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Comparison of Fluorescent and High-pressure Sodium Lamps on Growth of Leaf Lettuce

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Abstract. **Radiation from high-pressure sodium (HPS) lamps provided more than a 50% increased yield (fresh and dry weight of tops) of loose-leaf lettuce cultivars Grand Rapids Forcing and RubyConn, compared to that obtained by radiation from cool-white fluorescent (CWF) lamps at equal photosynthetic photon flux; yet, input wattage was ≈36% less. It was postulated that the considerable output of 700 to 850 nm radiation from the HPS lamp was a significant factor of the increased yield. Under HPS lamps, the leaves of both cultivars were slightly less green with very little red pigmentation ('RubyConn') and slightly elongated, compared to CWF, but plant productivity per unit electrical energy input was vastly superior with HPS.**

Koontz and Prince (5) showed that loose-leaf lettuce plants under cool-white fluorescent (CWF) lamps produced a 50% greater yield if the photoperiod was extended from 16 to 24 hr with the same total daily radiation (moles of photons). The photosynthetic photon flux (PPF) was 415 and 260 $\mu mol \cdot s^{-1} \cdot m^{-2}$ for the 16- and 24-hr photoperiods. If the irradiation could be provided by a more efficient lamp, further savings would result. High-pressure sodium (HPS) lamps are much cheaper to operate at equal PPF than are fluorescent lamps (2) Crops could be produced more economically if HPS lamps rather than fluorescent lamps were used in controlled environment rooms, provided that crop quality and yield were not diminished.

'RubyConn' and 'Grand Rapids Forcing' loose-leaf lettuce cultivars were subjected to a single 28-day trial and a two-trial, 25-day experiment. Eight plants from each cultivar were placed randomly under each radiation source for each experiment. Statistical analyses were performed on the data according to Steel and Torrie (9). Areas 1.2 × 1.2 m were irradiated by one 400-W HPS lamp or by sixteen 40-W CWF lamps. The HPS lamp was built into a large parabolic reflector (1.2 m^2 at the base) to provide efficient and uniform irradiation. All other environmental conditions were identical for both treatments, as they were run simultaneously in the same room, on the same table, and with the same nutrient solution.

The PPF, air temperature, relative humidity, carbon dioxide concentration, and solution temperature were 250 $\mu mol \cdot s^{-1} \cdot m^{-2}$, 24° ± 1°C (28-day experiment) or 27° ± 1°, 60% ± 10%, 1000 ± 100 ppm, and 27° ± 1°, respectively. Radiation was measured with a quantum flux sensor (LI-COR Model 190SB, 400 to 700 nm) at the height of 2-week-old plants. Near-infrared (LI-COR 220SB, 745 to 815 nm) was 1.83 and 0.40 $W \cdot m^{-2}$ for the HPS and CWF lamps. The irradiation did not diminish during an experiment. Plants were grown by the nutrient film technique, spaced on a 305-mm matrix. Four 35-mm-deep × 50-mm-wide × 2.4-m-long polyvinylchloride troughs were spaced 305 mm apart with eight plants each (four for each lamp type).

The full-strength nutrient solution contained (in $mmol \cdot liter^{-1}$): 15 NO_3, 1.0 H_2PO_4, 6.0 K, 5.0 Ca, 2.0 Mg, and 2.0 SO_4; (in $\mu mol \cdot liter^{-1}$), 54 Fe, 46 B, 9 Mn, 2.3 Zn, 0.8 Cu, 1.0 Mo, 157 Na, and 1.1 Cl. A pH of 5.5 to 6.3 was maintained with HNO_3. The total volume of the nutrient solution was 50 liters for the 32 plants. The flow rate was 10 $ml \cdot s^{-1}$ through each trough, entering the HPS end and exiting the CWF end.

Plants were germinated overnight in petri dishes with 1/10 strength nutrient solution and then placed in the capillary plant support (7). The seedlings were grown under continuous CWF irradiation at 220 $\mu mol \cdot s^{-1} \cdot m^{-2}$ PPF and temperature of 24° ± 1°C. They were transferred to the treatment room at day 7. The half-strength solution was continued for one more day.

In both experiments (Tables 1 and 2), plant weight (fresh and dry) under HPS were significantly ($P > 0.005$) greater than under the CWF radiation source. All plants grown under HPS lamps were heavier than those grown under CWF. 'RubyConn' was significantly ($P > 0.005$) greater, producing 20% more fresh weight under CWF and 32% more fresh weight under HPS lamps than 'Grand Rapids Forcing' (Table 2). For the 25-day experiment reported in Table 2, growth time was decreased from 28 to 25 days because of the rapid growth and to lessen the effects of tipburn on the results. Tipburn was minor and about the same for both radiation sources. No bolting occurred.

Under HPS lamps, the leaves of both cultivars were more elongated and less green than under the CWF lamps. Tibbitts et al. (11) found a lower than normal chlorophyll content of lettuce grown under HPS lamps. 'RubyConn' leaves did not develop the ruby pigment under HPS lamps.

