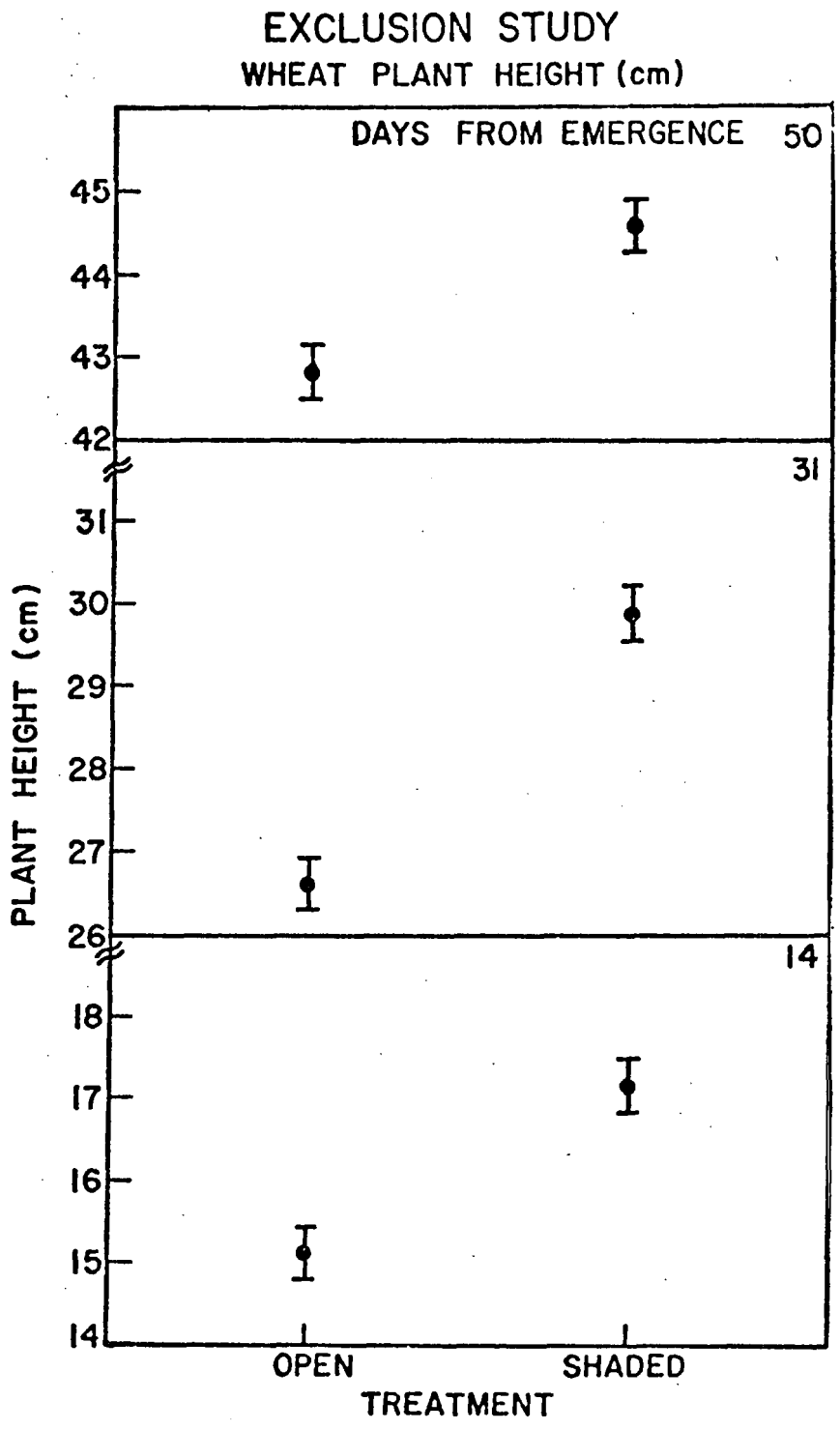

Figure 12. Wheat plant height in the open relative to 26% shade equivalent to sea level insolation.

However, again these results are unique to the wheat and were not obtained for the other species. Such results may be attributable to stunting effects of the extra UV-B radiation in the open; however, the differences are small. Of the many measurements made, no significant differences could be found with the other crop species.

A major confounding factor in exclusion studies such as these is caused by temperature differences under the different filters or shade treatments. Such temperature differences can cause plant changes which might be misinterpreted to be UV-B radiation effects. Therefore, careful temperature measurements were made and the summarized results are in TABLE 2 (more detailed results are in the appendix TABLE A-1). The average daytime temperatures of plants under 26% shade was slightly lower during the day but also slightly warmer at night. The average daytime temperatures of the plants under Aclar and cellulose acetate filtration (the UV-B radiation transmitters) were slightly lower than the plant temperatures under Mylar filtration. Otherwise the temperatures were generally similar. The total solar radiation levels under the three filter treatments, open and shade are in TABLE 2. Note that under the filter treatments the total radiation level is between 90 and 100% of the open control. Aclar is the best transmitter. Note also that these filters must be effective transmitters of the long wavelength radiation which normally accounts for 50% of the total solar radiation. The solar spectra under the three filters are Figures 4 and 5. They indicate that the UV-B transmission of cellulose acetate and Aclar is essentially the same from 280 to 750 nm

and that the Mylar cuts out the UV-B and reduces the visible radiation to some extent.

Lamp study - As a general statement there was very little or no response of plants growing under lamps generating UV-B radiation. Certain sets of data are selected to illustrate this lack of response in the wheat lamp study (Figures 13 and 14). Note for example, at 204 mW/m^2 (unweighted between 280 and 320 nm) in Figures 13 and 14 there was no difference in wheat foliage dry weight or plant height throughout the observation period. For potato foliage dry weight there was no dependence on UV-B radiation level (Figure 15). In fact, the only effect observed was with the no lamp control treatment which showed less dry weight production under the positions that would have had higher irradiation of lamps had they been present! Other examples of no or small effects can be found in the appendix tables (note particularly TABLES WL-2 and PL-5). In any case the effect is small. The only visible symptoms of UV-B radiation injury were observed for radish when the cellulose acetate filters were removed from the lamps and the plants were irradiated with strong 254 nm radiation. In such radish plants cotyledon folding was observed soon after emergence.

The above results lead one to suspect that our lamps did not give enough UV-B irradiation to constitute a 40% enhancement of UV-B radiation. A number of studies were conducted to check this point. Figure 7 shows the lamp irradiance with cellulose acetate filtration at various plant positions under the lamps. The results shows that a gradation of irradiance (including UV-B radiation) was present and the radiation level

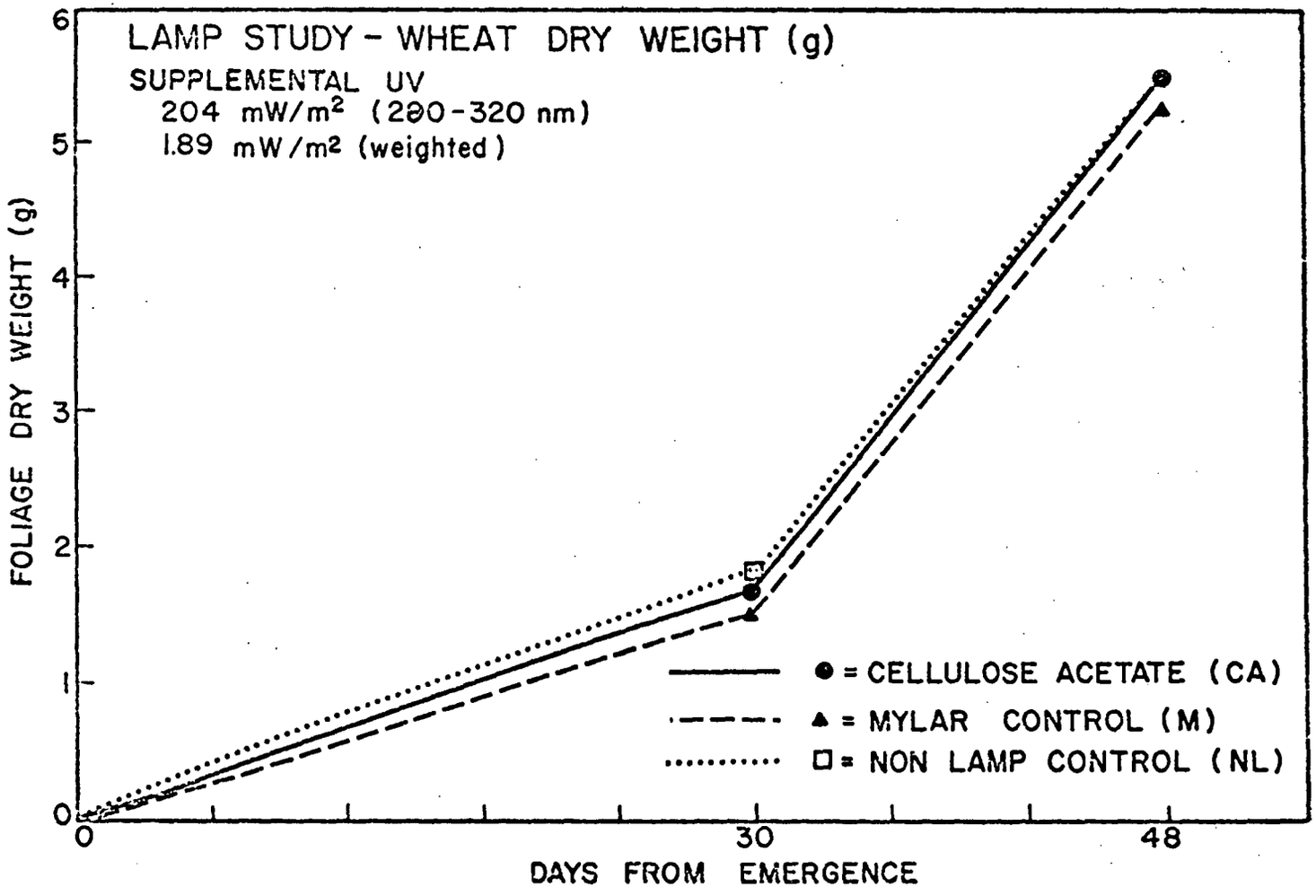

Figure 13. Comparison of the three lamp treatment responses with broad band UV-B irradiance held constant. Dry weights are the sum of the two plants.

