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ENVIRONMENTAL AND CULTURAL CONSIDERATIONS  
FOR GROWTH OF POTATOES IN CELSS

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The white potato (Solanum tuberosum) is being evaluated for use in CELSS because of its high ratio of edible to inedible biomass (80%) and highly nutritious tubers that consist of readily digestible carbohydrates (82%) and proteins (11%) (1). This edible portion can be easily prepared in many different ways to provide a wide variety to meals. The research with potatoes at Wisconsin has been underway for four years and directed toward both determining the range of yield response under different environmental conditions and establishing procedures for growing the crop effectively in space bases.

A major effort has been directed toward finding the combination of environmental conditions that maximizes the tuber production per unit area and unit time. The conditions, as shown in Figure 1, indicate the levels derived from the experiments conducted to this date that will produce the highest yield. This has been obtained using the Denali cultivar that was developed under long days in Alaska. The study of environmental conditions has been undertaken in 19 l or 38 l plastic containers filled with peat-vermiculite (50/50 v/v) and watered automatically 4 times daily with a balanced nutrient solution.

Temperature: The temperature of 16 C was derived from experiments undertaken at temperatures from 12 to 28 C as shown in Table 1. These data was taken from studies with Russet Burbank cv, grown for a period of 56 days at  $300 \mu\text{mol m}^{-2} \text{s}^{-1}$  of photosynthetic photon flux (PPF) with continuous irradiation and 70% RH (3). Tuber production was maximum at 16 C with shoot production

maximum at 24 C. Study has been made of the advantages of alternating temperatures over the 24 h period with cvs grown with  $400 \mu\text{mol m}^{-2} \text{s}^{-1}$  and 70% RH. It has been found that there is no advantage from an alternation of temperatures when the irradiation is continuous. A temperature change between 22 and 14 C after each 12 h period produced the same tuber weight as a constant 18 C temperature (Table 2). However that same temperature change with plants grown under 12 h irradiance, did produce a significant yield gain with Denali cv although only a small gain for Norland cv (Table 2). Of significant interest is that the alternation of temperature under the continuous light did essentially eliminate the continuous light injury that had been evident on certain cvs as Kennebec and Superior (4). This response is shown in the total plant weight data of Table 3. Effort has also been directed toward screening cultivars for effective tuberization under elevated temperatures. The 24 cultivars shown in Table 4 were grown for 56 days at 26 C under 70% RH and 12 h irradiance at  $700 \mu\text{mol m}^{-2} \text{s}^{-1}$ . Superior, Rutt, Troll, Haig, and Bake King cvs exhibited the highest number of initiated tubers and greatest tuber enlargement with no apparent plant stunting or chlorosis.

Irradiance: An irradiance level of  $600 \mu\text{mol m}^{-2} \text{s}^{-1}$  with continuous irradiance is indicated in Figure 1, for research indicates that tuber production will not be increased significantly with higher levels or irradiance. A comparison of tuber production at 400 and  $800 \mu\text{mol m}^{-2} \text{s}^{-1}$  with both 12 h and 24 h of irradiance is shown in Table 5. Denali cv was grown at 18 C and 70% RH for this study. Extending the photoperiod and increasing photon levels increased tuber yield. Note that plants at  $400 \mu\text{mol m}^{-2} \text{s}^{-1}$  for 24 h produced the same yield as plants grown at  $800 \mu\text{mol m}^{-2} \text{s}^{-1}$  for 12 h. These two treatments had the same total irradiance in each 24 hours. In contrast however, there as a significantly less shoot growth with the 12 h irradiance thus indicating that there was greater allocation of

photosynthates to tubers with the 12 h photoperiod. The yield gain with plants grown with 800  $\mu\text{mol}$  for 24 h over plants grown with 400  $\mu\text{mol}$  for 24 h varied with cultivar. Denali had a large increase in tuber weight but Norland and Russet Burbank had little or no increase (Table 6).

Study was made of the effect of light duration changes during a 16 week growing period as depicted in Figure 2, using both Denali and Norland cvs. Plants were grown at 16 C and 70% RH. Tuber production was not increased with any change of 12 h to 24 h or 24 h to 12 h (for four week periods) compared to the production obtained with continuous 24 h irradiation. However, the data in this figure does show that, when changes were made, the tuber production was greater if the early growth was under 12 h irradiance than if early growth was under 24 h irradiance.

