"Vertical Farming" Doesn't Stack Up

by Stan Cox and David Van Tassel

Agriculture in America has become an ecological, social and nutritional disaster of sufficiently huge scale to inspire a recent frenzy of book writing, filmmaking, conference-holding and project-initiating. The critiques that emerge are often right on the money, highlighting pesticide and nitrate pollution, soil erosion, the consequences of meat production in feedlots and confinement sheds, the destruction of rural communities and the poor nutritional quality of food. But proposed solutions have tended only to nibble at the edges of what is a catastrophe of continental scale.

A striking example of such ill fit between problem and proposed response can be found in the November 2009 issue of *Scientific American,* where Dickson Despommier, a professor of public health and environmental health sciences at Columbia University, makes the case for what he calls "vertical farming." [1] After doing a very good job of describing the terrible toll that agriculture takes on soil, water and biodiversity across the globe, Despommier's article lays out a proposal to replace soil-based farming with a system of producing food crops in tall urban buildings - to, he writes, "grow crops indoors, under rigorously controlled conditions, in vertical farms.

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Plants grown in high-rise buildings erected on now vacant city lots and in large, multistory rooftop greenhouses could produce food year-round using significantly less water, producing little waste, with less risk of infectious diseases, and no need for fossil-fueled machinery or transport from distant rural farms." (He provides additional details of his vision at verticalfarm.com.)

Despommier describes how one of his scenarios - which are based on the use of hydroponic or "aeroponic" methods of growing plants without soil - might work: "[L]et us say that each floor of a vertical farm offers four growing seasons, double the plant density, and two layers per floor - a multi plying factor of 16 (4 x 2 x 2). A 30-story building covering one city block could therefore produce 2,400 acres of food (30 stories x 5 acres x 16) a year."

By extrapolating numbers like those and assuming extraordinary leaps in technology, as well as the repeal of Murphy's Law, he has made such a convincing case for vertical farms that, he claims, "many developers, investors, mayors and city planners have become advocates."

The idea for vertical agriculture grows out of the realization that there are not enough exposed horizontal surfaces available in most urban areas to produce the quantities of food needed to feed urban populations. [2,3] But even if vertical farming were feasible on a large scale, it would solve no agricultural problems; rather, it would push the dependence of food production on industrial inputs to even greater heights. It would ensure such dependence by depriving crops not only of soil but also of the most plentiful and ecologically benign energy source of all: sunlight.

Groping in the dark

Agriculture as it has always been practiced - call it "horizontal farming" - casts an extremely broad, green "net" across the landscape to capture solar energy, which plants use in producing food. Photosynthesis converts a small percentage of the solar energy that falls on a leaf into the chemical energy in food. But that small percentage is enough; sunlight is plentiful, and left to themselves plants do not have to rely on any other source of energy to grow and produce.

Nevertheless, modern agriculture has managed to make food production an energy-losing proposition. Its emphasis on increasing yield per unit of land and per unit of human labor has meant a sharp increase in the input of fossil energy - with farms often using more energy to produce the food than is contained in the food. Some of the most notorious features of factory farming are dark, dank hog and poultry confinement operations; now, Despommier's plan would create plant-confinement operations as well. Most of the attention that vertical farming has received in the media has been embedded in the context of rooftop gardens, greenhouses, and "green" high-rise facades. [3] But those methods for growing modest amounts of expensive food (usually vegetables) differ from Despommier's plan to "farm" the interiors of buildings in that they are at least capable of capturing solar energy efficiently.

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For obvious reasons, no one has ever proposed stacking solar photovoltaic panels one above the other. For the same reasons, plots of crops cannot be layered one above the other without providing a substitute for the sunlight that has been cut off. Even with all-glass walls, the amount of light reaching plants on all but the top story of a high-rise would fall far, far short of what is needed. (On a sunny day, a room with plenty of windows may look well-lit to our eyes' wide-open pupils, but that light intensity is a tiny fraction of what is needed for crop production.) A significant portion of the light hitting the building would be turned back by the glass, and direct sunlight would penetrate into the interior of a vertical farm only when the sun is low in the sky (especially if, as Despommier recommends, two layers of plants are stuffed into each story.) Even then, it would reach the crop plants at a low angle, so that each square inch of leaf would receive much less light than if the light were hitting the leaf from above.

As a result, the lion's share of a vertical farm's lighting would have to be supplied artificially, consuming resource-intensive electricity rather than free sunlight. We decided to ask, "What would be the consequences of a vertical-farming effort large enough to allow us to remove from the landscape, say, the United States' 53 million acres of wheat?" That's not an unreasonable question. In fact, it follows from Despommier's own reasons for promoting the practice. He argues, correctly, that soil is currently being abused on a massive scale; therefore, to address the problem, vertical farming would need to displace agriculture from a large proportion of the currently cropped landscape.

