Does Supplemental Lighting Make Sense for My Crop?

Chieri Kubota[1], A.J. Both[2], & John F. Burr[3]

[1]School of Plant Sciences – CEAC, The University of Arizona, AZ, USA
[2]Department of Environmental Sciences, Rutgers University, NJ, USA
[3]Krannert School of Management, Purdue University, IN, USA

A simple method to find how much profit you get by adding one more mole of PAR

The problem: Supplemental lighting has been considered a key technology to assure high crop productivity during the time when insufficient photosynthetically active radiation (PAR) or daily light integral (DLI, cumulative PAR) is achieved under natural lighting. Growers need to decide whether supplemental lighting is profitable.

Current recommendations:

Supplemental lighting is recommended when the DLI inside the greenhouse is not meeting the anecdotal crop-specific minimum DLI (typically 10-12 mol m^{-2} d^{-1}). For example, a greenhouse with DLI of 8 mol m^{-2} d^{-1} requires 4 more moles DLI by supplemental lighting to meet the minimum recommendation for tomato of 12 mol m^{-2} d^{-1} (Dorais, 2004). However, while growers can assure acceptable production levels under these DLI, a question of whether use of electrical lighting (LEDs, HPS, etc.) can generate profit or not needs to be answered before making the investment.

This poster presents a simple approach for growers to find the costs and return (and thereby profit) before deciding on making the critical investment of electric lighting.

Step 1: Find your cumulative yield curve over PAR

For vegetable crops, this is often a linear response. Using your cumulative PAR (mol m^{-2}) and cumulative yield (kg m^{-2}), you can create a chart to find the slope (the crop specific PAR productivity, g mol^{-1}) as shown in Figures 1-3.

Step 2: Find expected market price

This can be wholesale market price or direct market price, depending on the grower's business model. Consider percent gross margin (e.g., 65.6% in our analysis) since producing more means higher costs for operation.

Step 3: Find your crop-specific efficacy

The results of Steps 1 & 2 will be your crop-specific efficacy of lighting, telling you how much gross profit you generate per one mole of PAR ($ mol^{-1}). Ranges of values of crop-specific efficacy are shown in our example analysis (Table 1).

Step 4: Decide the target PPF and number of lamps of selected types

Find the DLI necessary to add by electric lighting and the hours to operate per day, this would specify the target PPF (photosynthetic photon flux). This process can be done by a theoretical method (Figure 4) or by a lighting company.

Step 5: Find the cost of operating lamps to add one mole of PAR per m^2

For example, if the target PPF is 100 µmol m^{-2} s^{-1}, the needed operation time to achieve 1 mol m^{-2} is 2.78 hours. Following the equations shown in Figure 4, you can find the electricity cost to get 1 mole of PAR per m^2.

Step 6: Find the heating fuel cost offset

When the greenhouse is heated during the time supplemental lights are used, the offset of heating fuel costs can be considered. Figure 5 shows the costs with and without such offset. Offset becomes smaller when efficient lighting is used.

Table 1. Crop specific efficacies per mole of photosynthetically active radiation. Crop productivity was obtained by linear regression (as shown below) and assumed to be the same regardless of light source (sunlight vs. electric lighting). Efficacies of lighting were derived from corresponding crop productivities, wholesale prices and average industry gross margin.

Crop type	PAR productivity* (FW) (g/mol)	Wholesale value ($/kg)**	Efficacy of lighting (gross profit) ($/mol)***
Tomato (TOV)	7.6-14 g/mol	$2.00/kg	$0.010-0.018/mol
Tomato (cocktail & cherry)	4.6-6.5 g/mol	$4.00/kg	$0.012 -$0.017/mol
Lettuce	3.7-6.9 g/mol	$6.00-$9.00/kg	$0.011 -$0.041/mol
Strawberry	1.5-2.1 g/mol	$6.00-$10.00/kg	$0.006 -$0.014/mol

*Source data: University of Arizona data for all crops; Dorais (2004) for TOV tomato; Both et al. (1997) for lettuce
**Information from non-disclosed sources
***Crop PAR productivity x wholesale value x % gross margin (65.6%)