Studies undertaken under low earth orbital light dark periods of 60 min light and 30 min dark were compared to plants grown under 16 h light and 8 h dark. Plants were grown at 18 C and 70% RH for 8 weeks. The tuber and total plant dry weight was reduced about 50% under the orbital light cycle (Table 7). Large reductions in stomatal opening and leaf photosynthetic rates were found in plants grown under the orbital light cycle (2).

Carbon Dioxide: Supplementation of the ambient carbon dioxide concentration to maintain 1000  $\mu\text{mol mol}^{-1}$  levels has increased tuber weight when potatoes have been grown under 12 h photoperiods but not when grown under continuous irradiation (Table 8) (5, 7). Potatoes, Denali cv, were grown at 16 C and 70% RH. The percentage gain in yield was greater with supplementation at 400  $\mu\text{mol m}^{-2} \text{s}^{-1}$  than at 800  $\mu\text{mol m}^{-2} \text{s}^{-1}$  however a similar gain in total plant weight at both irradiance levels was obtained. Additional study should be made of supplementation at higher irradiance levels with 12 h photoperiods and at low irradiance levels at continuous irradiance. Study of supplementation at elevated humidity levels, indicated no added benefit of supplementa-

tion at 80% as compared to 50% relative humidity level. Screening of the cultivars listed in Table 4 with elevated carbon dioxide, under high irradiance, using continuous irradiance at  $700 \mu\text{mol m}^{-2}\text{s}^{-1}$  PPF, has indicated that the cultivars, Desiree, Ottar, Haig, Denali, and Rutt have the highest capabilities for photosynthetic dry matter accumulation.

Humidity: Increasing the humidity level from 50 to 80% has produced greater than 50% increase in yield of tubers for Denali cv but less than 10% increase for Norland cv (Table 9) (6). Potatoes were grown at  $400 \mu\text{mol m}^{-2}\text{s}^{-1}$  of continuous irradiation and 18 C temperature for 8 weeks. The total plant dry weight was similar under 50 and 80% RH, indicating that the elevated humidity encouraged a greater percentage allocation of photosynthates to the tubers. A similar response with increasing RH has been found with plants grown under 12 h irradiation periods.

#### Cultural Studies for Growth of Potatoes in Space Bases

Root Environment: Research with nutrient film procedures, with and without media, has demonstrated that tuber production can be obtained either without any, or with only a shallow layer of media. High production has been obtained without the deep soil layers utilized in field plantings. However it has been found that a shallow layer of media is apparently essential for high production of tubers, for without the media, tubers form under the root mat feeding the plant and lift the roots out of the nutrient solution and cause injury to the root system. This is avoided if a 1 or 2 cm layer of media is utilized. Baked montmorillinitic clay (arcillite) has been found to be particularly effective because the roots can be easily separated from the media and the material can withstand high temperature sterilization. The root compartment must be kept dark to avoid light contacting the tubers and encouraging the accumulation of toxic glycoalkaloids in the tubers. The root compartment must also be closed to maintain a near saturated environment so

that there is no significant evaporation from the surface of the exposed tubers. Evaporation of the film of nutrient solution on the surface of the tubers causes an accumulation of salts and produces an injurious burn on the enlarging tubers.

Plant Spacing: The production of potatoes, cv Denali, was studied at different spacings in plastic trays 54 cm wide, 83 cm long and 11 cm deep under an environment of  $400 \mu\text{mol m}^{-2} \text{s}^{-1}$  at 16 C and 70% RH for 87 days. Wire fencing was placed around each tray to contain the shoots to the tray area. The trays were filled with peat vermiculite medium and planted with two, four or eight potato plants which provided .224, .112 and .056  $\text{m}^2$ , respectively, of growing area for each plant. The shoot and dry weight per unit area increased with decreasing space per plant (increasing number of plants per tray) as shown in Table 10. It is suspected that the increasing yield with close spacing was a result of the more rapid development of a solid canopy covering the surface of the tray area.