Our calculations, based on the efficiency of converting sunlight to plant matter, show that just to meet a year's US wheat production with vertical farming would, just for lighting, require *eight times* as much electricity as all US utilities generate in an entire year. [4] And even if it were energetically possible, growing the national wheat crop under lights could substitute for only about 15% of US cropland. Could it succeed, that energy buildup of unprecedented scale would still leave 85% of cropland in place.

Despommier suggests using renewable sources to supply the power needed for vertical farming but fails to consider the scale-up that would be required. Wind, solar, biomass, geothermal and other renewable electricity sources combined account for about 2% of US generation. So to grow the national wheat crop vertically using renewable sources would mean scaling up the nation's renewable sector *400-fold* just to run the lights! (His proposals for doubling plant density, using round-the-clock light or pushing year-round production, even if they could be made to work, would increase production per unit of area but would not decrease the energy needed for lighting per unit of food produced.)

One of our colleagues suggested a tongue-in-cheek alternative: "What about vertical nuclear energy? We could stack reactors in skyscrapers alongside the farming skyscrapers, to provide the electricity!" Fortunately, no one's going to try that, because just to grow our wheat we'd have to add another 4000 or so nuclear reactors to the hundred or so currently in the US.
To have a much greater impact on soil conservation efforts, we'd want to move the US corn crop - about a quarter of our cropped acreage, and some of the most badly abused - indoors. But corn makes wheat's electricity

consumption look modest. Because wheat naturally grows mostly in fall, winter and spring and produces lower yields than summer crops like corn, its light requirement is lower. Similar calculations to those in note 4 below, but for the US corn crop, result in a lighting requirement reaching 40 times the current US electricity supply.

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Maybe trying to satisfy the nation's huge grain requirements with vertical farming is too ambitious. Assume instead that we were to take a more modest approach and grow all vegetables under lights. If they received a similar level of lighting per unit area to that used for wheat, we would "only" have to double our national electricity generation. But removing all vegetable production from the landscape would preserve no more than 2% of our currently cropped soils.

A question of control

Based on its energy requirements for lighting alone, vertical farming would be incapable of substituting for a substantial share of our soil-based agricultural production. But the lighting problem is only the first among many obstacles facing high-rise agriculture. Climate control to achieve suitable growing conditions would add huge energy requirements. And light fixtures would release more energy as heat than as light, which in summer would put huge loads on air-conditioning systems. To maintain the good health of plants grown indoors, humidity and air circulation must be very precisely controlled, often at a high energy cost. And before any of those needs would come the gargantuan resource requirements for construction of the towers themselves.

Then there would be the impracticalities and energy requirements for producing and hauling artificial growth media, fertilizers, water and other resources hundreds of feet up and getting harvests out of the towers. Pesticides could not be eliminated and would undoubtedly be applied in many situations. If Despommier has ever worked in a greenhouse, he knows that some of the pathogens and insects that damage crops in the field can be excluded, but many others will flourish. Powdery mildew, aphids, mites, or other pests can easily wipe out greenhouse-grown crops of wheat, for example, if chemical control is not used.

The system inevitably would also require an enormous input of manual labor. As a hydroponic model, Despommier points approvingly to 300-plus acres of greenhouses near Willcox and Snowflake, Arizona, in which EuroFresh Farms grows vegetables. Energetically, EuroFresh has no relevance to vertical farming, because it is a horizontal operation that makes good use of Arizona sunshine. But with four employees per cropped acre, it does provide a good example of the large manual labor requirements of a massive, intensive hydroponic operation.

EuroFresh's geographical location is no accident. It lies close to the nation's southern border, and the company employs large numbers of immigrant workers. It also employs inmates from a nearby branch of Arizona State Prison. If EuroFresh is to provide an encouraging example for vertical farming, other questions come to mind. Who will own and control the agricultural high-rises? How and from where will the stoop-labor force for vertical farming be recruited? What will become of the farm families whose central role in the nation's life has been replaced by vertical-farming operations? Will they find themselves migrating to the cities to tend corporate tomato vines? □

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The EuroFresh greenhouses can also illustrate some of the pitfalls of high-input indoor farming. In April, 2009, the company filed for Chapter 11 bankruptcy, having fallen victim, according to the *Arizona Daily Star*, to "its debt burden, labor troubles and crop pest problems [including invasions of white flies]." [5] (EuroFresh emerged from bankruptcy in November.)

