

Peak production of vegetative cuttings for bedding plants in the U.S. (November to March) occurs during the period of lowest sunlight. One option to provide more light, and therefore increase both photosynthesis and yield of cuttings, is to use high-pressure sodium (HPS) lamps. The key question for growers, however, is whether the increased yield in cuttings will more than offset the cost of purchase, installation, and operation of HPS.

We conducted research on supplemental lighting of stock plants over the past two years at the University of New Hampshire (UNH) (Durham, NH), in collaboration with a commercial grower (Pleasant View Gardens, Loudon, NH) and a lighting supplier (P.L. Light Systems, Inc.). We quantified the effect of HPS lighting on yield and profitability for ten species of annual bedding plants. This article presents specific results from our research and provides guidelines to help you decide whether supplemental lighting will be a worthwhile investment for your greenhouse operation.

1. Understand light units

Light level is described in several different ways, which makes it hard to interpret recommendations from different sources. Table 1 shows how to convert from foot-candles (which is the most common light unit used by the U.S. greenhouse industry) to other units. We will describe light energy in two ways for this article:

(a) Instantaneous light (measured in foot-candles). If you go out into the greenhouse with a light meter, the meter probably measures the light level at that instant in foot-candles. In contrast, researchers favor measuring instantaneous light in micromoles. $\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ of Photosynthetically Active Radiation (PAR) because this unit represents the light spectrum used by plants in photosynthesis. To convert foot-candles to micromoles. $\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ of PAR for sunlight, using Table 1, multiply by 0.20 (e.g. 2000 foot-candles \times 0.20 equals 400 micromoles. $\cdot\text{m}^{-2}\cdot\text{s}^{-1}$). The conversion factor between foot-candles and micromoles. $\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ in Table 1 depends on the light source.

(b) Daily light integral (measured in moles/day of PAR). Over the course of a day, plants receive a lower amount of light in the morning and afternoon, and a peak of light around midday. If you add up all of the light energy accumulated over the course of the day, also called the “daily light integral”, you can express this energy as moles/day. You can think of foot-candles or micromoles. $\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ of PAR as drips of energy hitting the ground every second, and moles/day as a bucket accumulating all of the drips of energy over the course of the day. To convert from an average 1000 foot-candles of sunlight over 12 hours, using Table 1, that would equal $1000 \times 0.00071 \times 12 = 8.5$ moles/day.

Table 1. Conversion between different light units

Unit	Type of measurement	Mainly used by	Compared with 1 foot-candle		
			Sunlight	H.P. Sodium	M. Halide
Foot-candles	Visible (human eye)	Industry (U.S.)	1	1	1
Lux	Visible (human eye)	Industry (Europe)	10.76	10.76	10.76
micromoles. $\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ of PAR (400-700 nm)	Quanta of light in PAR range	Horticulture research	0.20	0.13	0.15
moles/day (PAR)	“daily light integral”: accumulated PAR light during an entire day	Horticulture research	foot-candles \times 0.00071 \times hours of light	foot-candles \times 0.00047 \times hours of light	foot-candles \times 0.00054 \times hours of light
Watts/ m^2 (PAR)	Energy in PAR range	Engineers, research	0.043	0.026	0.033
Watts/ m^2 (total energy)	Total energy	Engineers, research	0.101	0.074	0.089

2. How much light reaches a greenhouse crop?

Figure 1 shows the average pattern of moles/day of light inside a greenhouse in the northern third of the United States (represented by Ohio conditions). These data are based on “light maps” that were developed by Dr. James Faust at Clemson University using 30 years of light data (you can view the detailed light maps at <http://virtual.clemson.edu/groups/hort/faculty/faust/maps.htm>)

Depending on the season, location, and cloud cover, daily light integral **outdoors** in the U.S. can range between 1 and 70 moles/day. Assuming 50% transmission to allow for the

greenhouse covering, framing, and other obstructions, daily light integral in the northern U.S. averages around 6 moles/day during November to January, and above 26 moles/day in mid-summer.

For comparison, the Dec.-Jan. light level (with 50% transmission) in Ohio, Tennessee, and Florida would be approximately 6, 9, and 12 moles/day. Therefore, there is twice the light level in Florida than Ohio during mid-winter. The need for, and crop yield response to, supplemental lighting is therefore much greater in the northern U.S.