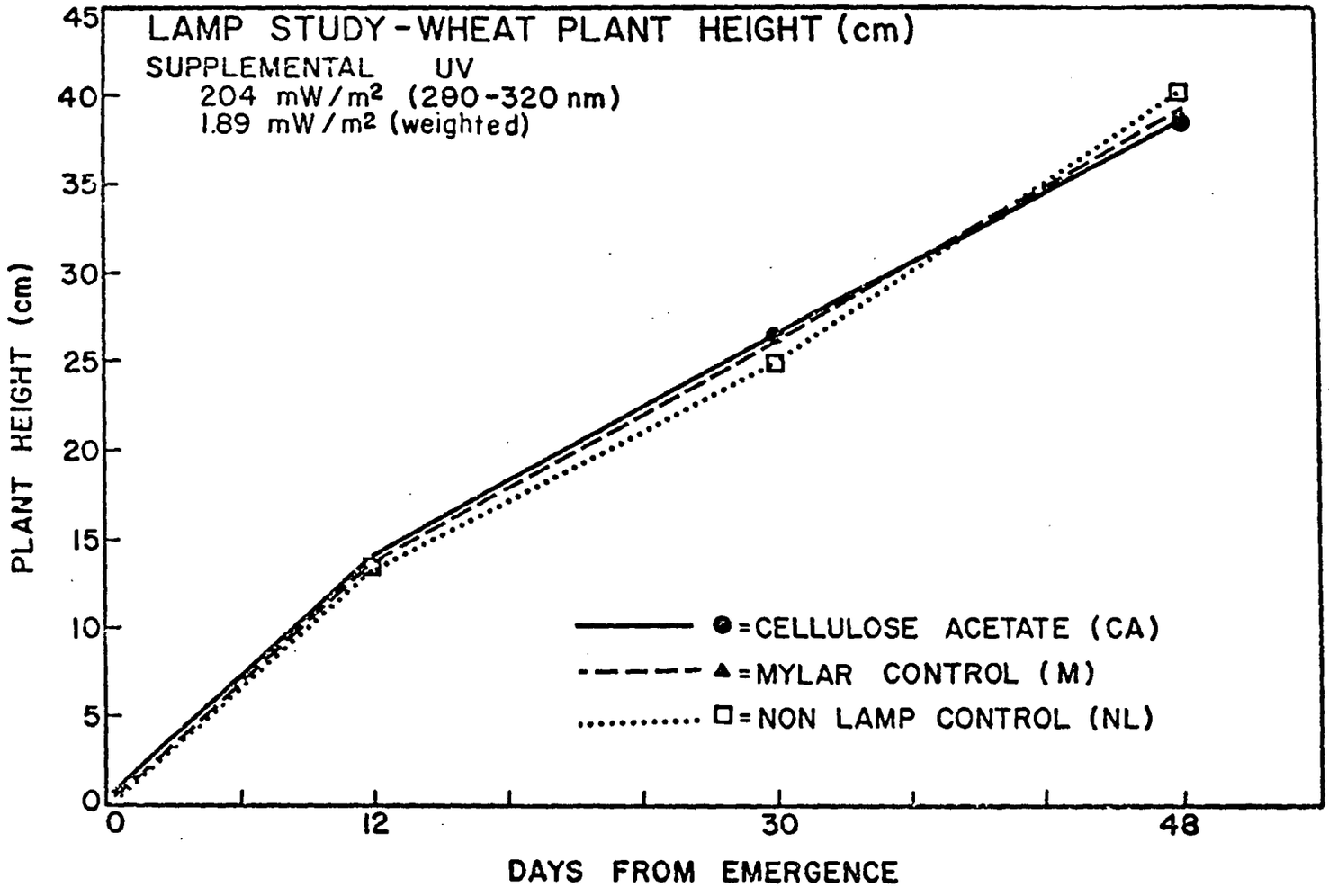

Figure 14. Comparison of the three lamp treatments responses with broad band UV-B irradiance held constant.

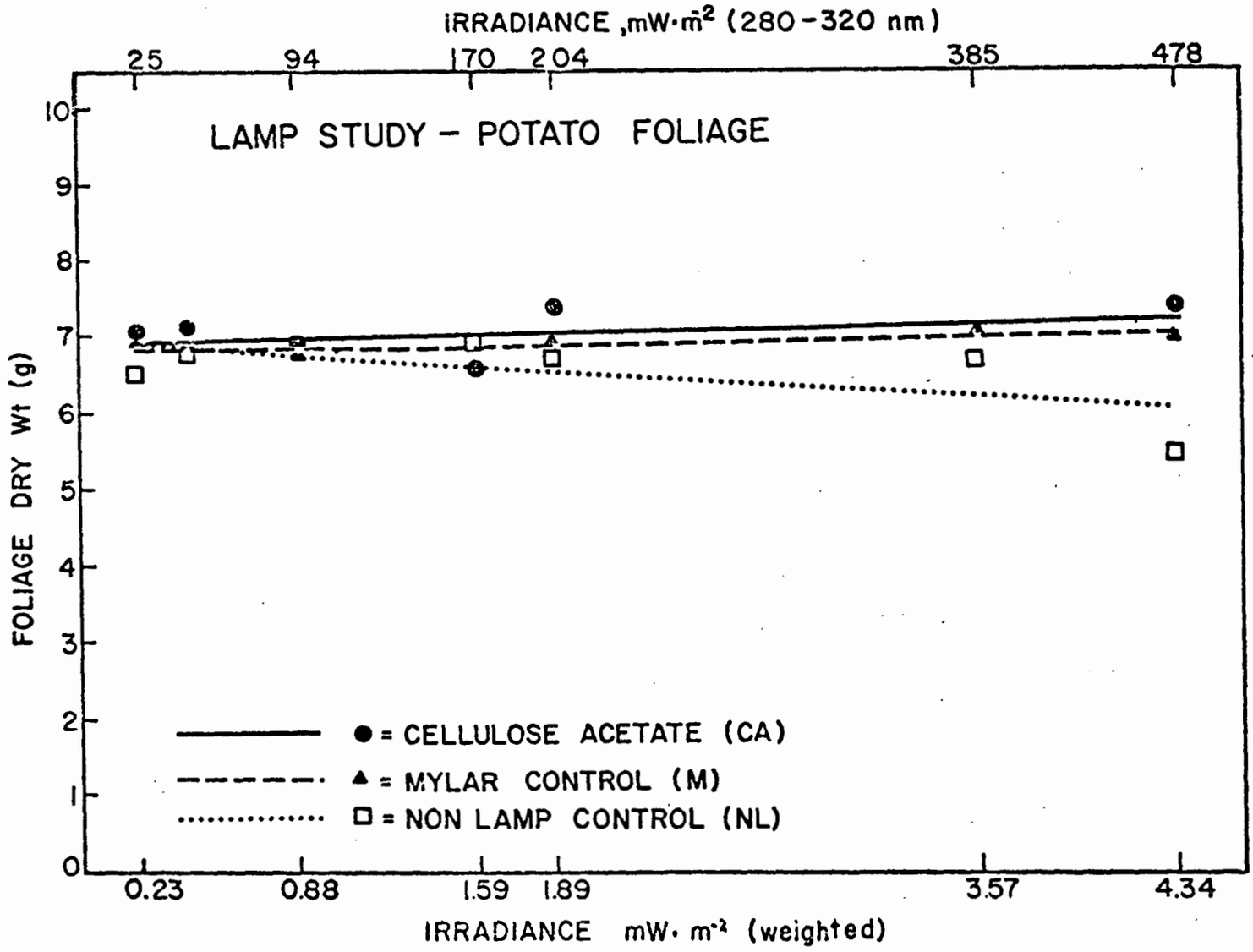

Figure 15. Comparison of interaction means fitted to linear models, 294 hrs lamp exposure during 49 days.

decreased with increasing diagonal distance from the lamps. The irradiation magnitude observed is also the expected magnitude to cause at least a 40% UV-B radiation enhancement (more probably a 160% enhancement directly under the lamps). In Figure 8 the cellulose acetate and Mylar filtered FS40 lamp spectra are presented for the highest plant irradiation position under the lamps. Note the general absence of radiation in the UV-A-PAR region (320-700 nm). Based on this it seems unlikely the lamps should induce additional photoreactivation etc. in the irradiated plants. However, compare the Colorado solar (natural) UV-B spectrum with the lamp spectra, i.e. compare Figure 5 with Figure 7. Such preliminary data suggests that the UV-B irradiance from the sun is overwhelming. Considerably more study at high elevation will have to be conducted.

