The RISE of VERTICAL FARMS

Growing crops in city skyscrapers would use less water and fossil fuel than outdoor farming, eliminate agricultural runoff and provide fresh food

By Dickson Despommier

KEY CONCEPTS

- Farming is ruining the environment, and not enough arable land remains to feed a projected 9.5 billion people by 2050.
- Growing food in glass high-rises could drastically reduce fossil-fuel emissions and recycle city wastewater that now pollutes waterways.
- A one-square-block farm 30 stories high could yield as much food as 2,400 outdoor acres, with less subsequent spoilage.
- Existing hydroponic greenhouses provide a basis for prototype vertical farms now being considered by urban planners in cities worldwide.

—The Editors

Together the world's 6.8 billion people use land equal in size to South America to grow food and raise livestock—an astounding agricultural footprint. And demographers predict the planet will host 9.5 billion people by 2050. Because each of us requires a minimum of 1,500 calories a day, civilization will have to cultivate another Brazil's worth of land—2.1 billion acres—if farming continues to be practiced as it is today. That much new, arable earth simply does not exist. To quote the great American humorist Mark Twain: "Buy land. They're not making it any more."

Agriculture also uses 70 percent of the world's available freshwater for irrigation, rendering it unusable for drinking as a result of contamination with fertilizers, pesticides, herbicides and silt. If current trends continue, safe drinking water will be impossible to come by in certain densely populated regions. Farming involves huge quantities of fossil fuels, too—20 percent of all the gasoline and diesel fuel consumed in the U.S. The resulting greenhouse gas emissions are of course a major concern, but so is the price of food as it becomes linked to the price of fuel, a mechanism that roughly doubled the cost of eating in most places worldwide between 2005 and 2008.

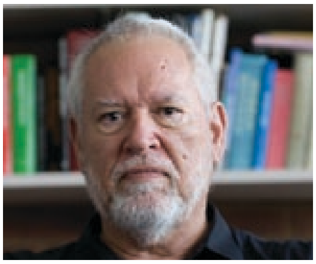
Some agronomists believe that the solution lies in even more intensive industrial farming, carried out by an ever decreasing number of highly mechanized farming consortia that grow crops having higher yields—a result of genetic modification and more powerful agrochemicals. Even if this solution were to be implemented, it is a short-term remedy at best, because the rapid shift in climate continues to rearrange the agricultural landscape, foiling even the most sophisticated strategies. Shortly after the Obama administration took office, Secretary of Energy Steven Chu warned the public that climate change could wipe out farming in California by the end of the century.

What is more, if we continue wholesale deforestation just to generate new farmland, global warming will accelerate at an even more catastrophic rate. And far greater volumes of agricultural runoff could well create enough aquatic "dead zones" to turn most estuaries and even parts of the oceans into barren wastelands.

As if all that were not enough to worry about, foodborne illnesses account for a significant

KENN BROWN *Mondolithic Studios*

[THE AUTHOR]



Dickson Despommier is professor of public health and microbiology at Columbia University and president of the Vertical Farm Project, which functions as a clearinghouse for development work (see www.verticalfarm.com). As a postdoctoral fellow at the Rockefeller University years ago, he became friends with René Dubos, a renowned agricultural sciences researcher who introduced him to the concept of human ecology.

number of deaths worldwide—salmonella, cholera, *Escherichia coli* and shigella, to name just a few. Even more of a problem are life-threatening parasitic infections, such as malaria and schistosomiasis. Furthermore, the common practice of using human feces as a fertilizer in most of Southeast Asia, many parts of Africa, and Central and South America (commercial fertilizers are too expensive) facilitates the spread of parasitic worm infections that afflict 2.5 billion people.

Clearly, radical change is needed. One strategic shift would do away with almost every ill just noted: grow crops indoors, under rigorously controlled conditions, in vertical farms. 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. Vertical farming could revolutionize how we feed ourselves and the rising population to come. Our meals would taste better, too; "locally grown" would become the norm.

The working description I am about to explain might sound outrageous at first. But engineers, urban planners and agronomists who have scrutinized the necessary technologies are convinced that vertical farming is not only feasible but should be tried.