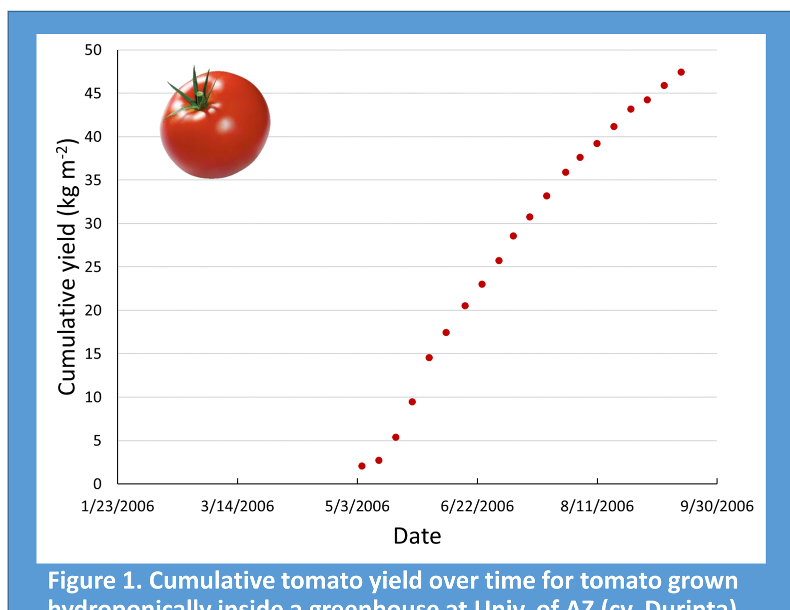


Figure 1. Cumulative tomato yield over time for tomato grown hydroponically inside a greenhouse at Univ. of AZ (cv. Durinta)

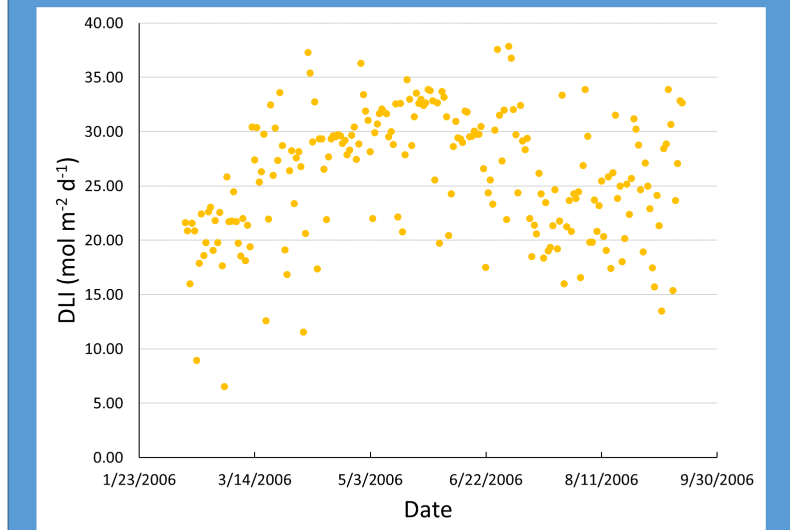


Figure 2. Daily light integral (DLI, mol m^{-2} d^{-1}) inside the greenhouse of Univ. of AZ during the tomato cultivation.

An example process of finding the crop-specific PAR productivity (g mol^{-1} or kg mol^{-1})