There was an additional complicating factor in these lamp studies. Regardless of treatment there was a growth effect that could be detected under the lamp fixtures which was probably caused by the fixture microclimate. For example in wheat it was evident after the first set of observations taken 14 days after emergence that plant height was a function of position under the lamp fixtures Figure 16 . Figure 16 presents regression lines as a result of least squares fit to a "power" model. The power model accounted for 71%, 16%, and 60% of the variability in wheat height with regard to "unlit" (non-lamp), cellulose acetate, and Mylar filtered lamps, respectively. A linear model gave a somewhat higher R^2 for the UV-B transmitter, cellulose acetate. However, in either case the relationship between plant height and diagonal distance was negative

(inverse) while plant height and UV-B irradiance was positive, i.e. better growth in the positions subject to higher UV-B radiation. In any case, the effect illustrated in Figure 16 is very small. Since this occurred under all three treatments, the effect might be due to the protection of the centrally located plants from the primary UV-B source, the sun.

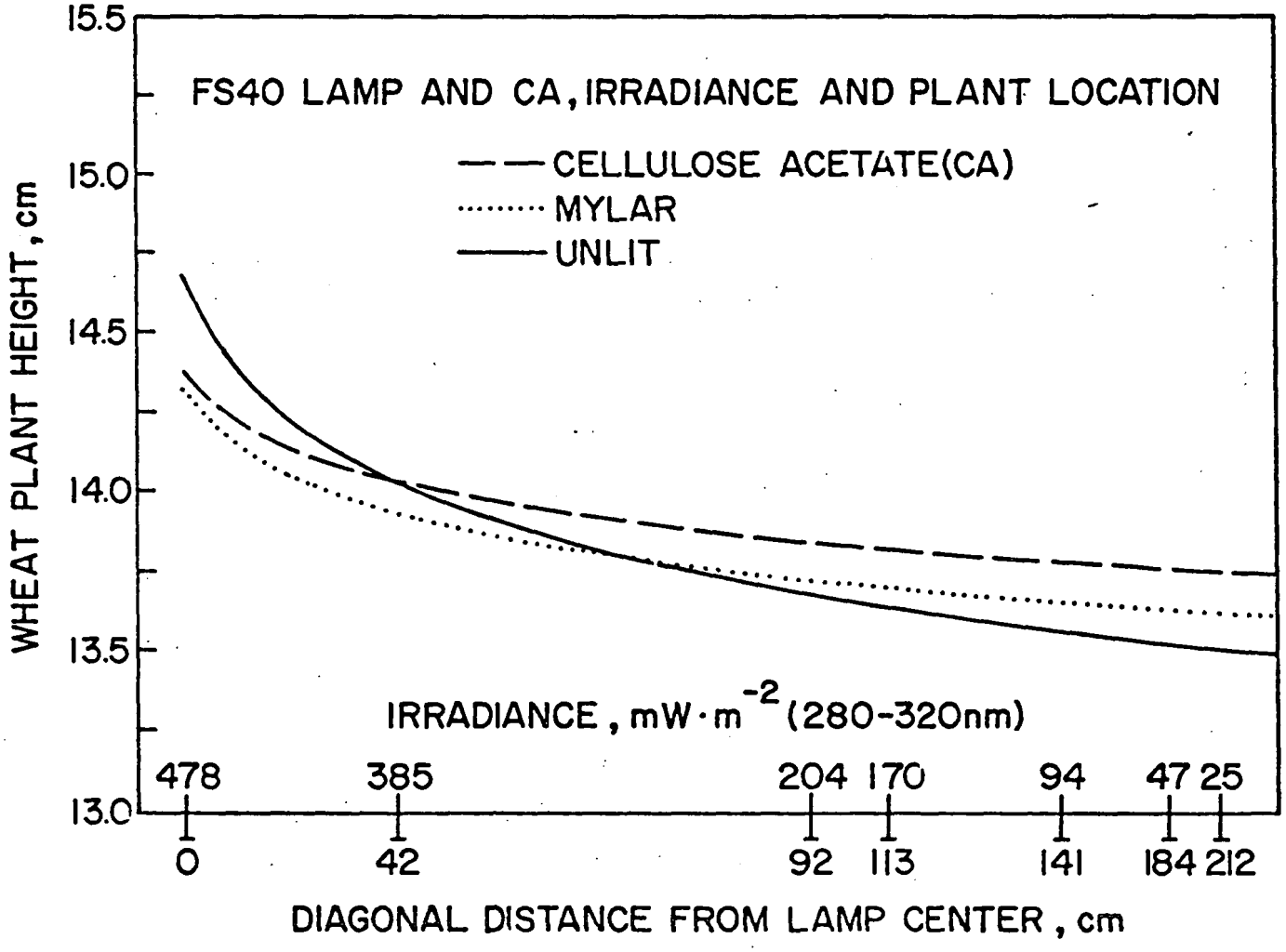

Figure 16. Wheat plant height as a function of diagonal distance from center of lamp fixtures (plant plane) and irradiance. Measurements made with the IRL Spec. D, spectroradiometer at night.

Of the 71 parameters evaluated in our two field studies including over 15,000 measurements on four crop species, only suppression of wheat vertical growth in exclusion studies could be considered a real response to solar UV-B irradiance level that corresponds to a stratospheric ozone depletion of 20%. Economic concern based on this study seems unwarranted. Indeed "short stem" wheat is popular and has constituted part of the "green revolution" popular in some areas of the globe.

The lamp study was carried out using a similar field procedure to that described by Sisson and Caldwell (1975) in that solar irradiance was supplemented when the solar altitude exceeded 40°; Figure 2. During this period the sun would contribute greater than 80% of each days's UV-B irradiance (Caldwell, 1968). As it happened no clear cut response was noted in this study. Explanations might include the fact that biologically effective solar UV-B was overwhelming (Figure 2) relative to biologically effective lamp UV-B. Another explanation is that some microclimate (such as shading) under the lamp fixtures protected the plants and counteracted the adverse effect of UV-B radiation. Also the high UV-A-PAR radiation typical of this high elevation site may have contributed to strong photoreactivation or provided other means of repair of UV-B radiation damage. Another factor possibly having some bearing on the outcome of the lamp study may be the fact that the 4 crop species employed are considered cool season species and may be in some way resistant to UV-B injury. Cotton a decidedly warm season crop appears sensitive to UV-B injury at least in the seedling stage of

growth (Krizek 1975, Carns and Christiansen 1975).

No visual evidence such as lesions (Caldwell, 1968), browning (Moore, 1971), red pigmentation, glazing or leaf curviture (Caldwell, 1971) was noted with regard to any of the four species studied in this test. Particular attention was paid to the center lamp position (4.34 $mW.m^{-2}$) lamp contribution at 280-320 nm and the open treatment (8.28 $mW.m^{-2}$) at 280-320 nm. The preceeding are weighted values related to UV-B Beltsville Sun Equivalents.

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APPENDIX

Various experiments were conducted which were preliminary or provide additional technical information. Such results are collected here without detailed analysis. Results collected include:

1) The spectrum of Aclar (Figure A1)
2) The UV-B radiation output from FS40 lamps filtered with cellulose acetate as a function of time energized and lamp temperature (Figure A-2 and A-3).
3) A potential solar UV-B collector and irradiator which could be used to enhance solar UV-B radiation without the use of filtered lamps (Figure A-4).
4) Detailed temperature analysis for plants in exclusion study (TABLE A-1).
5) Preliminary results for wheat leaf viability tests for UV-B irradiated leaves. The test involved the use of elctrolyte leakage as a measure of leaf tissue cell lysis (TABLE A-2).
6) Tabulated technical data for exclusion studies on wheat, potato, and radish (TABLES WE-1; PE-1; RE-1).
7) Tabulated technical data for various FS40 lamp irradiations on wheat (TABLES WL-1 to WL-5), potato (TABLES PL-1 to PL-6), radish (TABLES RL-1 to RL-6), and pea (TABLES PEL-1 to PEL-3).

Information developed during our studies would indicate that perhaps cellulose acetate should be solarized 8 hours prior to use as FS40 lamp filters. Since lamp output begins to decline at 6^{o} C ambient temperature,

the mountain researcher should measure UV-B irradiance in situ at the beginning and end of the illumination period. Fortunately, in our lamp study, temperatures were above 6° C at the beginning and end of the illumination period. Aclar appears to be a good "window" for use in exclusion studies, however, 1.5 mil film used in our studies does not have a comfortable safety margin with regard to tearing. Five mil material is suggested.