Do No Harm

Growing our food on land that used to be intact forests and prairies is killing the planet, setting up the processes of our own extinction. The minimum requirement should be a variation of the physician's credo: "Do no harm." In this case, do no further harm to the earth. Humans have risen to conquer impossible odds before. From Charles Darwin's time in the mid-1800s and forward, with each Malthusian prediction of the end of the world because of a growing population came a series of technological breakthroughs that bailed us out. Farming machines of all kinds, improved fertilizers and pesticides, plants artificially bred for greater productivity and disease resistance, plus vaccines and drugs for common animal diseases all resulted in more food than the rising population needed to stay alive.

That is until the 1980s, when it became obvious that in many places farming was stressing the land well beyond its capacity to support viable crops. Agrochemicals had destroyed the natural cycles of nutrient renewal that intact ecosystems use to maintain themselves. We must switch to agricultural technologies that are more ecologically sustainable.

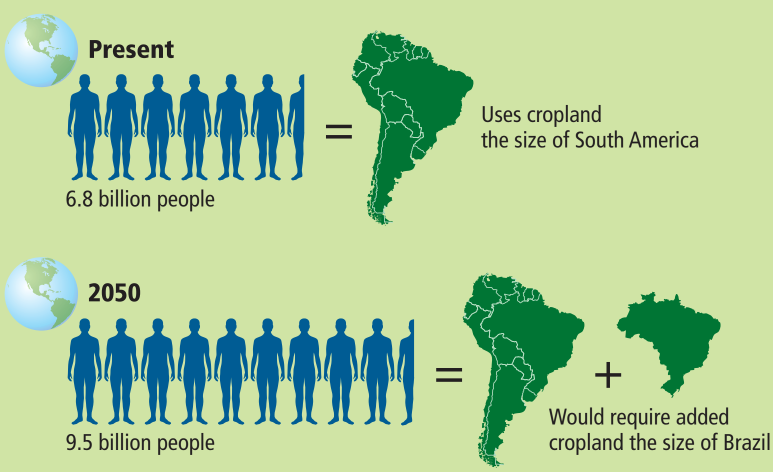
As the noted ecologist Howard Odum reportedly observed: "Nature has all the answers, so what is your question?" Mine is: How can we all live well and at the same time allow for ecological repair of the world's ecosystems? Many climate experts—from officials at the United Nations Food and Agriculture Organization to sustainable environmentalist and 2004 Nobel Peace Prize winner Wangari Maathai—agree that allowing farmland to revert to its natural grassy or wooded states is the easiest and most direct way to slow climate change. These landscapes naturally absorb carbon dioxide, the most abundant greenhouse gas, from the ambient air. Leave the land alone and allow it to heal our planet.

Examples abound. The demilitarized zone between South and North Korea, created in 1953 after the Korean War, began as a 2.5-mile-wide strip of severely scarred land but today is lush and vibrant, fully recovered. The once bare corridor separating former East and West Germany is now verdant. The American dust bowl of the 1930s, left barren by overfarming and drought, is once again a highly productive part of the nation's breadbasket. And all of New England, which was clear-cut at least three times since the 1700s, is home to large tracts of healthy hardwood and boreal forests.

[PROBLEM]

Feeding the Future: Not Enough Land

Growing food and raising livestock for 6.8 billion people require land equal in size to South America. By 2050 another Brazil's worth of area will be needed, using traditional farming; that much arable land does not exist.



COURTESY OF STEVEN CHEN (*Despommier*); LAURIE GRACE (*illustration*)

FARMING EXACTS a heavy toll on the environment: fertilizer runoff feeds large algae blooms that create ocean dead zones (*left; blue and green swirls*); irrigation and vehicles waste massive quantities of water and fossil fuels (*top right*); and pesticides contaminate food, land and groundwater (*bottom right*).

JACQUES DESCLOITRES *Modis Land Rapid Response Team/NASA/GSFC/Visible Earth (phytoplankton bloom)*; DAVID R. FRAZIER *Getty Images (irrigation)*; PAUL GREBLIUNAS *Getty Images (spraying pesticide)*

The Vision

For many reasons, then, an increasingly crowded civilization needs an alternative farming method. But are enclosed city skyscrapers a practical option?

Yes, in part because growing food indoors is already becoming commonplace. Three techniques—drip irrigation, aeroponics and hydroponics—have been used successfully around the world. In drip irrigation, plants root in troughs of lightweight, inert material, such as vermiculite, that can be used for years, and small tubes running from plant to plant drip nutrient-laden water precisely at each stem's base, eliminating the vast amount of water wasted in traditional irrigation. In aeroponics, developed in 1982 by K. T. Hubick, then later improved by NASA scientists, plants dangle in air that is infused with water vapor and nutrients, eliminating the need for soil, too.