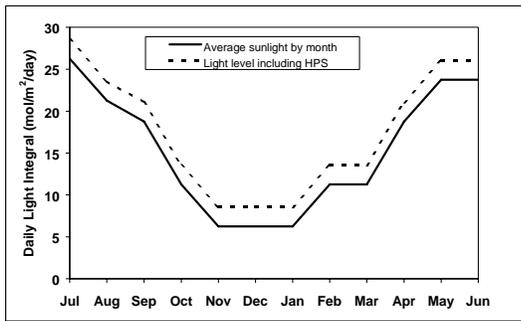


Figure 1 Daily light integral in Ohio received at the greenhouse bench level during different months of the year (solid line). The solid line assumes 50% light transmission. The dotted line represents sunlight plus an additional 3 moles/day contributed by HPS at 75 micromoles.m⁻².s⁻¹ (575 ft-c) for 12 hours/day.

3. Maximize light transmission

The worst conditions for growing stock would be in a double poly greenhouse with plants grown on benches under hanging baskets – not an uncommon situation!

Light level reaching plants inside a greenhouse can vary between 35 and 75% of outdoor light levels. Choosing glass or high-transmission synthetic glazing materials rather than polyethylene, and taking care to reduce overhead structures above the growing bench (such as conduit, piping and hanging baskets) can significantly increase light reception by the crop. In addition to considering HPS lights, investigate these options for your business.

4. HPS has the biggest impact during dark months

The amount of PAR light added by HPS or Metal Halide lamps can be calculated from Table 1. Multiply the number of foot-candles x the hourly correction factor (from Table 1) x the hours lit to get the moles/day.

For example, if you run HPS at 575 foot-candles for 11 hours, then

$$575 \times 0.00047 \times 11 = 3 \text{ moles/day}$$

Low sunlight increases the relative effect of supplemental lighting on total light level, and therefore on plant growth. Figure 1 shows the light contributed by sunlight alone, and also the total amount of light (another 3 moles/day) if HPS was run at 575 ft-c (75 micromoles.m⁻².s⁻¹) for 11 hours. During November to January, an extra 3 moles/day from HPS would provide about 48% more light compared with sunlight alone. In contrast, HPS would only provide 12% more light during June to August, which are the brightest months. The potential impact of HPS on plant growth and revenue is therefore greatest from November through January.

5. To save energy, turn HPS off during the peak sunny period of the day.

When sunlight level is low over the course of a day, adding HPS light has a bigger impact on plant growth than adding HPS when sunlight level is high. For example, when sunlight is 150 micromoles.m⁻².s⁻¹, adding an extra 75 micromoles.m⁻².s⁻¹ from HPS lamps represents an increase of 50%. But when sunlight is 750 micromoles.m⁻².s⁻¹, the addition of 75 micromoles.m⁻².s⁻¹ HPS represents an increase of only 10%.

In research conducted with Dr. James Faust in January 2001, we developed a photosynthetic-light response curve for *Scaevola aemula* ‘New Wonder’ stock plants (Figure 2). Growers can use this information to know at what light level HPS lamps should be turned on and when supplemental light no longer increased photosynthetic rate for *Scaevola*. From our study of *Scaevola aemula* ‘New Wonder’ supplemental lighting should be used when sunlight levels are below 400 micromol.m⁻².s⁻¹ of sunlight (2000 ft-c). Note that because HPS cannot be quickly cycled on or off, an environmental computer system should be used to efficiently control lighting without damaging fixtures.

Figure 2

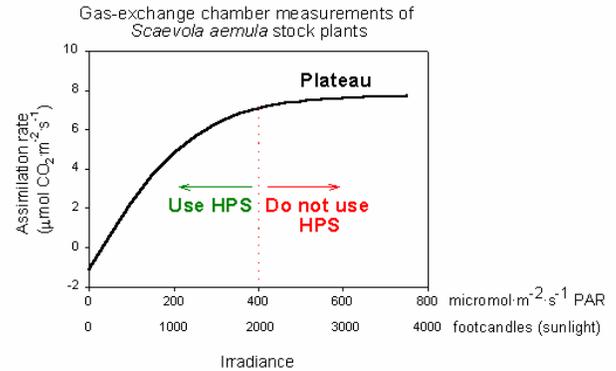


Figure 2. Light-photosynthesis response curve developed from whole-plant gas-exchange measurements of *Scaevola aemula* ‘New Wonder’ stock plants in a greenhouse at Clemson University. Above 400 micromol.m⁻².s⁻¹ (2000 ft-c) of light, there was little response to HPS.