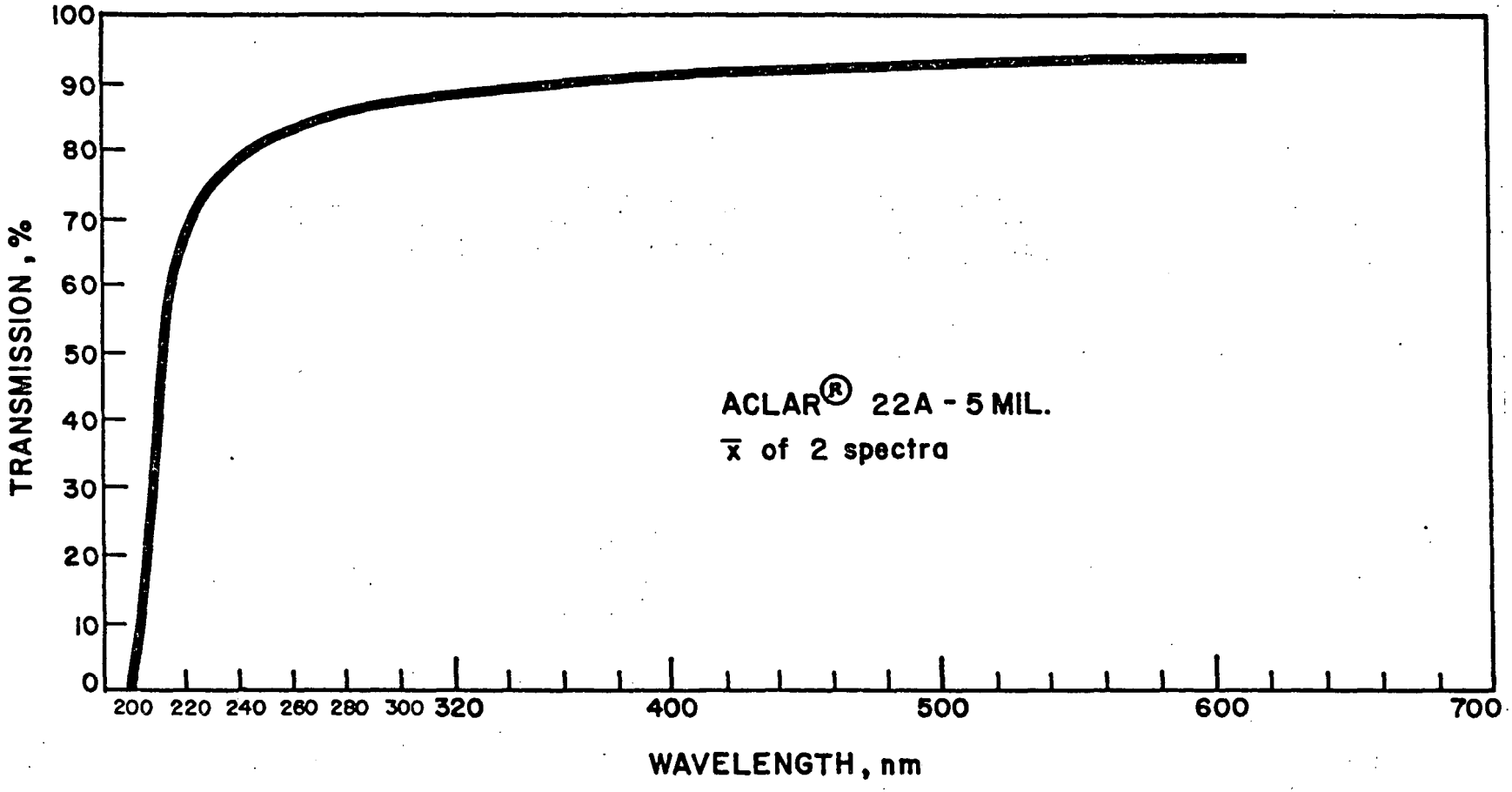


Figure A-1. Laboratory spectra developed with Perkin and Elmer spectrophotometer. Aclar is a flexible thermoplastic film manufactured by Allied Chemical Corporation from fluorinated-chlorinated resins.

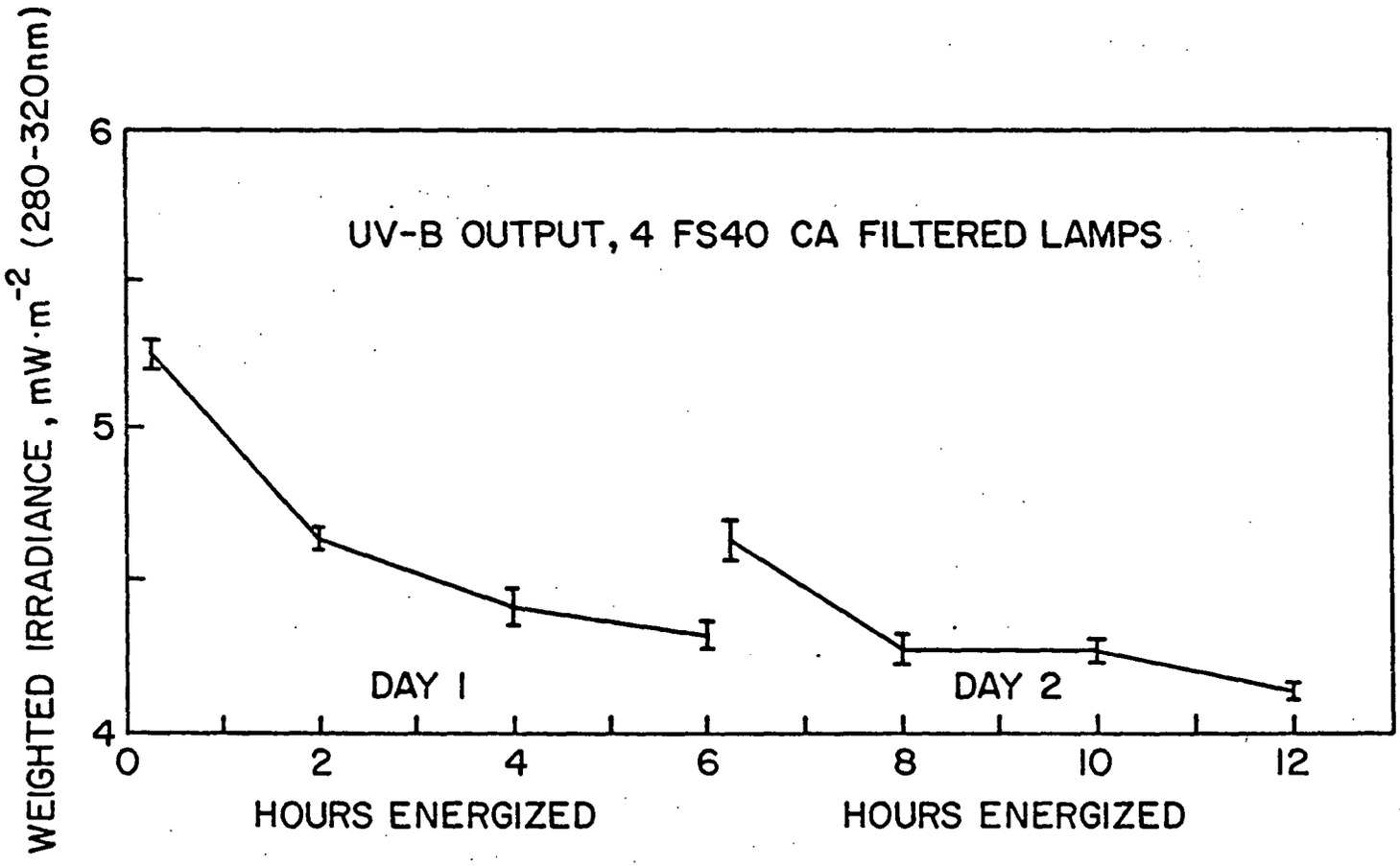
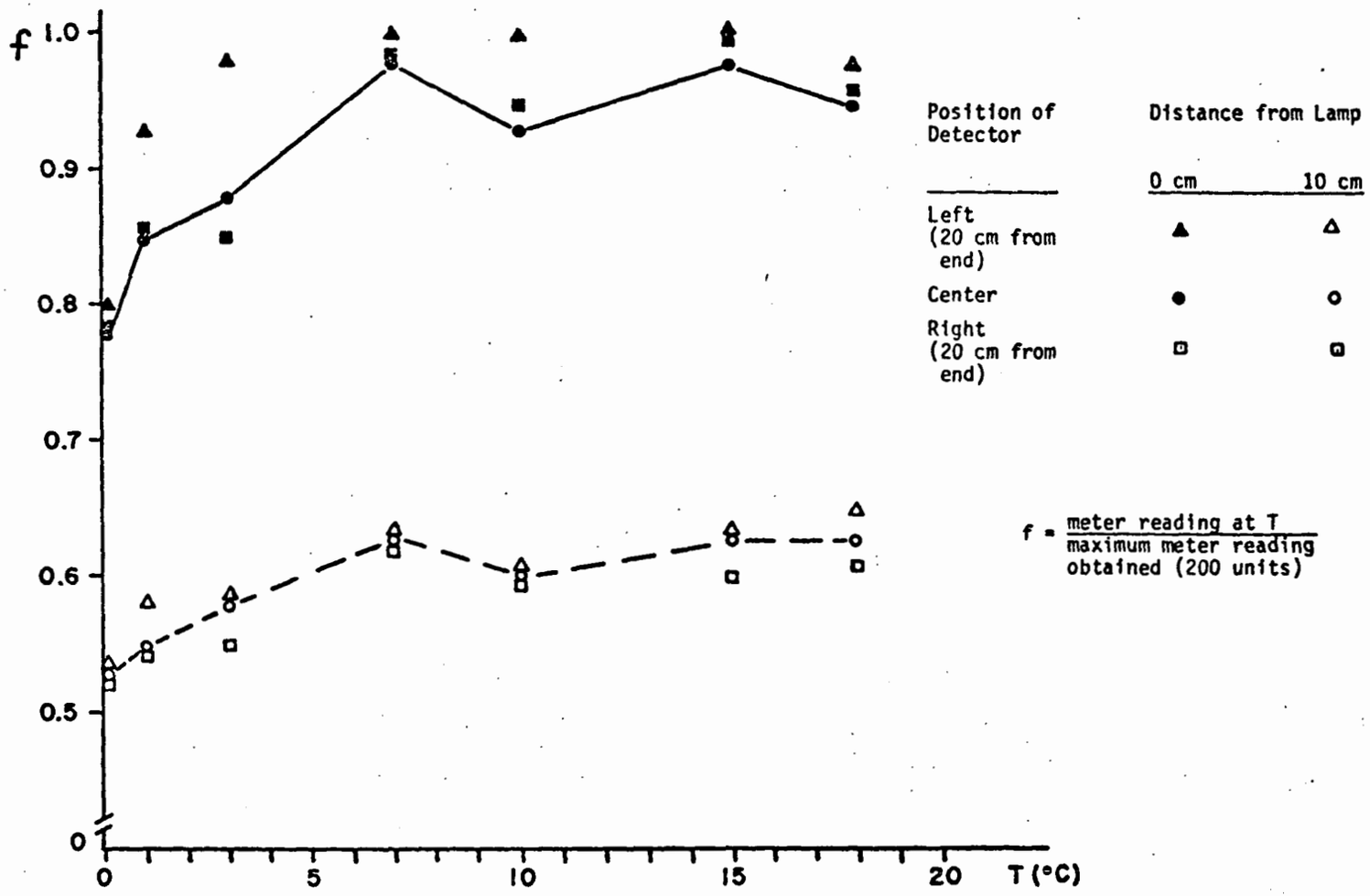


Figure A-2. Variability in broad band UV-B irradiance for 2, 6 hour periods including 7, 4-lamp sets. Prior to the test lamps were operated for 100 hrs. and cellulose acetate was solarized for 6 hrs.