Agronomist William F. Gericke is credited with developing modern hydroponics in 1929. Plants are held in place so their roots lie in soilless troughs, and water with dissolved nutrients is circulated over them. During World War II, more than eight million pounds of vegetables were produced hydroponically on South Pacific islands for Allied forces there. Today hydroponic greenhouses provide proof of principles for indoor farming: crops can be produced year-round, droughts and floods that often ruin entire harvests are avoided, yields are maximized because of ideal growing and ripening conditions, and human pathogens are minimized.

Most important, hydroponics allows the grower to select where to locate the business, without concern for outdoor environmental conditions such as soil, precipitation or temperature profiles. Indoor farming can take place anywhere that adequate water and energy can be supplied. Sizable hydroponic facilities can be found in the U.K., the Netherlands, Denmark, Germany, New Zealand and other countries. One leading example is the 318-acre Eurofresh Farms in the Arizona desert, which produces large quantities of high-quality tomatoes, cucumbers and peppers 12 months a year.

Most of these operations sit in semirural areas, however, where reasonably priced land can be found. Transporting the food for many miles adds cost, consumes fossil fuels, emits carbon dioxide and causes significant spoilage. Moving greenhouse farming into taller structures within city limits can solve these remaining problems. I envision buildings perhaps 30 stories high covering an entire city block. At this scale, vertical farms offer the promise of a truly sustainable urban life: municipal wastewater would be recycled to provide irrigation water, and the remaining solid waste, along with inedible plant matter, would be incinerated to create steam that turns turbines that generate electricity for the farm. With current technology, a wide variety of edible plants can be grown indoors [*see illustration on opposite page*]. An adjacent aquaculture center could also raise fish, shrimp and mollusks.

Start-up grants and government-sponsored research centers would be one way to jump-start vertical farming. University partnerships with companies such as Cargill, Monsanto, Archer Daniels Midland and IBM could also fill the bill. Either approach would exploit the enormous talent pool within many agriculture, engineering and architecture schools and lead to prototype farms perhaps five stories tall and one acre in footprint. These facilities could be the "playground" for graduate students, research scientists and engineers to carry out the necessary trial-and-error tests before a fully functional farm emerged. More modest, rooftop operations on apartment complexes, hospitals and schools could be test beds, too. Research installations already exist at many schools, including the University of California, Davis, Pennsylvania State University, Rutgers University, Michigan State University, and schools in Europe and Asia. One of the best known is the University of Arizona's Controlled Environment Agriculture Center, run by Gene Giacomelli.

Integrating food production into city living is a giant step toward making urban life sustainable. New industries will grow, as will urban jobs never before imagined—nursery attendants, growers and harvesters. And nature will be able to rebound from our insults; traditional farmers would be encouraged to grow grasses and trees, getting paid to sequester carbon. Eventually selective logging would be the norm for an enormous lumber industry, at least throughout the eastern half of the U.S.

Practical Concerns

In recent years I have been speaking regularly about vertical farms, and in most cases, people raise two main practical questions. First, skeptics wonder how the concept can be economically viable, given the often inflated value of properties in cities such as Chicago, London and Paris. Downtown commercial zones might not be affordable, yet every large city has plenty of less desirable sites that often go begging for projects that would bring in much needed revenue.

In New York City, for example, the former Floyd Bennett Field naval base lies fallow. Abandoned in 1972, the 2.1 square miles scream out for use. Another large tract is Governors Island,

GROWING TECHNIQUES

Three technologies would be exploited in vertical farms.