6. Stock plant response to HPS varies between species

Commercial producers usually grow a diverse mix of species and cultivars within the same greenhouse. We evaluated the response of ten different species & cultivars of annual bedding plants to HPS. Two levels of supplemental light (46 or 75 micromol.m⁻².s⁻¹ (350 or 575 ft-c) HPS) were compared to growth under ambient sunlight conditions (which averaged 156 micromol.m⁻².s⁻¹ during the photoperiod). Because several of the species studied were long-day plants and we wanted to keep plants vegetative, we lit plants for 11-hours **during daylight hours** (beginning near dawn and ending near dusk).

Supplemental light significantly increased the number of cuttings harvested from stock plants for three species grown at the University of New Hampshire (*Petunia hybrida*, *Scaevola aemula* and *Verbena*) and four species grown at Pleasant View Gardens (*Petunia hybrida*, *Osteospermum*, *Scaevola aemula* and *Aloysia triphylla*) (Figure 3A & B).

The variable response between cultivars means that growers should conduct simple trials with each cultivar to quantify the effect of HPS lighting on cutting number. For example, one greenhouse could be fitted with HPS lights. A small number of stock plants could be grown under lights and the number of cuttings harvested per week recorded and compared to production under sunlight alone.

Figure 3A

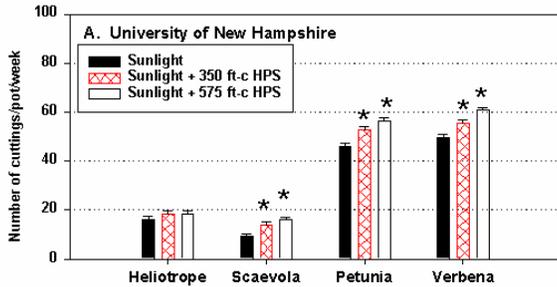


Figure 3(A) Number of cuttings per pot per week averaged from November 1999 to February 2000 under three light levels at the University of New Hampshire.

Figure 3B

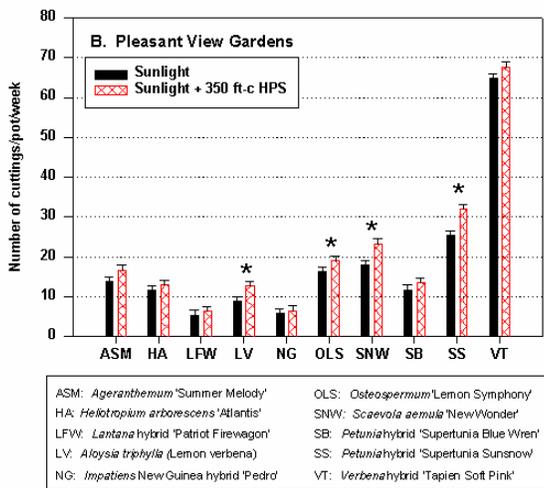


Figure 3(B). Number of cuttings per pot per week for ten species under two light levels, averaged from November 1999 to March 2000 at Pleasant View Gardens. Species denoted with the * symbol had a statistically significant response to lighting. 350 and 575 ft-c HPS equal 46 and 75 micromoles.m⁻².s⁻¹.

7. How much does supplemental lighting cost?

Our analysis of the cost to purchase and installation of HPS lighting at two light levels, 46 or 75 micromol·m⁻²·s⁻¹ (350 or 575 ft-c), showed an investment cost of \$3.80 or \$6.10 per square foot, respectively (Table 2). We assumed that 400 W fixtures were used, costing \$210 each, and installation was by a grower paid \$12.15 an hour. If you have a high-walled greenhouse that would allow you to install 600 or 1000-watt fixtures, your investment cost will be lower per square foot than these figures. The useful life on fixtures can be measured in decades, with minimal maintenance to clean fixtures and replace bulbs every few years depending on use (bulb life is around 16,000 hours).