Root and Stolon Containment: The effect of root and stolon containment was studied in trays constructed of 0.3 thick polyvinyl chloride sheeting that were 96 cm by 96 cm and 20 cm high. Two trays were constructed with dividers to partition the tray area into 9 separate compartments, each 32 cm by 32 cm. Two trays were left with no compartmentalization. The trays were filled with peat-vermiculite media. Nine potato plants (cv Denali) were planted in each tray with a single plant positioned in the center of each compartment or in similar locations in the open tray. An automatic watering system was installed with four drip tubes positioned beside each plant and nutrient solutions waterings were made to excess four times each day. Plants were grown with  $700 \mu\text{mol m}^{-2} \text{s}^{-1}$  irradiation at 16 C and 70% RH for 59 days. No difference in tuber or total plant dry weight was found with the two types of trays.

Continuous Harvesting: Potatoes, cv Denali, were grown in the trays described in the spacing study but filled with only 2 cm of arcillite and covered with first a sheet of black plastic and then a sheet of white plastic. Two plants were grown in each tray at an irradiation of  $600 \mu\text{mol m}^{-2} \text{s}^{-1}$  PPF of 12 h duration, 16 C and 70% RH. When plants had been grown for 8 weeks, all tubers over  $\approx 5$  cm in diameter were removed from two trays by reaching under the cover with the room dark and separating the tubers from the stolons. This harvest was repeated at weekly intervals to the 16th week. The total weight of tubers harvested from trays over this 8 week period was 541 grams per plant compared to 572 grams per plant from trays that were undisturbed for 16 weeks. Thus no real difference in yield was evident. Tuber removal disturbed the source-sink balance in the plants as evidenced by the collapse of small areas of tissue on exposed leaflets within 24 h after the removal of the tubers at the first harvest.

Within-Canopy Lighting: Four light pipes from TRI Industries of Burnaby, B.C. have been obtained and installed between plants just above the container level. These pipes are fabricated with flexible prismatic film that promotes propagation of radiation along the length of the pipe. The pipes are 250 cm in length and 15 cm in diameter and constructed so that light is propagated down the pipe and emitted quite uniformly out of the two sides of the pipe. Each pipe is fitted with a 250 W metal halide lamp at each end. The construction and uniformity in irradiation from the pipes is shown in Figure 3. Irradiation was elevated about 40% over the first 40 cm and then was quite uniform over the center area of the pipes. The lamps have been installed in a controlled environment room, 18 inches apart and just above the level of the plant pots. Three rows of potato plants, 6 in each row, are being grown between the rows of pipes. The irradiation from overhead CWF lamps is  $300 \mu\text{mol m}^{-2} \text{s}^{-1}$  PPF and maintained continuously along with the continuous lighting from the pipes. The room is maintained at 18 C and 70%

RH. Potato growth has been very vigorous, with no evidence of leaf epinasty. The pipes have a cool surface temperature so that leaves are not stressed by longwave radiation and leaves commonly abut on the pipe. It was hoped that the increased irradiance within the canopy would decrease branching but this has not been found. Branching is very vigorous and appears similar to plants irradiated only from overhead lighting.

Research efforts in the coming year will be directed toward the following efforts.

a) Study will be made of the wavelengths controlling branching in the plant. It is suspected that the ultraviolet or infrared wavelengths may have controlling effects on branching. Reduction of branching has significant implications for use of potatoes to reduce the amount of space required and to insure maximum allocation of photosynthates to the tubers.

b) Extended investigations will be undertaken to establish the optimum nutrient concentrations and balance for potatoes being grown under different environmental conditions. Of particular concern will be study of the form of nitrogen, level of phosphorus, and balance between the different cations.

c) Continued study will be made with cultivars shown to have superior qualities in the screening tests described previously. Production studies, involving growth for 20 weeks, will be undertaken with Haig and Trogg cvs to determine their relative productivity compared to the previously studied cvs Denali, Norland, and Russet Burbank.

## REFERENCES

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Table 1. Effect of temperature on tuber and shoot dry weight of Russet Burbank cv grown for 56 days at  $300 \mu\text{mol m}^{-2} \text{s}^{-1}$  PPF of 24 h duration and 70% RH.

Temperature (°C)	Tuber Dry weight per plant (gm)	Shoot Dry weight per plant (gm)
12	73 ± 3	50 ± 3
16	123 ± 9	86 ± 3
20	95 ± 19	91 ± 5
24	2 ± 2	150 ± 10
28	---	116 ± 3

Table 2. Effect of alternating temperature every 12 hours upon tuber dry weight of two potato cultivars and 12 hour irradiation at  $400 \mu\text{mol m}^{-2} \text{s}^{-1}$  PPF, 18°C, and 70% RH.