A high-rise trap

As a proposal to grow food intensively in close proximity to large human populations, vertical farming has managed to catch a ride on the increasingly popular "local food" wave. But as Branden Born and Mark Powell of the University of Washington have argued, localization of food sources as an end in itself does not in any way guarantee that ecological sustainability or social justice will result. To assume the inherent superiority of the local scale, without a critical analysis of the production methods used, the issue of economic control, the types of crops grown and the total quantities of food that can be produced, is to fall into what they call the "local trap." [6]

The local trap, Born and Powell argue, not only can lead to undesired outcomes; it also elbows out of the discussion other approaches, ones working at other scales, that may well give more ecologically and socially desirable results. Despommier's proposal provides a striking example of the local trap in action.

The solution to soil and water degradation is not to strip food-producing plants from the landscape only to grow them, deprived of sunlight, in vertical factory farms. Instead, we have to address the Achilles heel of agriculture itself: that it has displaced, on a massive scale, diverse stands of natural perennial vegetation (such as prairies, savannahs and forests) with monocultures of ephemeral, weakly rooted, soil-damaging annual crops such as corn, soybean and wheat. So far, the weaknesses of the current food-production system have been compensated for agronomically through greater and greater inputs of fossil fuels and other resources, but those efforts have only worsened the ecological impact.

The landscape cannot be saved by further increases in resource use, as would occur with "vertical farming," but rather through what we might call "three-dimensional farming," a system that is arranged horizontally across the landscape to capture and use sunlight but also puts down, deep, long-lived roots to protect the soil, manage water and nutrients efficiently and help restore the below-ground ecosystems that agriculture has destroyed. That will require converting cropland to the production of diverse, food-producing, perennial crops. It will mean a reliance on natural processes and cohesive rural communities, not technological fantasies. [7]

Stan Cox and David Van Tassel are plant breeding researchers at The Land Institute in Salina, Kansas (www.landinstitute.org). Cox's book Losing our Cool: Uncomfortable Truths about our Air-Conditioned World, *will be published in June by The New Press.*

Notes

1. Dickson Despommier, The rise of vertical farms, *Scientific American,* November 2009.
2. See Stan Cox, Broken Agriculture, CounterPunch, May 31, 2008, http://www.counterpunch.org/cox05312008.html
3. See, for example, Gretchen Vogel, Upending the traditional farm, *Science* 319(2008):752-753.
4. The following is a very rough estimate of the amount of power needed just for lighting. Note this is under ideal conditions for nutrients, temperature, and other productivity factors. Under excellent conditions, wheat has radiation use efficiency of 2.8 grams of biomass produced per 106 joule of photosynthetically active radiation (PAR). So to produce one metric ton (106 g) of wheat biomass requires [106 g / (2.8 g/106 J)] = 3.6 x 1011 joules of PAR over a season under ideal conditions.

Suppose an excellent 50% harvest index (ratio of grain mass to total biomass), so that a metric ton of wheat grain requires 7.1 x 1011 joules (actually more because the protein and oil in the grain require extra energy to produce, but ignore that.) The US produced 60 million metric tons of wheat grain in 2009, so that required 6 x 107 times 7.2 x 1011, or 4.3 x 1019 joules of intercepted light energy to produce.

A metal halide greenhouse light (which provides light rich in the wavelengths needed for photosynthesis) requires 2.9 joules of electricity input to produce one joule of photosynthetically active radiation, so to produce 4.3 x 1019 joules of PAR would require 1.2 x 1020 joules of electricity at the socket. One kilowatt-hour is 3.6 x 106 joules, so 3.4 x 1013 kWh of electricity would be required to run those lights.

Total delivered US electricity supply from all sources in 2007 was 4.2 x 1012 kWh. So the entire US electricity supply would have to be increased eightfold just to substitute for the solar radiation converted to biomass by the annual wheat crop.

We acknowledge that the vertical crop would capture small quantities of sunlight through the glass walls of the vertical farm, and that the top floor could be a fully functional greenhouse or garden. That would reduce the artificial lighting requirements, but recall that all of the assumptions of the above calculations err in favor of optimism. Deviations from optimum crop growth, harvest index and health, or less than ideal distribution of light fixtures very close to the crop canopy, reflection of a small portion of PAR from leaves (which does occur), waste of light falling on bare earth between plants in their early growth stages, or any other unforeseen negative impacts on yield will have the effect of increasing the amount of artificial light provided, and electricity consumed, per unit of production calculated above. If anything, the calculated requirement of an eightfold increase in US electricity supply is an underestimate.

5. Dan Sorenson, Eurofresh files Ch. 11; big source of Willcox jobs, *Arizona Daily Star,* 22 April, 2009.
6. Branden Born and Mark Purcell, Avoiding the local trap, *Journal of Planning Education and Research* 26(2006):195-207.
7. For details, see Stan Cox, Shrinking the agricultural economy will pay big dividends, *Synthesis/Regeneration* 48 (Winter 2008) and Jerry D. Glover, Cindy M. Cox and John P. Reganold, Future farming: A return to roots? *Scientific American,*August, 2007.