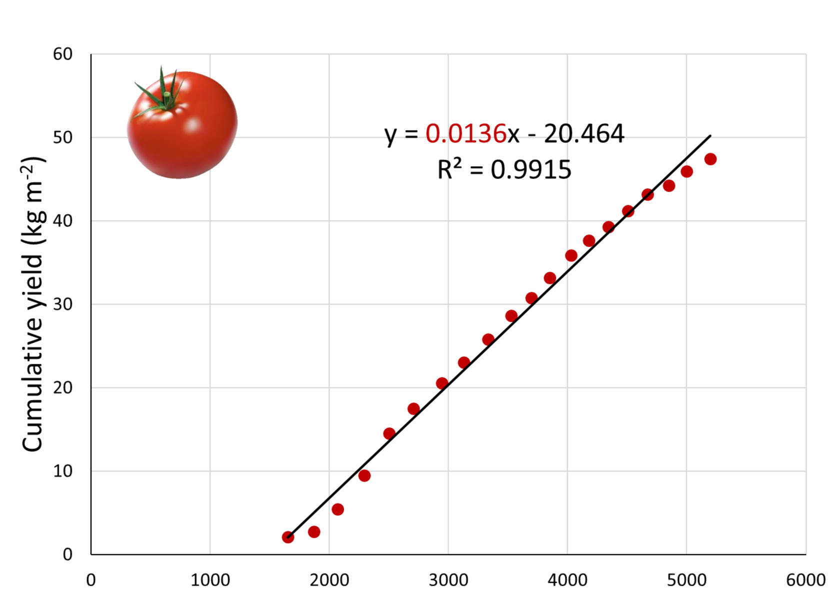
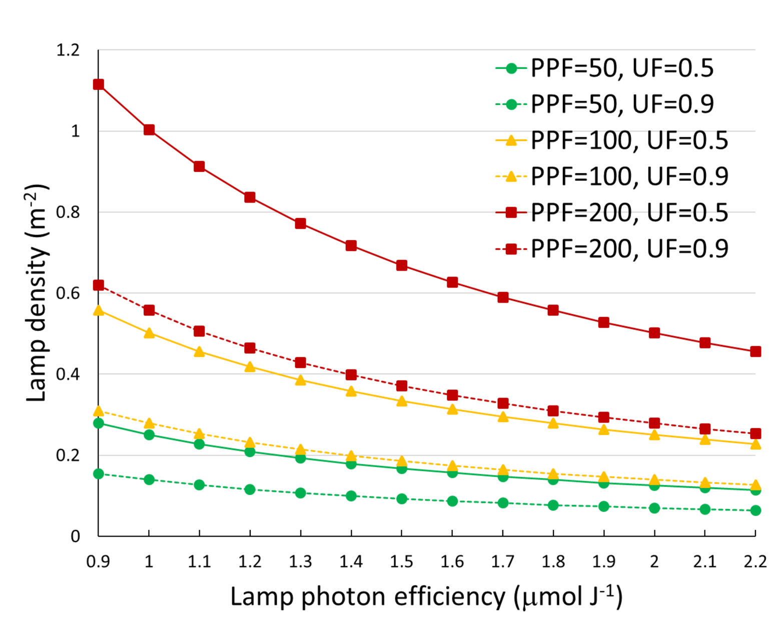


Figure 3. An example of cumulative yield of tomato (cv. Durinta) relative to cumulative PAR. Data obtained at the University of Arizona (Figures 1 & 2, left). The slope (0.0136 kg mol^{-1}) represents the PAR productivity and was obtained by linear regression.



$$N = \frac{PPF \cdot A}{LPE \cdot E \cdot UF \cdot MF}$$

$$LPD\ [\mathrm{W\ m^{-2}}] = \frac{E \cdot N}{A}$$

$$LPC\ [\mathrm{kWh\ m^{-2}\ mol^{-1}}] = \frac{LPD \cdot MH}{10^3}$$

A: Target area to illuminate or greenhouse floor area (m^2)
E: Lamp power input per unit (W)
MF: Maintenance factor
MH: Hours of lighting needed to add 1 mol m^{-2} DLI ($MH = 10^6/(PPF \cdot 3600)$)
LPC: Lamp power consumption (kWh m^{-2} mol^{-1})
LPD: Lamp input power density (W m^{-2})
LPE: Lamp photon efficiency (µmol J^{-1} or µmol s^{-1} W^{-1})
N: Number of lamps (total)
PPF: Photosynthetic photon flux averaged over the target surface (µmol m^{-2} s^{-1})
UF: Utilization factor

Figure 4. Effects of lamp photon efficiencies, target PPF and lamp utilization factor (UF) on lamp density (number of lamps per m^2, N/A in the equations). The equations (right) show the process of finding lamp electricity consumption to achieve 1 mol of PAR per m^2. By multiplying LPC by the electricity price, the electricity cost per mole of PAR can be found.