Lamp input wattage was 736 for the 16 CWF lamps (46 W/lamp) and 470 for the HPS lamp. Thus, the HPS lamp required only 64% as much electricity to provide the same PPF as the CWF lamps. The CWF lamps were 490 mm from the stem base, and the HPS lamp was 1000 mm. The HPS lamp was positioned higher in order to give the same PPF as the CWF lamps. The one HPS lamp, then, could have provided more PPF and, presumably, more plant yield than that obtained in these experiments.

Radiation beyond 700 nm was not taken into account with the PPF measurements. The CWF and HPS lamps emitted considerable thermal infrared (IR, >2700 nm) with more IR from CWF than HPS (224 vs. 128 W). The HPS lamp provided much more radiation than CWF lamps in the 700- to 2700-nm region (88.5 vs. 6.1 W). The numbers are based on data from Cathey and Campbell (2) and Thimijan and Heins (10). More than half of this radiation for HPS lamps was in the 700- to 850-nm region, with the main

Table 1. Response of lettuce to radiation source, 28-day seed to harvest.

Type of lamp	Cultivar: Grand Rapids Forcing	RubyConn
	Top fresh wt (g ± SE)[z]	
Cool-white fluorescent	207 ± 14	225 ± 11
High-pressure sodium	250 ± 16	310 ± 12
Weight increase (%)[y]	21	38
	Top dry wt (g ± SE)[z]	
Cool-white fluorescent	11.66 ± 0.92	11.89 ± 0.54
High-pressure sodium	14.44 ± 1.11	16.85 ± 0.72
Weight increase (%)[y]	24	42
	Root dry wt (g ± SE)[z]	
Cool-white fluorescent	0.97 ± 0.05	1.23 ± 0.07
High-pressure sodium	1.12 ± 0.09	1.64 ± 0.04
Weight increase (%)[y]	15	33

[z]Significant at the 0.005 level of probability.
[y]Due to radiation from high-pressure sodium lamps.

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Table 2. Effect of lettuce weight of radiation source, 25-day seed to harvest.

Type of lamp	Cultivar			
	Grand Rapids Forcing		RubyConn	
	Top fresh wt (g ± SE)			
Cool-white fluorescent	107	± 4	128	± 5
High-pressure sodium	154	± 7	203	± 8
Weight increase (%)[y]	52		58	
	Top dry wt (g ± SE)			
Cool-white fluorescent	5.75 ± 0.29		6.81 ± 0.30	
High-pressure sodium	8.69 ± 0.38		11.12 ± 0.50	
Weight increase (%)[y]	51		63	

[z]Significant at the 0.005 level of probability.

[y]Due to radiation from high-pressure sodium lamps.

peak at 819 nm.

Cathey and Campbell (2) stated that "crop production correlates more closely with radiation if the wavelengths from 400 to 850 nm are included." In a study of the response of 'Grand Rapids' lettuce to far-red and infrared radiation, Krizek and Ormrod (6) evaluated the base-line growth experiments reported by Hammer et al. (4) and determined that as the input wattage levels of incandescent lamps was increased, while keeping the PPF constant (400 to 700 nm), fresh and dry weights of the tops increased significantly.

Deutch and Rasmussen (3) also showed that plant yield was increased by lamps emitting radiation between 750- and 1000-nm wavelengths compared to fluorescent lamps. The comparisons were made with various lamp types at equal illumination levels (15,000 lux as measured with a selenium photocell). They did not believe that the increased yield was due to increased leaf temperature.

Tibbitts et al. (11) concluded that lettuce yield was determined by PPF and not by spectral irradiance. They compared four combinations of high-pressure sodium, metal halide, and tungsten halogen at equal PPF. However, the lamps tested did not include fluorescent, and all produced significant IR radiation.

Increasing the thermal IR irradiance was shown by Sager (8) to increase the dry weight of lettuce ('Black Seeded Simpson') grown at low air temperatures (10° and 16°C) but decrease weight at higher temperatures (24° and 32°). All had equal PAR (434 $W \cdot m^{-2}$). At the lower temperature, daylight fluorescent lamps with added IR produced more dry weight than HPS lamps, but at the two higher temperatures, HPS lamps were slightly better.

In agreement with Cathey and Campbell (2), our work suggests that, for comparing lamps on plant growth, irradiance values expressed in $W \cdot m^{-2}$ for the range of 400 to 850 nm relate to plant growth better than $W \cdot m^{-2}$ for the range of 400 to 700 nm or $\mu mol \cdot s^{-1} \cdot m^{-2}$ PPF (which is 400 to 700 nm by definition). However, wavelengths >850 nm also may be important for lamp evaluations; for example, Cathey and Campbell (1) found higher fresh weight of 'Grand Rapids' lettuce grown under HPS compared to CWF lamps, even though the irradiation ($W \cdot m^{-2}$) was equal between 400 and 850 nm.

Leaf elongation is another possible contributing factor in regard to increased growth of loose-leaf lettuce under HPS lamps compared to CWF lamps. Leaves are longer under HPS lamps. Since our plants were spaced relatively far apart (305 mm) and did not contact one another until day 21 for HPS and 23 for CWF, the plants under HPS lamps most likely received more total irradiation per plant (less self-shading).

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