Table 2. Example investment costs for high-pressure sodium lamps to provide 46 or 75 μmol·m⁻²·s⁻¹ (350 or 575 foot-candles) in a 30 ft. x 144 ft. double-poly free-standing greenhouse.

	46 μmol·m ⁻² ·s ⁻¹ (350 foot-candles)	75 μmol·m ⁻² ·s ⁻¹ (575 foot-candles)
Lamp design		
Number of 400W fixtures	40	66
kW/greenhouse (400W bulb + 64W ballast)	18.6	30.6
Square feet of floor space/lamp	108	65
Initial costs		
Purchase cost of fixtures @ \$210	\$8,400	\$13,860
Installation cost @ \$190 ^a	\$7,600	\$12,540
Total purchase and installation	\$16,000	\$26,400
Investment cost/square foot of greenhouse floor space	\$3.80	\$6.10

^aAssumes a permanent installation by a grower paid \$12.15/hour.

Once lights are purchased, the operating cost depends primarily on electrical charge and the number of hours per day the lights are on. Figure 4 expresses the cost of lighting on a per square foot basis assuming that lights are operated for 11 hours. For example, if electrical charge was \$0.10/kWh, the total investment and operating cost of 46 micromol·m⁻²·s⁻¹ (350 ft-c) HPS would be approximately \$0.06 per square foot per week.

Figure 4

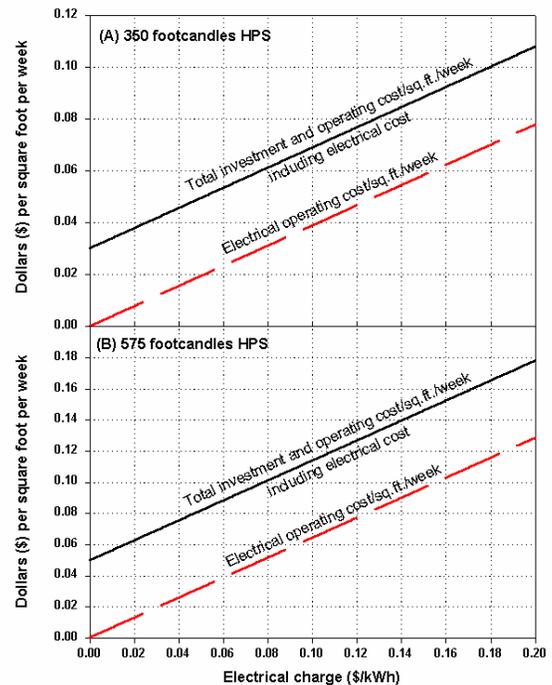


Figure 4. Investment and operating costs per square foot per week for two HPS light levels with varying electrical charge assumptions. 350 and 575 ft-c HPS equal 46 and 75 micromoles.m⁻².s⁻¹.

8. Profitability of HPS varies between species

To determine if lighting would be profitable for the ten species evaluated in our research at UNH and Pleasant View Gardens, we calculated the additional net return per square foot per week from supplemental lighting (Figure 5A & B). Additional net return equals the value of extra cuttings produced with lighting, minus the labor cost to harvest cuttings, minus the investment and operating costs of lights (from Figure 4).

Additional net return was positive (i.e. lighting was profitable) for all species grown at UNH and for seven of the ten species grown at Pleasant View Gardens. For some species (*Lantana montevidensis* 'Patriot Firewagon' and *Petunia* 'Supertunia Blue Wren') the value of the extra cuttings produced did not exceed the costs of lighting. In the case of New Guinea *Impatiens*, the value of the extra cuttings equaled the cost of lighting (just broke even).