Lamps were operated for approximately 200 hours prior to test.
A G.E. "214S ultraviolet meter" was used.



Relative Intensity Output, f, of FS40 Lamp as a Function of Temperature, T (°C). A Reflector was not used. Only points for lamp center measurements are connected.

Figure A-3.

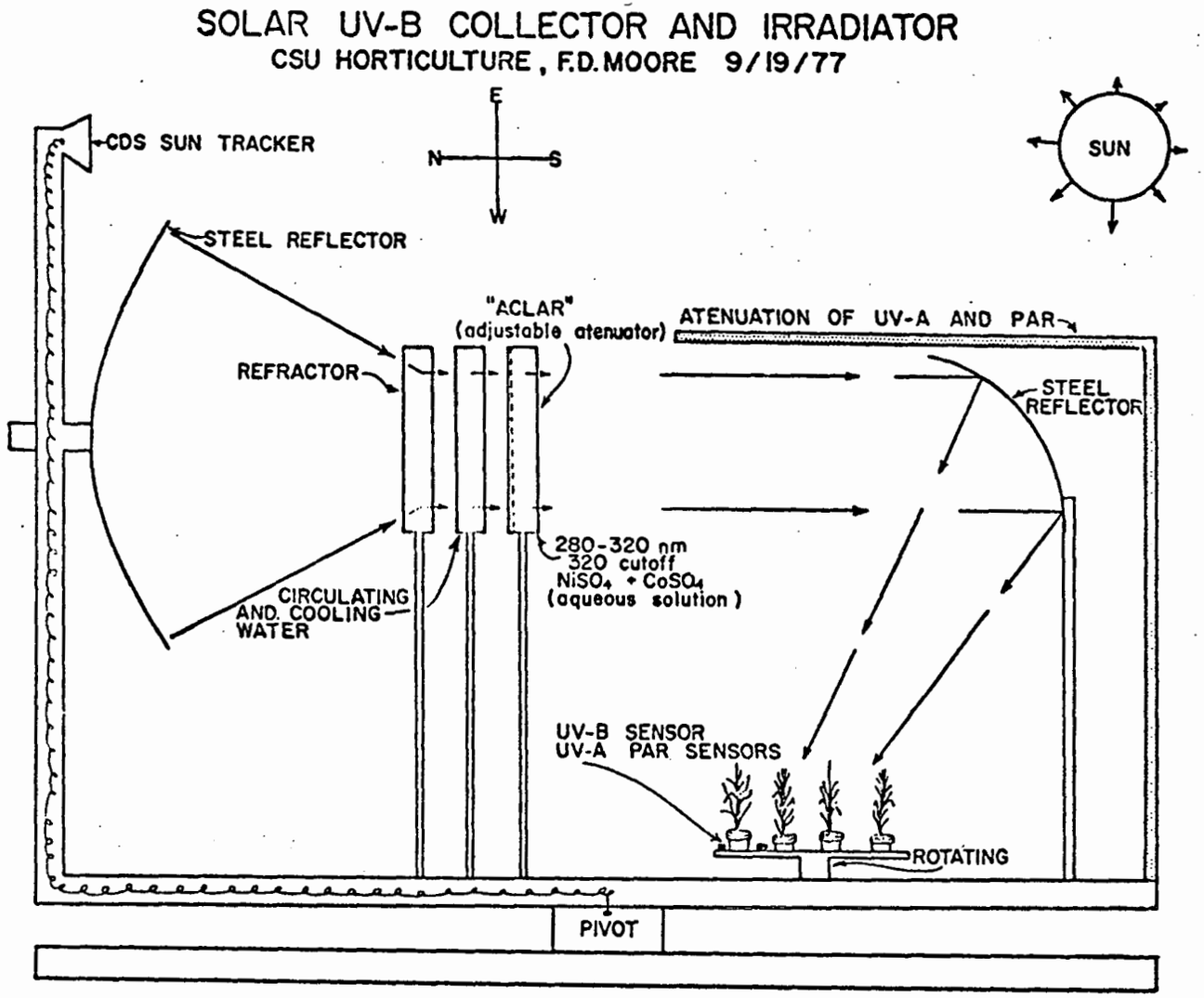


Figure A-4. Design of a potential solar UV-B research tool.

TABLE A-1. EXCLUSION STUDY: AIR, PLANT, AND NATIVE SOIL TEMPERATURES, POTATO[1]

Solar filter		24 hr mean temperatures (°C)		
		air	plant	soil
None (open)	max	20.8	19.0	24.5
	mean	12.9	12.7	16.2
	min	5.5	7.0	8.0
Cellulose acetate	max	21.8	19.8	30.5
	mean	13.6	14.1	18.8
	min	6.0	8.5	10.5
Aclar	max	20.6 [21.20][2]	21.5 [20.65]	28.0 [29.25]
	mean	12.9 [13.25]	14.2 [14.15]	17.3 [18.05]
	min	5.8 [5.90]	8.3 [8.40]	9.8 [10.15]
Mylar	max	21.3	21.5	29.5
	mean	13.1	14.3	18.9
	min	5.8	8.3	10.5
Shade	max	21.1	18.0	24.5
	mean	12.7	12.7	16.0
	min	5.4	7.5	9.0

[1] Temperatures were measured continuously for a period of one hour every third hour (8 times for each of two 24 hr periods). Precision is $\pm$ 0.4°C.

[2] Values in boxes are means of both UV-B transmitters to be compared with Mylar.

TABLE A-2. RELATIVE WHEAT LEAF ELECTROLYTE LEAKAGE [1,2]

Evaluation	Samples showing visual injury (% electrolytes leaked)	Samples appearing healthy (% electrolytes leaked)
1	29	56
2	17	13
3	57	12
4	32	37
5	27	13
6	31	21
mean	32	25

1. Results in the two columns were not significantly different at even the 10% level (unpaired t test).

2. Relative electrolyte leakage was $x = 7 \pm 1.5\%$ standard deviation.

TABLE WE-1. MEANS AND MEAN SQUARES FROM EXCLUSION EXPERIMENT, WHEAT

	FRESH WT	DRY WT	FRESH WT	DRY WT	PLANT HT	PLANT HT	PLANT HT	HEAD LENGTH	HEADS	TILLERS
Exposure (hrs, days)	186,31	186,31	300,50	300,50	84,14	186,31	300,50	300,50	300,50	300,50
Units	g	g	g	g	cm	cm	cm	cm	%	no/plant
Open	3.88a[1]	0.71	8.30	2.49	15.1c	26.6d	42.8d	1.7c	60.0b	2.4a
Shade	3.97a	0.67	8.30	2.39	17.2b	29.9a	44.6c	1.2c	45.2c	2.0c
CA	3.58b	0.79	8.26	2.46	17.0b	27.9c	46.4b	3.7a	78.0a	2.2b
AC	3.58b	0.66	8.28	2.42	17.0b	28.0c	47.3a	2.5b	71.2a	2.0bc
M (-UVB)	3.78ab	0.72	8.07	2.42	18.6a	28.9b	46.3b	3.9a	79.7a	2.0b
Treatment										
MS	2.98**	0.008	0.472	0.004	73.1**	210.5**	304.3**	138.91**	19766.1**	2.185**
df	4	4	4	4	4	4	4	4	4	4
Error										
MS	0.81	0.011	1.895	0.021	1.8	7.5	8.2	3.59	942	0.271
df	465	8	225	8	225	705	465	465	465	465
Total observation	480	15	240	15	240	720	480	480	480	480
Observations/$\bar{x}$	96	3	48	3	48	144	96	96	96	96

[1]Column means separated by LSD, 5% level. Means followed by the same letter are not significantly different

TABLE PE-1. MEANS AND MEAN SQUARES FROM EXCLUSION EXPERIMENT, POTATO

	FOLIAGE FW g	FOLIAGE DW g	TUBER FW g	TUBER DW g	FW/TUBER g	DW/TUBER g	FOL FW/ TUB FW	FOL DW/ TUB DW	TUBER NO	STEM NO	TUBERS/ STEM
Open	67.81c[1]	7.35	29.54	14.21	14.21	2.76	0.45b	0.25	11.7	8.8	1.5
Shade	80.73a	7.79	28.18	14.30	14.30	2.70	0.54a	0.28	11.3	8.3	1.4
CA	71.59bc	7.72	29.05	12.12	12.12	2.41	0.49ab	0.27	12.7	8.6	1.5
AC	73.70abc	7.62	28.44	13.98	13.98	2.59	0.51a	0.27	11.2	8.8	1.4
M(-UVB)	76.22ab	7.93	28.21	14.52	14.52	2.83	0.53a	0.28	11.3	9.1	1.3
Treatment											
MS	354.00*	0.7192	188.84	5.309	14.17	0.3921	0.0206**	0.0029	5.626	1.113	0.1821
df	4	4	4	4	4	4	4	4	4	4	4
Error											
MS	118.79	0.8441	123.04	5.746	20.51	0.7444	0.0048	0.0012	11.679	6.993	0.3071
df	60	60	60	60	60	60	60	60	60	60	60
Total observations	75	75	75	75	75	75	75	75	75	75	75
Observations/ $\bar{x}$	15	15	15	15	15	15	15	15	15	15	15

[1]Column means separated by LSD, 5% level. Means followed by the same letter are not significantly different.

