The Case for Peri-Urban Horizontal Greenhouses

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Peri-urban farming has been a historically-important industry in many countries, but is less important today in the United States. Expanding interest in local food production based, in part, on the energy to transport fresh produce across the U.S., with the resulting carbon footprint, have created a focus on food-miles and urban agriculture. However, high land and energy costs, limited access to open spaces of sufficient size and proper shape, and shading from surrounding tall buildings reduce options for agriculture in the urban setting. One suggestion has been vertical greenhouses located in the urban core. Peri-urban farming in horizontal, traditional greenhouses can be a preferred alternative.

Peri-urban is a term for land between the suburbs and surrounding countryside. It coincides with the greenbelt of many cities, and important infrastructure components (e.g., high-speed roads, natural gas, and 3-phase electric power) are usually still accessible. Peri-urban food production is typically applied on small to moderate scales, which complements the concept of urban agriculture.

The value of photosynthetic light is often undervalued in urban agriculture proposals, particularly in discussions of vertical (multi-storied) greenhouses and plant factories. Closed-building growing methods require all or nearly-all electric lighting, in contrast to horizontal greenhouses. What is the advantage of horizontal greenhouses? A specific example can be instructive.

The example is a greenhouse in upstate New York (www.fingerlakesfresh.com.) Data show that, even in this cloudy climate, 70% of the required yearly light inside the greenhouse comes from the sun when daily light integral control provides 17 mol $m^{-2}day^{-1}$ (6205 mol $m^{-2}yr^{-1}$.) If the sun provides 70%, electric lighting must provide 1860 mol $m^{-2}yr^{-1}$. The carbon footprint difference is illustrated by a few simple calculations.

Assume supplemental lighting with a luminaire wall-plug efficacy of 3 mol PAR kWh^{-1}. Productivity in the example greenhouse is c. 760 heads $m^{-2}yr^{-1}$ (Bibb lettuce, 150 to 160 g per head). Electricity to produce lettuce with all electric lighting will, thus, be 6205/3 = 2068 kWh $m^{-2}yr^{-1}$, or 2068/760 = 2.72 kWh $head^{-1}$. In a horizontal greenhouse, 30% of 2.72 = 0.82 kWh per head will be required.

Generating electricity releases CO_2 to the atmosphere. In the U.S. today, averaged over the grid and all sources, 0.46 kg of CO_2 are emitted per kWh of electricity. The density of CO_2 at standard conditions is 1.98 kg m^{-3}. Generating 2.72 kWh releases 2.72*0.46 = 1.25 kg, or 1.25/1.98 = 0.63 m^3 of pure CO_2 to the atmosphere for every head of lettuce with all supplemental light. With 70% of the light from the sun, this is reduced from 1.25 kg to 0.38 kg per head, or 0.63 m^3 to 0.19 m^3. How does this compare to imported fresh produce?

	Truck, cross-country	Vertical, closed	Horizontal, glazed
kWh per head		2.72	0.82
kg CO_2 per head	0.13	1.25	0.38
m^3 CO_2 per head	0.067	0.63	0.19

A frequently touted advantage of local food production is the smaller carbon footprint when less diesel fuel for truck transport is needed. An estimate of the trucking carbon footprint for imported produce can be found on page 4.15 of the 2008 study http://www.cornellcea.com/final%20reports/Energy%20Scoping%20Study%20Final%20Report.pdf. Diesel fuel to transport lettuce from the West Coast to New York State adds c. 0.8 kg of CO_2 per kg of lettuce (or 0.4 m^3 kg^{-1}) to the atmosphere. One kilogram of lettuce is c. 6 heads; trucking releases 0.4/6 = 0.067 m^3 of CO_2 per head.

This is less CO_2 than for local lettuce production in the Northeast. Lighting can be reduced in a closed plant factory by c. 25% when CO_2 is supplemented, but other savings are limited. Opportunities exist for significant improvements with greenhouses. It is difficult to imagine how trucking efficiency can be substantially increased.

Does this mean neither peri-urban nor inner-urban production is appropriate? I suggest not. For example, the light integral/CO_2 control algorithm detailed in U.S. patent 7,502,655 shows greenhouse supplemental light can be reduced c. 50% in Ithaca, NY, with properly controlled light and CO_2, control that makes both natural and supplemental light more efficient. A different and sunnier greenhouse location, such as Hartford, CT, Baltimore, MD, or Islip, NY, will deliver 85% of the yearly light from the sun, which further reduces CO_2 release per head by half. This can reduce carbon dioxide emission to less than required for transport, and reduces the horizontal greenhouse carbon footprint to a much lower number than possible for vertical, closed greenhouses. Further improvements of lighting technologies, and creative control strategies, provide exciting opportunities and challenges for CEA engineers to create even more efficient peri-urban greenhouse food production systems.