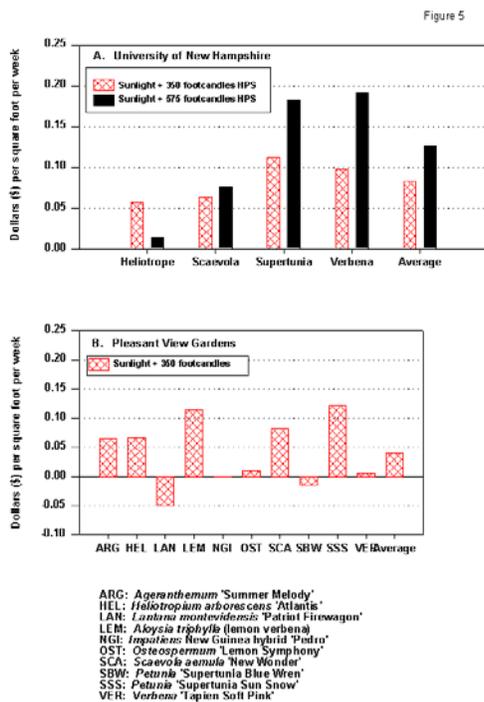


Figure 5. Additional net return (\$) per square foot per week from supplemental lighting at (A) University of New Hampshire and (B) Pleasant View Gardens. Net return equals the value of extra cuttings, minus the labor cost to harvest cuttings, minus investment and operating costs of the lights assuming \$0.10/kWh of electricity. 350 and 575 ft-c HPS equal 46 and 75 micromoles.m⁻².s⁻¹.

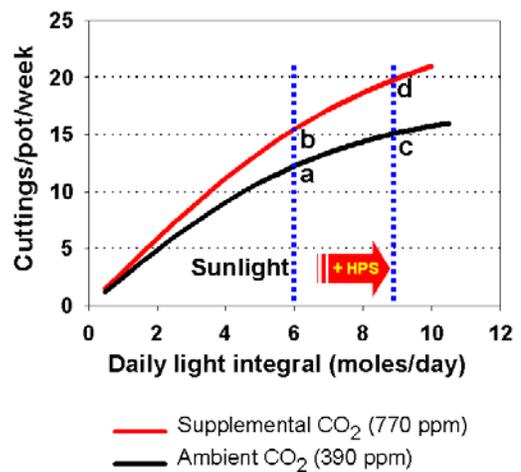
9. Supplemental carbon dioxide (CO₂) increases effect of HPS

Carbon dioxide supplementation is a cost-effective technology that is underused in the U.S. Both light level and carbon dioxide are needed for photosynthesis. As light level

increases, photosynthetic rate is less limited by light and increasingly more limited by CO₂ concentration. Low CO₂ is especially limiting on days with high light during the winter, because plants consume CO₂ during photosynthesis and if the vents are closed then CO₂ is not replenished from the outside air. As a result, many growers who use supplemental lighting also invest in CO₂ enrichment to maximize photosynthesis.

We undertook research during winter 2000-2001 where *Scaevola* plants were grown under a range of light levels, using either shade or supplementing with 3 moles/day of HPS (Figure 6). Ambient sunlight during the experiment was 6 moles/day. We grew the plants with either CO₂ enrichment (770 ppm) or ambient CO₂ (390 ppm).

Ambient sunlight and CO₂ resulted in approx. 12 cuttings/pot/week (Figure 6, point a). Supplementing CO₂ without HPS (point b) resulted in an extra 3 cuttings/pot/week. Adding 3 moles/day of HPS with ambient CO₂ (point c) also



resulted in another 3 cuttings. The greatest increase in production (7 extra cuttings, point d) was observed when supplemental HPS and CO₂ enrichment were applied together. Although we do not yet have precise economic figures, under our research conditions at UNH, CO₂ supplementation was clearly a profitable technology.

Figure 6. *Scaevola aemula* 'New Wonder' cuttings per pot per week grown under a range in daily light integral, and with either ambient CO₂ (390 ppm) or supplemental CO₂ (770 ppm). Ambient sunlight level equaled 6 moles/day, and 3 moles/day were added with HPS.

10. Lighting design is important for best results

When purchasing and installing supplemental lights, growers should solicit the help of greenhouse engineers or commercial suppliers of horticultural lighting. It is essential to have uniform distribution of light, and to use the correct number of fixtures, in order to achieve the target light level. Taking your own best guess at how many lights to install and where to put them is likely to result in uneven growth.

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