TABLE RE-1. MEANS AND MEAN SQUARES FROM EXCLUSION EXPERIMENT, RADISH.

	FOLIAGE FW	FOLIAGE DW	FOLIAGE FW	FOLIAGE DW	ROOT FW	ROOT DW	ROOT FW	ROOT DW	FOLIAGE FW/ROOT FW	FOLIAGE DW/ROOT DW	FOLIAGE FW/ROOT FW	FOLIAGE DW/ROOT DW
Exposure (hrs.,days)	144,24	144,24	216,36	216,36	144,24	144,24	216,36	216,36	144,24	144,24	216,36	216,36
Units	g	g	g	g	g	g	g	g	g	g	g	g
Open	2.80a[1]	0.35	4.66b	0.62b	4.34a	0.29	11.52b	0.76b	1.72	1.22	0.46	0.83
Shade	2.47b	0.28	4.20b	0.54b	3.04b	0.19	9.18c	0.62c	1.11	1.50	0.50	0.88
CA	2.71ab	0.33	5.60a	0.79a	3.88a	0.25	14.83a	0.95a	0.76	1.33	0.43	0.84
AC	2.61ab	0.31	5.39a	0.76a	3.83a	0.23	14.21a	0.90ab	0.77	1.48	0.40	0.84
M(-UVB)	2.86a	0.35	5.44a	0.73a	4.40a	0.29	13.20ab	0.89ab	0.93	1.22	0.44	0.83
Treatment MS	0.9881*	0.0026	15.17**	0.0341**	12.48**	0.0056	218.6**	0.0537**	6.66	0.0573	0.055	0.0016
df	4	4	4	4	4	4	4	4	4	4	4	4
Error MS	0.3884	0.0009	1.7357	0.0034	2.168	0.0018	19.8	0.0060	7.57	0.0361	0.025	0.0085
df	195	8	195	8	195	8	195	8	195	8	195	8
Total observations	210	15	210	15	210	15	210	15	210	15	210	15
Observations/$\bar{x}$	42	3	42	3	42	3	42	3	42	3	42	3

[1]Column means separated by LSD, 5% level. Means followed by the same letter are not significantly different.

TABLE WL-1. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT WHEAT FOLIAGE, WT, LAMP EXPOSURE 192 HRS DURING 32 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	4.2	3.7	4.2	0.91	0.76	0.92
3.57	385	3.8	4.0	4.0	0.82	0.85	0.85
2.52	273	4.2	3.8	4.4	0.85	0.78	0.93
1.89	204	4.0	4.0	3.8	0.84	0.81	0.83
1.59	170	3.8	3.8	4.1	0.82	0.80	0.88
1.12	123	3.8	4.2	4.4	0.84	0.87	0.96
0.88	94	3.9	4.0	4.1	0.82	0.82	0.80
0.65	85	3.6	3.6	3.5	0.77	0.75	0.76
0.44	47	4.1	3.9	3.7	0.89	0.82	0.81
0.23	25	4.2	4.1	3.7	0.90	0.86	0.81
$\pm$UVB means		4.0	3.9	4.0	0.85	0.81	0.85

Source	df.	Mean squares: Fresh wt	Mean squares: Dry wt
$\pm$ UVB	2	0.20	0.0376
Error a	2	6.70	0.1695
Irradiance	9	1.21	0.0289
Interaction	18	0.73	0.0169
Error b	27	1.27	0.0163

Fresh weight total observations, 480; $\pm$ UVB, 160; irradiance, 16

Dry weight total observations; 240; $\pm$ UVB, 80; irradiance, 8

TABLE WL-2. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT WHEAT FOLIAGE WT. LAMP EXPOSURE 300 HRS DURING 50 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	7.9	8.6	9.0	2.5	2.5	2.8
3.57	385	8.2	8.2	9.4	2.5	2.6	2.6
2.52	273	9.0	8.4	9.1	2.8	2.7	2.8
1.89	204	8.7	9.3	9.3	2.7	2.9	2.9
1.59	170	9.1	8.6	9.4	2.8	2.9	2.9
1.12	123	8.5	8.5	9.0	2.6	2.8	2.8
0.88	94	8.2	8.9	9.6	2.6	2.8	3.0
0.65	85	9.3	8.3	9.0	2.9	2.6	2.8
0.44	47	8.8	8.2	8.8	2.7	2.6	2.8
0.23	25	8.0	8.5	8.6	2.5	2.7	2.7
$\pm$UVB means		8.6_b	8.6_b	9.1_a	2.7	2.7	2.8

Source	df.	Mean squares: Fresh wt	Mean squares: Dry wt
$\pm$ UVB	2	8.41**	0.69
Error a	2	1.90	0.27
Irradiance	9	1.46	0.17
Interaction	18	1.05	0.08
Error b	27	0.08	0.01

Fresh weight total observations, 240; $\pm$ UVB, 80; irradiance, 8

Dry weight, same

$\pm$ UVB mean separation (within parameter) by LSD, 5% level. Means followed by the same letter are not significantly different.

TABLE WL-3. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT WHEAT PLANT HEIGHT, LAMP EXPOSURE 84 HRS DURING 14 DAYS AND 192 HRS DURING 32 DAYS

UVB LAMP IRRADIANCE		PLANT HT (84 hrs)			PLANT HT (186 hrs)		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	cm	cm	cm	cm	cm	cm
4.34	478	14.2	14.3	14.7	27.9	26.6	26.6
3.57	385	14.2	13.9	13.9	25.8	25.8	25.7
2.52	273	13.5	13.7	13.4	26.6	26.4	25.2
1.89	204	14.5	14.0	13.7	26.7	27.8	25.2
1.59	170	13.4	13.5	13.7	25.2	26.2	26.6
1.12	123	13.3	13.7	15.5	24.7	26.6	26.4
0.88	94	14.3	13.5	13.2	25.5	26.4	27.6
0.65	85	13.0	13.7	13.2	24.8	24.7	24.4
0.44	47	13.8	13.9	14.0	25.8	24.7	25.5
0.23	25	13.0	13.5	13.4	24.9	26.2	24.9
±UVB means		13.7	13.8	13.7	25.8	26.1	25.8

		Mean squares	
Source	df.	Plant ht	Plant ht
± UVB	2	0.28	8.56
Error a	2	1.30	62.22
Irradiance	9	3.15*	34.14
Interaction	18	0.73	16.01
Error b	27	1.29	21.82

Plant height (84 hrs) total observations, 240; ± UVB, 80; irradiance, 8

Plant height (186 hrs) total observations, 720; ± UVB, 240; irradiance 24

TABLE WL-4. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENTS WHEAT PLANT HEIGHT AND HEAD LENGTH, LAMP EXPOSURE 300 HRS DURING 50 DAYS

UVB LAMP IRRADIANCE		PLANT HT			HEAD LENGTH		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	cm	cm	cm	cm	cm	cm
4.34	478	42.9	40.7	42.9	4.2	1.5	3.1
3.57	385	39.7	40.6	42.1	1.8	2.5	2.3
2.52	273	38.7	39.3	40.4	1.9	2.2	2.4
1.89	204	39.6	41.4	41.8	1.9	2.1	2.6
1.59	170	40.2	41.8	42.3	2.5	2.4	2.1
1.12	123	39.4	40.0	39.7	2.1	2.8	3.1
0.88	94	39.7	39.1	41.7	2.2	1.9	2.5
0.65	85	40.5	38.7	39.9	3.2	2.4	2.3
0.44	47	39.7	39.8	40.0	2.4	2.2	2.3
0.23	25	36.7	38.9	39.6	1.9	2.0	1.8
$\pm$ UVB means		39.7	40.0	41.0	2.4	2.2	2.4

		Mean squares	
Source	df.	Plant ht	Head length
$\pm$ UVB	2	76.2	2.46
Error a	2	67.2	19.86
Irradiance	9	55.7**	4.77
Interaction	18	12.1	4.72
Error b	27	13.9	2.81

Plant height total observations, 480; $\pm$ UVB, 160; irradiance 16

Head length, same

TABLE WL-5. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT WHEAT PLANT HEAD AND TILLER PRODUCTION, LAMP EXPOSURE 300 HRS DURING 50 DAYS

UVB LAMP IRRADIANCE		% HEADS			TILLERS/PLANT		
		+UVB	-UVB		+UVB	-UVB	
Weighted $mW.m^{-2}$	Non-weighted $mW.m^{-2}$	CA	M	U	CA	M	U
4.34	478	96.9	49.0	79.2	2.4	3.0	2.6
3.57	385	64.6	77.0	77.1	2.6	2.6	2.6
2.52	273	52.0	57.3	66.7	2.8	2.6	2.6
1.89	204	63.1	66.7	75.0	2.9	2.8	2.8
1.59	170	53.1	67.7	71.9	2.8	2.5	2.7
1.12	123	53.1	77.1	69.8	2.7	2.8	2.6
0.88	94	67.7	64.6	78.1	2.8	2.9	2.9
0.65	85	80.2	72.9	64.6	2.8	2.6	2.8
0.44	47	68.8	70.3	72.9	2.8	2.7	2.7
0.23	25	62.5	77.1	67.7	2.8	2.9	2.5
± UVB means		66.2	68.0	72.3	2.7	2.8	2.7