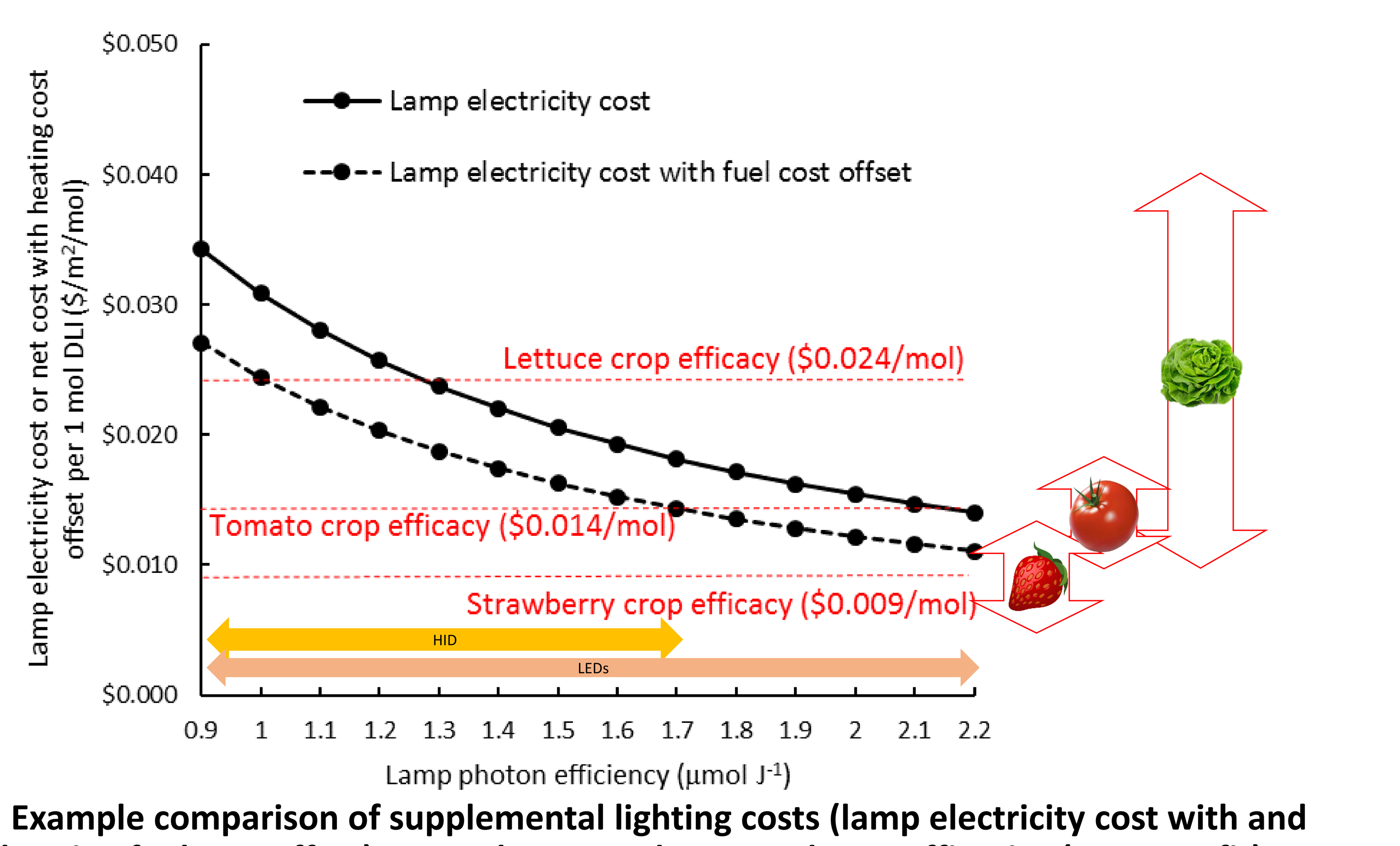


Figure 5. Example comparison of supplemental lighting costs (lamp electricity cost with and without heating fuel cost offset) per mole PAR and expected crop efficacies (gross profit) per mole PAR at different lamp photon efficiencies. Mean values (horizontal lines) of crop efficacies for lettuce, tomato, and strawberry are shown with the ranges (also shown in Table 1). Estimates were made for selected lamp utilization efficiency (UF = 0.9), lamp maintenance factor (MF = 0.9), and electricity price ($0.09 kWh^{-1}). For fuel cost offset estimation, all input electric energy (W m^{-2}) for the lamps was assumed to be eventually converted to heat in this analysis. When the crop efficacy exceeds the cost, lighting can be considered profitable under the condition.

CONCLUSIONS

A simple evaluation method was presented to determine crop-specific lighting efficacy and required lighting technology. This approach can be used by growers as a predictive tool and requires historical yield data (kg m^{-2}) and environmental data (cumulative light integrals). In our example analysis, the use of electric lighting was most profitable for lettuce and the least for strawberry. Use of efficient lamps reduces the lighting costs. In addition, selecting more optimized lighting spectrum as well as delivery method (such as intra-canopy or dynamic control of lighting hours) will increase the crop productivity and decrease the cost of lighting. More research based technology development is needed to assure increased productivity and lighting efficiency. In our study, capital expenditure and their amortization were not included, but these can be further analyzed by considering typical lamp prices and installation costs of different lighting technologies. This approach can be applied also for sole-source lighting, for which we need to add cooling electricity costs base on the cooling efficiency (i.e., COP), instead of subtracting heating fuel costs.

Arizona
College of Agriculture and Life Sciences
Controlled Environment Agriculture Center