Cultivar	Irradiation duration (h)	Tuber dry weight (g per plant)	
		22/14 C (12 h/12 h)	18 C (continuous)
Denali	24	378 ± 74	351 ± 51
Norland	24	288 ± 114	282 ± 19
Denali	12	405 ±	263 ±
Norland	12	332 ±	309 ±

Table 3. Effect of alternating temperatures each 12 hours upon dry weight of four cultivars, grown under continuous irradiance at  $400 \mu\text{mol m}^{-2} \text{s}^{-1}$  PPF and 0.6 kPa atmospheric moisture deficit.

Cultivar	Plant dry weight (g)	
	22/14 C (12 h/12 h)	18 C (continuous)
Denali	115.2 ± 7.1	133.5 ± 12.0
Norland	111.5 ± 7.5	117.1 ± 7.5
Kennebec	89.4 ± 6.4	7.5 ± 3.6
Superior	91.9 ± 8.1	12.9 ± 2.2

Table 4. Cultivars evaluated under a growing temperature of 26°C for capability to form tubers.

Cultivar	Country of origin	Cultivar	Country of origin
Alaska 114	US (Alaska)	New York 81	US
Alpha	Holland	Norland	US
Atlantic	US	North Dakota	US
Bake King	US	Ottar	Norway
Bintje	Holland	Russet Burbank	US
Denali	US (Alaska)	Rutt	Norway
Desiree	Holland	Snogg	Norway
Gualauge	Norway	Snow Chip	US (Alaska)
Haig	US	Spunta	Holland
Kennebec	US	Stately	US (Alaska)
La Rouge	US	Superior	US
New York 72	US	Troll	Norway

Table 5. Effect of irradiance level and duration on tuber and shoot weight of Denali cvs.

Photon Level ( $\mu\text{mol m}^{-2} \text{s}^{-1}$ )	Duration (h)	Dry weight per plant (g)	
		Tubers	Shoots
400	12	253 $\pm$ 19	97 $\pm$ 7
800	12	334 $\pm$ 11	117 $\pm$ 8
400	24	334 $\pm$ 45	217 $\pm$ 12
800	24	488 $\pm$ 51	185 $\pm$ 14

Table 6. Effect of photon level on tuber weight of different cultivars grown under continuous irradiation.

Photon level* ( $\mu\text{mol m}^{-2} \text{s}^{-1}$ )	Tuber dry weight per plant (g)		
	Denali	Norland	R. Burbank
400	334 $\pm$ 45	304 $\pm$ 41	339 $\pm$ 91
800	488 $\pm$ 51	317 $\pm$ 32	311 $\pm$ 78

\*24 h duration

Table 7. Comparison of potato growth with low earth orbital light:dark cycles of 60:30 minutes to growth with 16:8 hour light:dark cycle.

Duration		Dry weight per plant (g)	
Light	Dark	Tubers	Total Plant
60 min	30 min	168.8 ± 7.6	529.0 ± 32.7
16 hrs	8 hrs	373.9 ± 57.2	1030.0 ± 125.8

Table 8. Effect of elevated carbon dioxide level in combination with different irradiance amounts on weight of potato plots.\*

Photon level ( $\mu\text{mol m}^{-2}\text{s}^{-1}$ )	Duration (h)	Carbon dioxide level ( $\mu\text{mol mol}^{-1}$ )	
		<u>350</u>	<u>1000</u>
(g dry weight per plant)			
400	12	253 ± 19	363 ± 53
800	12	334 ± 11	456 ± 46
400	24	334 ± 45	366 ± 40
800	24	488 ± 51	469 ± 44

\*cv Denali

Table 9. Effect of humidity level on tuber production of two different cultivars of potatoes.

Humidity level (% RH)	Tuber dry weight per plant (g)	
	Denali	Norland
50	94 ± 13	209 ± 33
80	156 ± 36	227 ± 29

Table 10. Effect of plant spacing on tuber and shoot weight per unit area.