		Mean squares	
Source	df.	% heads	Tillers/plant
± UVB	2	1569.69	0.2271
Error a	2	4676.56	0.0521
Irradiance	9	1083.12	0.3336
Interaction	18	1868.39	0.3544
Error b	27	1335.25	0.2956

Percent heads total observations, 480; ± UVB, 160; irradiance 16

Tillers per plant, same

TABLE PL-1. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT POTATO FOLIAGE WEIGHT, LAMP EXPOSURE 294 HRS DURING 49 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	76.4	72.9	52.4	7.4	7.0	5.5
3.57	385	69.4	67.2	65.4	7.1	7.1	6.7
1.89	204	71.0	66.6	66.2	7.4	6.9	6.7
1.59	170	63.3	69.0	67.5	6.6	6.9	6.9
0.88	94	63.9	64.0	65.2	6.9	6.7	6.9
0.44	47	66.7	61.9	64.8	7.1	6.8	6.7
0.23	25	67.5	64.5	61.4	7.0	6.9	6.5
± UVB means		68.3	66.6	63.3	7.1	6.9	6.6

		Mean squares	
Source	df.	Fresh wt	Dry wt
± UVB	2	366.706	3.509
Error a	2	281.841	1.219
Irradiance	6	59.096	0.391
Interaction	12	211.476**	1.202*
Error b	18	51.590	0.385

Total observations for each parameter, 168; ± UVB, 56; irradiance, 8

TABLE PL-2. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT
POTATO TUBER WEIGHT PER PLANT, LAMP EXPOSURE
294 HRS DURING 49 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	142.6	157.9	132.3	28.0	31.0	25.8
3.57	385	153.8	151.3	143.0	31.0	29.6	28.5
1.89	204	155.9	152.1	146.9	31.4	30.5	29.1
1.59	170	147.1	148.7	152.4	29.6	29.2	30.0
0.88	94	153.6	152.7	144.4	30.2	30.3	27.2
0.44	47	155.4	147.9	152.7	30.8	28.9	29.5
0.23	25	150.2	152.1	138.7	29.3	29.6	26.8
± UVB means		151.2	151.8	144.3	30.0	29.9	28.1

Source	df.	Mean squares: Fresh wt	Mean squares: Dry wt
± UVB	2	965.072	62.7935
Error a	2	1021.540	41.8899
Irradiance	6	175.058	12.3421
Interaction	12	264.649	2.3623
Error b	18	208.740	10.7601

Total observations for each parameter, 168;
± UVB 56; irradiance, 8

TABLE PL-3. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENTS POTATO TUBER WEIGHT PER TUBER, LAMP EXPOSURE 294 HRS DURING 49 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	9.3	11.7	15.3	1.8	2.3	3.0
3.57	385	11.3	10.7	10.5	2.3	2.1	2.1
1.89	204	10.8	10.1	11.0	2.2	2.0	2.2
1.59	170	10.8	11.0	13.0	2.2	2.2	2.6
0.88	94	13.0	9.9	15.1	2.5	2.0	3.3
0.44	47	13.3	13.0	13.2	2.6	2.5	2.7
0.23	25	11.8	11.3	11.5	2.3	2.2	2.2
± UVB means		11.5	11.1	12.8	2.3	2.2	2.6

		Mean squares	
Source	df.	Fresh wt	Dry wt
± UVB	2	45.13	2.0943
Error a	2	7.62	0.5071
Irradiance	6	19.93	0.8593
Interaction	12	16.30	0.8507
Error b	18	10.46	0.5015

Total observations for each parameter, 168; ± UVB 56; irradiance, 8

TABLE PL-4. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT POTATO FOLIAGE WEIGHT PER TUBER WEIGHT, LAMP EXPOSURE 294 HRS DURING 49 DAYS

UVB LAMP IRRADIANCE		FRESH WT(ratio)			DRY WT(ratio)		
		+UVB	-UVB		+UVB	-UVB	
Weighted $mW.m^{-2}$	Non-weighted $mW.m^{-2}$	CA	M	U	CA	M	U
4.34	478	0.54	0.46	0.40	0.27	0.22	0.21
3.57	385	0.45	0.45	0.46	0.23	0.24	0.24
1.89	204	0.46	0.44	0.45	0.24	0.23	0.23
1.59	170	0.43	0.46	0.44	0.22	0.24	0.23
0.88	94	0.42	0.42	0.45	0.23	0.22	0.26
0.44	47	0.43	0.42	0.42	0.23	0.23	0.23
0.23	25	0.45	0.42	0.44	0.24	0.23	0.24
± UVB means		0.45	0.44	0.44	0.24	0.23	0.23

Source	df.	Mean squares: Fresh wt	Dry wt
± UVB	2	0.0043	0.0005
Error a	2	0.0013	0.0005
Irradiance	6	0.0051	0.0003
Interaction	12	0.0082**	0.0002
Error b	18	0.0024	0.0010

Total observations for each parameter, 168; ± UVB 56; irradiance, 8

TABLE PL-5. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, POTATO TUBER NUMBER AND STEM NUMBER, LAMP EXPOSURE 294 HRS DURING 49 DAYS

UVB LAMP IRRADIANCE		TUBER NO.			STEM NO.		
		+UVB	-UVB		+UVB	-UVB	
Weighted $mW.m^{-2}$	Non-weighted $mW.m^{-2}$	CA	M	U	CA	M	U
4.34	478	15.3	13.8	9.3	9.3	10.8	7.5
3.57	385	13.8	15.0	14.1	9.3	10.3	9.3
1.89	204	14.8	15.4	14.0	8.5	8.6	8.8
1.59	170	14.9	14.8	13.0	13.8	10.6	7.1
0.88	94	12.4	15.9	9.9	7.9	9.4	7.4
0.44	47	12.1	12.3	12.1	8.5	9.1	7.0
0.23	25	13.4	14.9	12.5	8.1	10.9	9.1
± UVB means		13.8^{1}_{a}	14.6_{a}	12.1_{b}	9.3	9.9	8.0

		Mean squares	
Source	df.	Tuber no.	Stem no.
± UVB	2	86.8218*	54.0576
Error a	2	2.1790	13.0779
Irradiance	6	22.5198	16.5258
Interaction	12	15.1920	15.1944
Error b	18	14.0247	26.2596

Total observations for each parameter, 168;
± UVB 56; irradiance, 8

[1] ± UVB mean separation (within parameter) by LSD, 5% level. Means followed by the same letter are not significantly different.

TABLE PL-6. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, NUMBER OF POTATO TUBERS PER STEM, LAMP EXPOSURE 294 HRS DURING 49 DAYS

UVB IRRADIANCE		TUBERS/STEM		
		+UVB	-UVB	
Weighted $mW.m^{-2}$	Non-weighted $mW.m^{-2}$	CA	M	U
4.34	478	1.7	1.3	1.2
3.57	385	1.6	1.5	1.6
1.89	204	1.8	1.8	1.6
1.59	170	1.7	1.4	1.9
0.88	94	1.6	1.7	1.5
0.44	47	1.5	1.4	1.9
0.23	25	1.8	1.4	1.4
± UVB means		1.7_a[1]	1.5_b	1.6_a

Source	df.	Mean squares Tubers/stem
± UVB	2	0.3157**
Error a	2	0.0010
Irradiance	6	0.2564
Interaction	12	0.3060*
Error b	18	0.1369

Total observations for each parameter, 168;
± UVB 56; irradiance 8

[1] ± UVB means separation (within parameter) by LSD 5% level. Means followed by the same letter are not significantly different.

TABLE RL-1. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, RADISH FOLIAGE WEIGHT, LAMP EXPOSURE 144 HRS DURING 24 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	2.19	2.63	2.59	0.24	0.31	0.29
3.57	385	1.87	2.20	2.38	0.23	0.26	0.28
2.52	273	2.04	1.92	2.39	0.24	0.23	0.27
1.89	204	1.97	2.00	2.28	0.23	0.24	0.30
1.59	170	2.25	1.93	2.47	0.26	0.22	0.29
1.12	123	2.35	1.98	2.28	0.30	0.23	0.28
0.88	94	2.25	1.86	2.30	0.27	0.22	0.29
0.65	85	2.26	2.09	2.29	0.28	0.24	0.29
0.44	47	2.63	2.08	1.98	0.32	0.24	0.25
0.23	25	2.42	2.18	2.09	0.29	0.26	0.25
$\pm$ UVB means		2.23	2.09	2.30	0.27	0.25	0.28

		Mean squares	
Source	df.	Fresh wt	Dry wt
$\pm$ UVB	2	0.97	0.0216
Error a	2	0.71	0.0167
Irradiance	9	0.27	0.0025
Interaction	18	0.38	0.0068
Error b	27	0.25	0.0044

Total observations for each parameter, 240;
$\pm$ UVB, 80; irradiance, 8

TABLE RL-2. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT RADISH FOLIAGE WEIGHT, LAMP EXPOSURE 168 HRS DURING 28 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	3.49	2.98	3.22	0.35	0.28	0.36
3.57	385	2.85	2.63	3.22	0.29	0.29	0.39
2.52	273	2.78	2.67	3.18	0.26	0.25	0.38
1.89	204	3.56	2.96	3.47	0.32	0.29	0.40
1.59	170	3.54	2.26	2.75	0.34	0.23	0.32
1.12	123	3.33	2.11	3.13	0.33	0.33	0.38
0.88	94	2.70	2.90	3.19	0.31	0.28	0.39
0.65	85	3.03	2.81	3.23	0.32	0.27	0.37
0.44	47	3.02	3.00	2.94	0.32	0.30	0.36
0.23	25	3.36	2.97	3.37	0.33	0.31	0.40
± UVB means		3.17	2.83	3.17	0.32	0.28	0.38

