Growing horticultural crops indoors vs. in a greenhouse

Various proposals related to urban agriculture have been based on growing food crops without any natural light, or very little. Compensating light sources have been suggested, such as: using electrically-generated light, using concentrating or other mirrors, using photovoltaic panels to operate lights, using LEDs, and installing high-cost items such as fiber optic networks.

Can this work? Is it sustainable?

Below is a sequence of calculations (based on real data or very generous assumptions) that examines one aspect of growing entirely indoors — the additional carbon dioxide emitted to the atmosphere from utility electricity generated for lighting.

Assume:

- Lighting at a PPF efficacy of 2 μmol/s/W (better than the best HPS luminaires);
  2 μmol/s/W *3600 s/hr = 7200 μmol/W-hr = 0.0072 mol/W-hr = 7.2 mol/kWh.
- Daily Light Integral (DLI) = 17 mol/m^2-day (to produce lettuce >= 5 oz/head in 35 days from seeding, for example, as done at Cornell (www.cornellcea.com.))
- Lettuce production = 900 5 oz heads/m^2-yr (based on Cornell's lettuce greenhouse production data).
- In Ithaca, NY, simulations and greenhouse operating data show we get 70% of the required yearly photon flux from the sun, and 30% from supplemental lights.
- Away from Ithaca, one can expect to get ~85% of the yearly light from the sun (based on computer analyses using historical data.)
- "Averaged" utility plant CO_2 emissions: approximately 2 lb CO_2/kWh (see graph below).

Calculations:

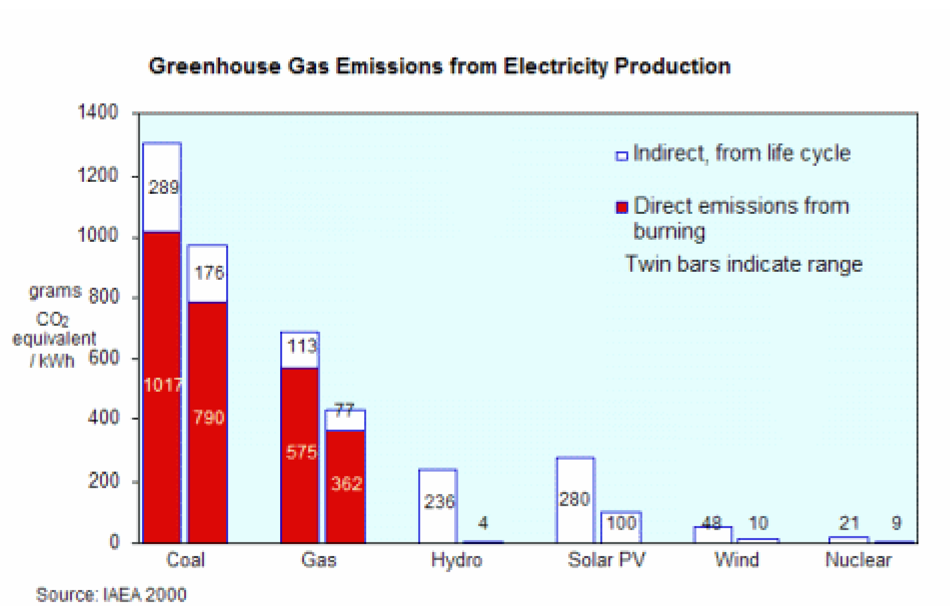
- Light: 17 mol/m^2-d * 365 = 6205 mol/m^2-yr, from all sources (natural and supplemental)
  6205 mol/m^2-yr /10.76 ft^2/m^2 = 577 mol/ft^2-yr
- 900 five-ounce heads/m^2-yr / 10.76 ft^2/m^2 = 84 heads/ft^2-yr
- 577 mol/ft^2-yr/84 heads/ft^2-yr = 6.9 mol/head
- 6.9 mol/head / 7.2 mol/kWh = 0.96 kWh/head, if all from supplemental lighting
- kWh/head = 0.96 if no natural light; or 0.29 (30% supplemental light in an Ithaca greenhouse) or 0.15 (15% supplemental light in a southern New England or New Jersey greenhouse, for example.)
- Difference, Ithaca vs. totally closed production = 0.96 – 0.29 = 0.67 kWh/5 oz head, with an extra 2.0*0.67 = 1.34 lb of CO_2 emitted per 5 oz head if electricity is from an "averaged" power plant and there is no natural light. This is a mass of CO_2 emitted that is more than four times the mass of the lettuce produced, with very generous assumptions that favor growing indoors without using sunlight.

Discussion:

- Actual results can lead to double the calculated ratio of CO_2 emitted to the atmosphere. Eight commercial greenhouse luminaires (400 W HPS) were tested at Cornell (Albright and Both, 1994) and the resulting mol/kWh ratios ranged from 2.84 to 3.51, with a mean of 3.01. If this is used instead of the value of 7.2 above, the calculated ratio rises to more than ten pounds of additional CO_2 emitted for every pound of lettuce produced.
- The ratio of emitted CO_2 with all supplemental lighting, compared to greenhouse production with appropriately sized and controlled supplemental lighting, will be greater when the local climate provides more yearly sunshine. Ithaca, N.Y., for which the above calculations are based, and which is located in one of the cloudiest regions of the U.S.
- Photosynthetic lighting can be reduced significantly when CO_2 is supplemented in the plant production area. However, when full supplemental lighting is also needed, the

cooling load in the confined space will generally lead to continual venting; making use of supplemental CO_2 problematic (costly to replace vented CO_2, and much will be vented.)

- Mirrors to direct sunlight into a vertical farm greenhouse, for example, have been suggested. However, mirrors reflect diffuse light diffusely. In the Northeast, much of the yearly solar light arrives as diffuse radiation, so the mirror area must be increased (more than double the plant growing area) to compensate for this loss, plus other losses. Concentrating mirrors would require tracking in two degrees of freedom, which is beyond "costly" for any area that is more than double the growing area. Furthermore, mirrors would direct light from the side, making it difficult to irradiate the crop uniformly. Finally, solar angles in summer are very different from solar angles in the winter, making tracking of any sort difficult and expensive.
- Can photovoltaic panels make up the difference? See the accompanying discussion paper.
- LED technologies are improving, and their costs shrinking. However, claims that today's commercial LEDs are much more efficient are not justified by data – current LED arrays are typically compared to incandescent lamps, which are notoriously inefficient. However, HID luminaires are also much more efficient than incandescent bulbs, with efficiencies comparable to LEDs.



http://www.world-nuclear.org/education/comparativeco2.html

References:

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