EFFECT OF LAMP TYPE AND TEMPERATURE ON DEVELOPMENT, CARBON PARTITIONING AND YIELD OF SOYBEAN

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ABSTRACT

Soybeans grown in controlled environments are commonly taller than field-grown plants. In controlled environments, including liquid hydroponics, height of the dwarf cultivar "Hoyt" was reduced from 46 to 33 cm when plants were grown under metal halide lamps compared to high pressure sodium lamps at the same photosynthetic photon flux. Metal halide lamps reduced total biomass 14% but did not significantly reduce seed yield. Neither increasing temperature nor altering the difference between day/night temperature affected plant height. Increasing temperature from 21 to 27°C increased yield 32%. High temperature significantly increased carbon partitioning to stems and increased harvest index.   © 1997 COSPAR. Published by Elsevier Science Ltd.

INTRODUCTION

Short-stature, high yielding cultivars are desirable in controlled environments because volume is often limited. However, soybeans grown in controlled environments are taller than field-grown plants (Downs and Thomas, 1990). Red:far red ratios, specifically phytochrome 660:730 nm, have been implicated as the cause of internode elongation (Pausch *et al.*, 1991), although soybeans may also respond to a balance of red and blue light (Britz and Sager, 1990). Wheeler *et al.* (1991) reported that there was a threshold intensity of blue light (30 μmol•m^{-2}•s^{-1}) necessary to reduce stem elongation. However elongation is also dependent upon the total photosynthetic photon flux (PPF) from lamps (Tibbitts *et al.*, 1983).

Another factor affecting stem length is temperature, which is easily manipulated in a controlled environment. The reduced plant water potential usually associated with high temperatures can be minimized by growing plants hydroponically at high humidity and elevated CO_2. Elevated CO_2 reduces photorespiration which generally increases with temperature. Thus crops grown in controlled environments should have higher temperature optimums than field grown plants. Optimum field temperatures for soybean have been characterized (Raper and Kramer, 1987), but the results may be affected by reduced plant water potential and increased photorespiration.

Our objective was to study soybean canopy height, carbon partitioning, and yield under high pressure sodium (HPS) versus metal halide (MH) lamps at varied and constant day/night temperatures in a CO_2-enriched, hydroponic, controlled environment.

MATERIALS AND METHODS

Soybean cv. 'Hoyt' canopies were grown in Plexiglas chambers (0.47 x 0.36 x 0.61 m) at a density of 36 plants•m^{-2} (6 plants per chamber). This density was used based on preliminary trials, which indicated that higher densities increased stem elongation and lower densities increased time to canopy closure. An extensive controlled environment screening showed 'Hoyt', a determinate cultivar, to be the shortest and highest yielding. All indeterminate cultivars were unacceptably tall. Chambers were positively pressurized for an open gas exchange system as described by Bugbee (1992). Seeds were germinated in moist diatomaceous earth (Isolite) and transplanted when the hypocotyls had elongated to at least 4 cm (about 6 days). Plants were transferred to an aerated nutrient solution, 21 cm deep, in a 30 L tub. Closed cell foam plugs in a blue Styrofoam lid supported the plants. Nutrient solution was replenished to maintain solution level. Nutrient solution electrical conductivity (140 ± 44μS) and pH (5.6 ± 0.6) were monitored and controlled as necessary. Ammonium sulfate was added as needed to counteract the rise in pH caused by nitrate uptake.

Five day/night temperature regimes were used: 29/25, 26/22, 24/24, 23/19, and 21/21°C. Root temperatures were kept constant at the average daily temperature of the shoot: 27, 24, 24, 21, and 21°C, respectively. Shoot air and root-zone temperatures were measured with thermocouples and maintained by computer-controlled heaters. Each set of temperature treatments (5 chambers) was placed under either MH or HPS lamps. All chambers were in a single growth room with light treatments separated by a heavy Mylar sheet. A photosynthetic photon flux of 450 μmol•m^{-2}•s^{-1} was maintained at the top of the canopy. This supplied approximately 40 and 140 μmol•m^{-2}•s^{-1} of blue light in HPS and MH lamps, respectively. Intensity was maintained within four percent by shading each chamber with neutral density filters. Aluminized Mylar around the chamber was maintained at canopy height to minimize the edge effect caused by side lighting. The photoperiod was 12-h. Carbon dioxide concentration was enriched to 1100 μmol•mol^{-1}.