Source	df.	Mean squares: Fresh wt	Mean squares: Dry wt
± UVB	2	3.08	0.1718
Error a	2	2.06	0.0638
Irradiance	9	0.73	0.0068
Interaction	18	0.48	0.0041
Error b	27	0.25	0.0039

Total observations for each parameter, 240;
± UVB, 80; irradiance, 8

TABLE RL-3. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, RADISH ROOT WEIGHT, LAMP EXPOSURE 144 HRS DURING 24 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	3.27	4.10	4.20	0.19	0.24	0.26
3.57	385	2.56	3.29	3.54	0.15	0.20	0.23
2.52	273	3.11	2.24	4.18	0.18	0.14	0.25
1.89	204	3.01	2.99	3.62	0.17	0.19	0.23
1.59	170	3.93	2.84	4.01	0.23	0.18	0.25
1.12	123	3.53	2.87	3.87	0.21	0.19	0.24
0.88	94	2.82	2.77	3.49	0.17	0.20	0.22
0.65	85	3.21	2.86	3.04	0.20	0.19	0.20
0.44	47	3.17	2.74	4.21	0.19	0.18	0.25
0.23	25	3.99	2.96	3.28	0.24	0.18	0.21
± UVB means		3.26	2.97	3.74	0.19	0.19	0.23

		Mean squares	
Source	df.	Fresh wt	Dry wt
± UVB	2	12.30	0.0429
Error a	2	10.20	0.0393
Irradiance	9	1.66	0.0044
Interaction	18	1.57	0.0048
Error b	27	2.14	0.0066

Total observations for each parameter, 240;
± UVB, 80; irradiance, 8

TABLE RL-4. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, RADISH ROOT WEIGHT, LAMP EXPOSURE 168 HRS DURING 28 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
4.34	478	6.23	6.10	8.11	0.44	0.42	0.50
3.57	385	4.70	4.47	5.72	0.34	0.35	0.41
2.52	273	5.57	4.72	6.61	0.37	0.37	0.45
1.89	204	6.50	5.47	4.67	0.47	0.40	0.34
1.59	170	6.28	4.40	6.00	0.44	0.34	0.41
1.12	123	5.92	4.91	6.26	0.41	0.37	0.43
0.88	94	5.70	5.61	6.42	0.41	0.41	0.43
0.65	85	5.07	5.49	5.45	0.38	0.39	0.38
0.44	47	5.59	4.84	5.99	0.41	0.37	0.41
0.23	25	5.41	4.51	6.06	0.39	0.37	0.45
± UVB means		5.70	5.05	6.13	0.41	0.38	0.42

		Mean squares	
Source	df.	Fresh wt	Dry wt
± UVB	2	23.51	0.0369
Error a	2	1.71	0.0115
Irradiance	9	5.70	0.0127
Interaction	18	2.86	0.0096
Error b	27	3.88	0.0130

Total observations for each parameter, 240;
± UVB, 80; irradiance, 8

TABLE RL-5. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, RADISH FOLIAGE WT PER ROOT WT, LAMP EXPOSURE 144 HRS DURING 24 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted $mW.m^{-2}$	Non-weighted $mW.m^{-2}$	CA	M	U	CA	M	U
4.34	478	1.34	1.47	1.16	0.69	0.75	0.63
3.57	385	1.62	1.58	1.58	0.77	0.93	0.92
2.52	273	1.48	1.81	1.11	0.80	1.04	0.59
1.89	204	1.49	1.47	1.56	0.72	0.75	0.78
1.59	170	1.22	2.14	1.51	0.61	1.45	0.84
1.12	123	1.52	1.24	1.94	0.76	0.72	0.84
0.88	94	2.64	1.50	2.28	1.51	1.67	1.18
0.65	85	1.68	1.62	1.45	0.86	1.00	0.76
0.44	47	1.78	2.29	1.99	0.91	1.66	0.96
0.23	25	1.30	1.46	1.79	0.66	0.81	0.96
± UVB means		1.61	1.66	1.64	0.83	1.08	0.85

Source	df.	Mean squares: Fresh wt	Mean squares: Dry wt
± UVB	2	1.58	0.057
Error a	2	1.83	1.105
Irradiance	9	1.29	1.522
Interaction	18	0.30	0.865
Error b	27	0.64	1.059

Total observations for each parameter, 240;
± UVB, 80; irradiance, 8

TABLE RL-6. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, RADISH FOLIAGE WT PER ROOT WT, LAMP EXPOSURE 168 HRS DURING 28 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted $mW.m^{-2}$	Non-weighted $mW.m^{-2}$	CA	M	U	CA	M	U
4.34	478	0.57	0.54	0.44	0.81	0.69	0.73
3.57	385	0.69	0.65	0.57	0.96	0.87	0.94
2.52	273	0.51	0.57	0.57	0.72	0.67	0.93
1.89	204	0.63	0.56	0.83	0.75	0.75	1.23
1.59	170	0.60	0.58	0.51	0.80	0.74	0.92
1.12	123	0.58	0.66	0.54	0.81	0.94	0.91
0.88	94	0.58	0.55	0.57	0.95	0.70	1.01
0.65	85	0.63	0.55	0.60	0.89	0.71	0.98
0,44	47	0.63	0.79	0.53	0.88	0.96	0.94
0.23	25	0.70	0.69	0.62	0.88	0.86	0.98
$\pm$ UVB means		0.61	0.61	0.58	0.85	0.79	0.96

		Mean squares	
Source	df.	Fresh wt	Dry wt
$\pm$ UVB	2	0.032	0.586
Error a	2	0.057	0.775
Irradiance	9	0.068	0.100
Interaction	18	0.047	0.084
Error b	27	0.055	0.087

Total observations for each parameter, 240;
$\pm$ UVB, 80; irradiance, 8

TABLE PEL-1. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, PEA FOLIAGE WEIGHT, LAMP EXPOSURE 138 HRS DURING 23 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
3.83	416	3.8	3.8	4.9	0.51	0.52	0.68
3.22	348	4.1	3.7	3.9	0.55	0.50	0.54
2.52	273	3.9	4.1	4.6	0.52	0.56	0.63
1.89	204	4.2	4.0	4.3	0.55	0.54	0.56
1.59	170	3.7	3.9	4.1	0.49	0.53	0.56
0.88	94	4.5	3.6	3.6	0.59	0.48	0.50
0.44	47	3.5	4.4	4.6	0.48	0.62	0.66
± UVB means		3.9	3.9	4.3	0.53	0.54	0.59

		Mean squares	
Source	df.	Fresh wt	Dry wt
± UVB	2	2.38	0.0608
Error a	2	0.95	0.0188
Irradiance	6	0.50	0.0135
Interaction	12	1.13	0.0244
Error b	18	1.19	0.0261

Total observations for each paramter, 168;
± UVB 56; irradiance, 8

TABLE PEL-2. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, PEA FOLIAGE WEIGHT, LAMP EXPOSURE 168 HRS DURING 28 DAYS

UVB LAMP IRRADIANCE		FRESH WT			DRY WT		
		+UVB	-UVB		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	g	g	g	g	g	g
3.83	416	5.8	6.4	8.1	0.96	1.01	1.26
3.22	348	6.3	6.7	7.0	1.02	1.03	1.10
2.52	273	7.3	6.6	7.3	1.15	1.01	1.13
1.89	204	7.4	7.0	7.3	1.17	1.13	1.14
1.59	170	6.8	6.5	7.5	1.06	1.03	1.19
0.88	94	6.8	6.5	6.5	1.14	1.04	1.05
0.44	47	6.9	6.0	7.5	1.13	0.99	1.23
± UVB means		6.8^{1}_{b}	6.5_{b}	7.3_{a}	1.09^{1}_{b}	1.03_{c}	1.16_{a}

Source	df.	Mean squares: Fresh wt	Mean squares: Dry wt
± UVB	2	9.38*	0.2196*
Error a	2	0.28	0.0034
Irradiance	6	1.24	0.0243
Interaction	12	2.02	0.0440
Error b	18	1.04	0.0190

Total observations for each parameter, 168;
± UVB 56; irradiance, 8

[1] ± UVB mean separation (within parameter) by LSD, 5% level. Means followed by the same letter are not significantly different.

TABLE PEL-3. MEANS AND MEAN SQUARES FROM LAMP EXPERIMENT, PEA PLANT HEIGHT, LAMP EXPOSURE 138 HRS DURING 23 DAYS

UVB LAMP IRRADIANCE		PLANT HEIGHT		
		+UVB	-UVB	
Weighted	Non-weighted	CA	M	U
$mW.m^{-2}$	$mW.m^{-2}$	cm	cm	cm
3.83	416	23.0	23.4	25.4
3.22	348	22.6	21.2	22.4
2.52	273	24.0	23.3	24.1
1.89	204	24.0	22.8	23.9
1.59	170	23.1	20.5	23.1
0.88	94	21.5	21.2	22.0
0.44	47	22.1	24.3	25.6
± UVB means		22.9	22.4	23.8

Source	df.	Mean squares Plant height
± UVB	2	28.80
Error a	2	9.29
Irradiance	6	25.78
Interaction	12	6.50
Error b	18	9.93

Total observations for each parameter, 168;
± UVB 56; irradiance, 8