Area per plant (m <sup>2</sup> )	Tuber dry weight (g m <sup>-2</sup> )	Shoot dry weight (g m <sup>-2</sup> )
.224	907 ±	830 ±
.112	1010 ±	882 ±
.056	1285 ±	952 ±

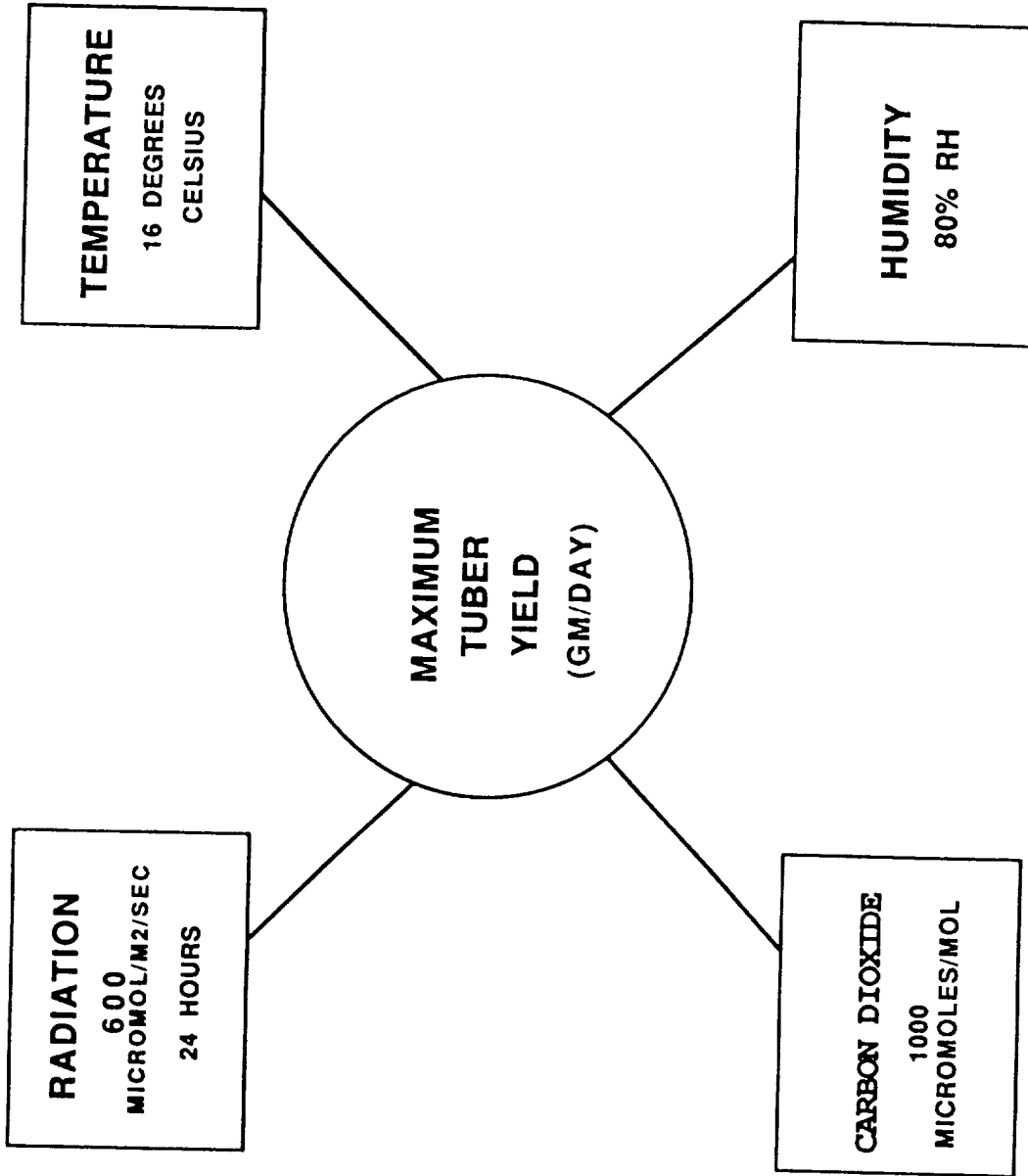


Figure 1. Conditions established for maximum tuber production per unit area and unit time.