Days to first flower was recorded as appearance of visible flower color. Plants were harvested at physiological maturity as indicated by loss of green color from the pods (Gbikpi and Crookston, 1981). At harvest, canopy height, from stem base to the top of the leaves, was measured *in situ*. Then plants were extended to their full height and measured to the growing tip of the main stem and longest branch. These different length measures were used as a more specific indication of internode elongation. Plants were separated into leaves, stems, pods, and roots, dried at 80°C for 48 hours, and weighed. Seed and pod number was recorded. Yield parameters and carbon partitioning (organ DW / total DW)were calculated from the harvest data. Main effects were tested using the light by temperature interaction error term with SAS ANOVA (SAS Institute, NC). Net canopy photosynthesis (P_{net}) was calculated from the measured change in CO_2 (infrared gas analyzer in differential mode) times air flow rate through the chamber divided by chamber ground area (Bugbee, 1992).

RESULTS

Effect of Lamp Type

MH lamps significantly reduced canopy height but slightly increased relative branch length (Table 1). The main stem of HPS plants were 87% the length of the longest branch while MH main stem was 75% of the longest branch. MH canopy height was taller than the longest branch length because canopy height included petiole lengths. Although not measured, petioles appeared to contribute more to height in MH canopies.

Table 1. Three plant length measures, seed yield, and yield components of soybeans grown under two lamp types. Each parameter is an average of the five chambers with different temperature regimes.

lamp type	canopy height (cm)	main stem length (cm)	longest branch length (cm)	seed yield ($g \cdot m^{-2} \cdot d^{-1}$)	photo-synthetic efficiency[†] ($g \cdot mol^{-1}$)	total biomass ($g \cdot m^{-2} \cdot d^{-1}$)	pods per m^2	seeds per pod	mass per seed (mg)
HPS	46.4	41.2	47.1	4.99	0.257	13.7	1486	1.91	159
MH	33.2	19.9	26.6	4.62	0.238	12.0	1385	1.85	167
p-value	<0.01	<0.01	<0.01	0.24	0.24	0.04	<0.01	0.10	0.42

[†]grams of seed per mol of PPF

Plants grown under MH lamps had 14% less biomass compared to plants under HPS lamps (Table 1). Reduced stem mass in MH plants was associated with an increase in harvest index (HI) (Table 2). All other component partitioning was similar. MH lamps also had slightly less seed yield than HPS lamps (Table 1). A difference in pod number and seeds per pod accounted for the trend in seed yield. P_{net} measurements were consistent with the yield differences between lamp types (Figure 1a).

Table 2. Carbon partitioning of soybeans under two lamp types. Measures are a percent of total dry weight. Sum of the five components equals 100%.

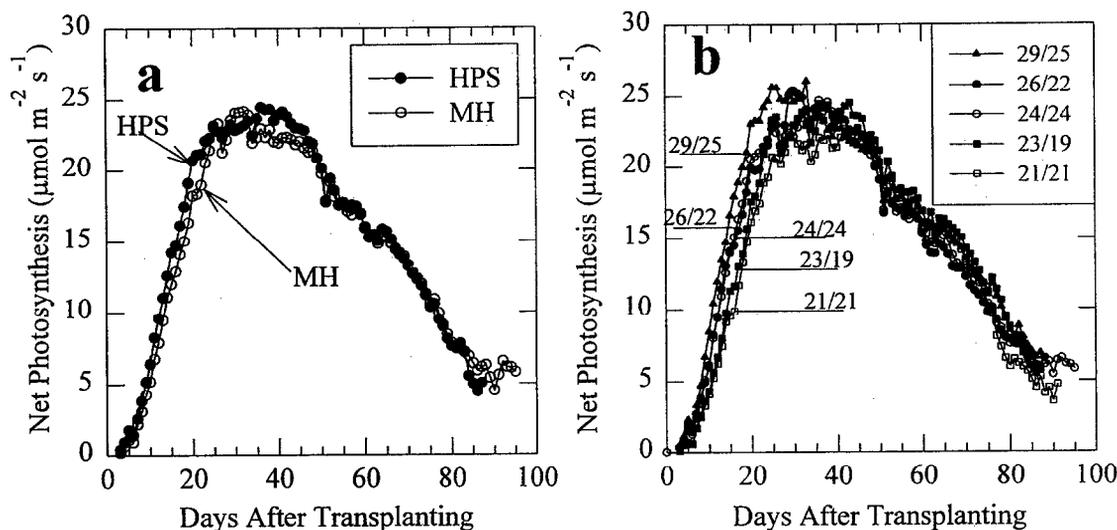| lamp type	seed (harvest index)	stem	leaves	pod	root
HPS	36.4	14.7	27.9	12.8	8.2
MH	37.7	12.2	28.6	12.2	9.3
p-value	0.18	<0.01	0.14	0.19	0.18

Fig. 1. Net photosynthesis (CO_2 uptake) of soybean canopies. Endpoints are an average day of harvest.
a) Comparison of lamp types. Measurements are an average of the five chambers of different temperatures.
b) Comparison of temperatures. Measurements are an average of the two chambers of differing lamp types.

Effect of Temperature

Higher temperatures increased seed yield via increased number of pods per square meter and seeds per pod (Table 3). We were surprised to find that cooler temperatures reduced the seed fill period. Higher temperatures increased P_{net} early in the life cycle (Figure 1b) but no trend was apparent after 35d. Total biomass (Table 3) and HI (Table 4) tended to decrease with lower temperatures.

Table 3. A comparison of yield and yield components for soybeans grown under five temperature regimes. Each parameter is an average of the two chambers of differing lamp type.

day/night temper- ature	seed yield ($g \cdot m^{-2} \cdot d^{-1}$)	$PE^{\dagger}$ ($g \cdot mol^{-1}$)	total biomass ($g \cdot m^{-2} \cdot d^{-1}$)	pods per m^2	seeds per pod	mass per seed (mg)	days to first flower	days to harvest	seed fill (days)
29/25	5.46	0.281	13.6	1483	1.96	167	19	87	68
26/22	5.43	0.280	13.1	1550	2.03	153	24	87	63
24/24	5.02	0.258	12.9	1594	1.89	160	27	90	63
23/19	4.13	0.213	12.6	1321	1.79	167	32	90	58
21/21	3.98	0.205	11.9	1230	1.73	169	33	90	57
p-value	0.06	0.06	0.46	<0.01	0.01	0.74	<0.01	0.67	

$^{\dagger}PE$ = photosynthetic efficiency

Table 4. Carbon partitioning of soybeans under five temperature regimes. Data are a percent of total dry weight. Sum of the five components equals 100%.

day/night temper- ature	seed (harvest index)	stem	leaves	pod	root
29/25	40.0	15.8	24.3	13.0	7.1
26/22	40.9	12.9	25.5	13.8	6.9
24/24	38.9	12.5	27.1	12.9	8.5
23/19	32.6	13.5	32.3	11.2	10.4
21/21	33.0	12.5	32.1	11.5	10.9
p-value	<0.01	0.03	<0.01	0.07	0.06

Percent leaf mass decreased with increasing temperatures probably because of delayed leaf senescence. Warm temperatures also tended to decrease percent root mass.

The day/night temperature scheme did not affect canopy height. For some species Erwin and Heins (1995) showed that altering the difference (DIF) between day/night temperature changed plant height but larger seeded species showed little response to DIF (Erwin, 1991). In our experiment, the canopies at +4 DIF (42 cm @ 26/22°C, 41 cm @ 23/19°C) were not significantly taller than at zero DIF (38 cm @ 24/24°C, 36 cm @ 21/21°C).

DISCUSSION

While short-stature canopies are desired in controlled environments, high yield is also a priority. The mechanism underlying biomass differences with spectral quality, specifically orange bias (HPS) versus a balanced spectrum (MH), is unknown. However, this biomass difference did not significantly affect yield. Because plant height and seed yield commonly are positively correlated (Wells et al., 1993), a slight difference in yield was to be expected. Taller plants under HPS lamps may have had better light interception. Higher P_{net}, longer internodes, larger leaves (data not shown), and more rapid canopy closure (data not shown) suggest that there is better light distribution and capture in the HPS canopy. Increasing plant density under MH lamps might overcome canopy closure differences but this would probably increase stem elongation after canopy closure, which would reduce

the height advantage.

A lack of significant effect on plant height indicates temperature can be manipulated to some extent to maximize yield without increasing canopy height. The high temperatures increased yield by increasing pod and seed number. Rapid canopy closure and higher photosynthesis contributed to the differences. High temperatures also hastened development as evidenced by shorter time to final vegetative-stage (data not shown) and decreasing time to first flower. We are currently testing temperatures above 29°C.

Measurement of P_{net} is important for calculating oxygen production for a bioregenerative life support system. Regardless of treatment, there was a broad peak in P_{net} between days 25 and 45. Early life cycle rate of increase in P_{net} was caused by rate of canopy closure and radiation capture. Differences between lamp types and between temperatures were apparent during this part of the life cycle. The decrease in P_{net} was due to senescence and treatment had no effect on the rate of decrease. Therefore we are focusing on environmental changes early in the life cycle to increase canopy closure.

ACKNOWLEDGMENTS

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