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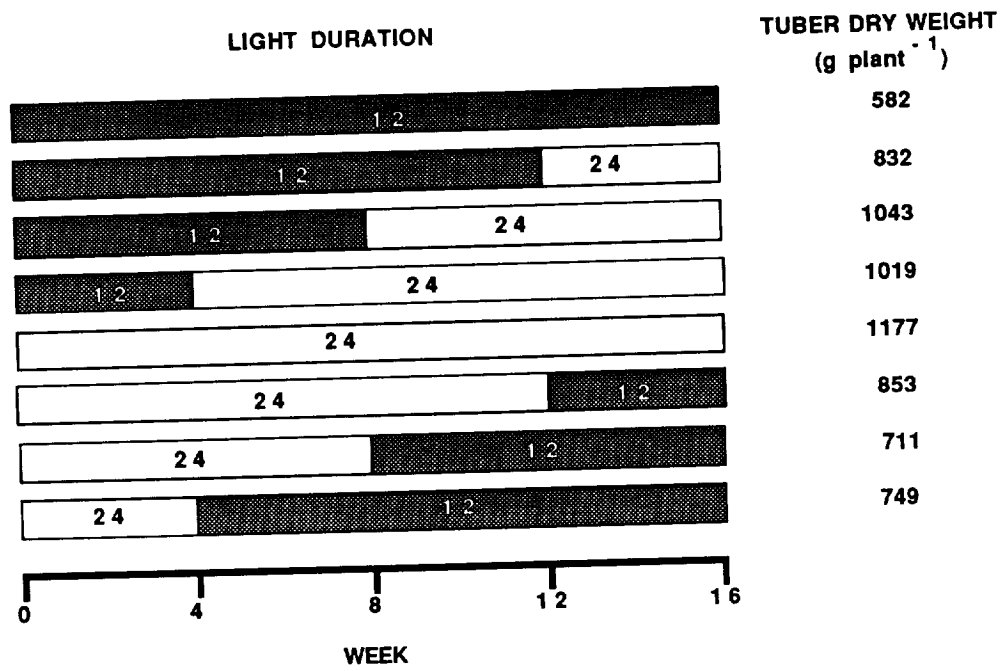


Figure 2. Effect of light duration changes at different times during a 16 week growth period on yield of potato tubers.

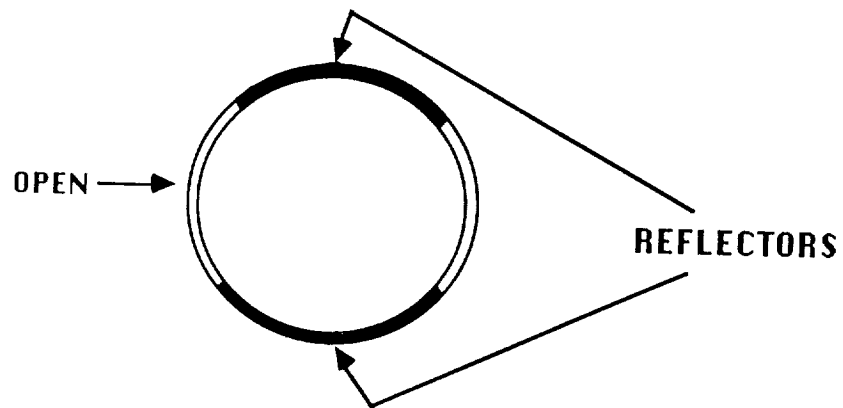
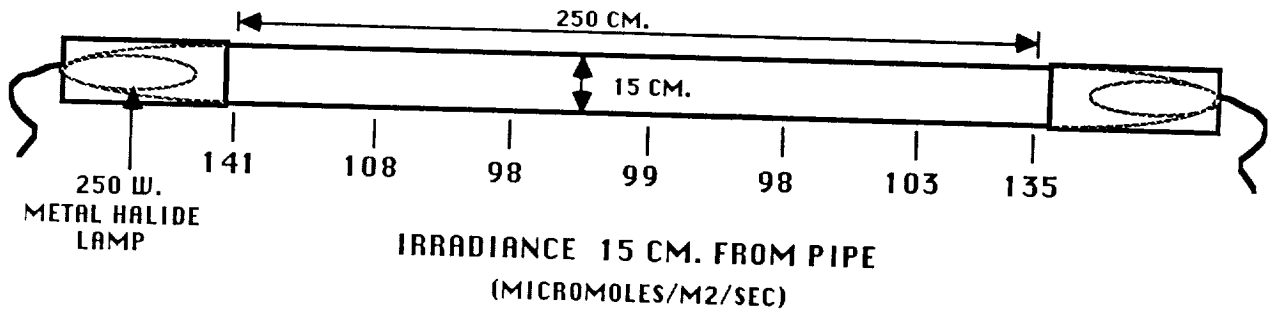


Figure 3. Distribution of irradiance from light pipes utilized for within canopy irradiance.