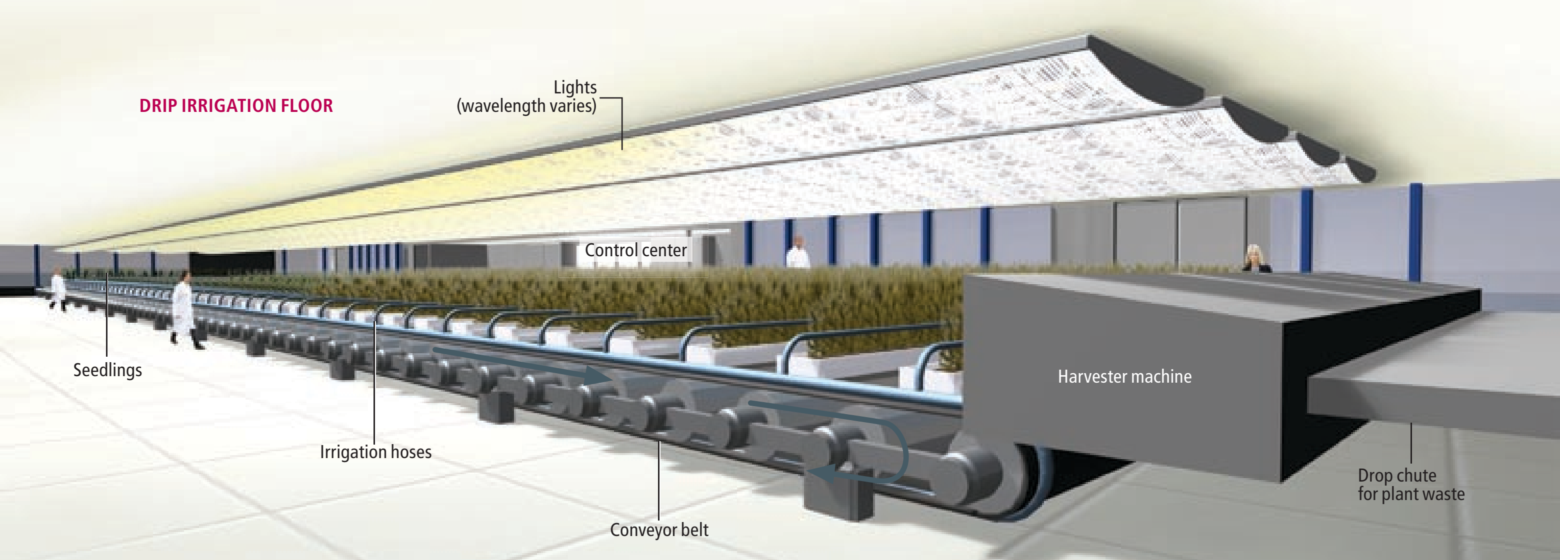
AEROPONICS
Plants are held in place so their roots dangle in air that is infused with water vapor and nutrients. Good for root crops (potatoes, carrots).

HYDROPONICS
Plants are held in place so their roots lie in open troughs; water with dissolved nutrients is continually circulated over them. Good for many vegetables (tomatoes, spinach) and berries.

DRIP IRRIGATION
Plants grow in troughs of lightweight, inert material, such as vermiculite, reused for years. Small tubing on the surface drips nutrient-laden water precisely at each stem's base. Good for grains (wheat, corn).

Maximum Yield

On most floors of a vertical farm [*see opposite page*], an automated conveyor would move seedlings from one end to the other, so that the plants would mature along the way and be at the height of producing grain or vegetables when they reached a harvester. Water and lighting would be tailored to optimize growth at each stage. Inedible plant material would drop down a chute to electricity-generating incinerators in the basement.



KEVIN HAND

High-Rise Crops

A 30-story vertical farm would exploit different growing techniques on various floors. Solar cells and incineration of plant waste dropped from each floor would create power. Cleansed city wastewater would irrigate plants intead of being dumped into the environment. The sun and artificial illumination would provide light. Incoming seeds would be tested in a lab and germinate in a nursery. And a grocery and restaurant would sell fresh food directly to the public.

EUROFRESH FARMS, enclosing 318 acres in Willcox, Ariz., has grown tomatoes, cucumbers and peppers hydroponically for more than a decade, proving that the technology—and indoor farming—can be efficient on a massive scale.

COURTESY OF HOLLIS GRAPHICS (*greenhouse*); COURTESY OF EUROFRESH FARMS (*aerial view*)

a 172-acre parcel in New York Harbor that the U.S. government recently returned to the city. An underutilized location smack in the heart of Manhattan is the 33rd Street rail yard. In addition, there are the usual empty lots and condemned buildings scattered throughout the city. Several years ago my graduate students surveyed New York City's five boroughs; they found no fewer than 120 abandoned sites waiting for change, and many would bring a vertical farm to the people who need it most, namely, the underserved inhabitants of the inner city. Countless similar sites exist in cities around the world. And again, rooftops are everywhere.

Simple math sometimes used against the vertical farm concept actually helps to prove its viability. A typical Manhattan block covers about five acres. Critics say a 30-story building would therefore provide only 150 acres, not much compared with large outdoor farms. Yet growing occurs year-round. Lettuce, for example, can be harvested every six weeks, and even a crop as slow to grow as corn or wheat (three to four months from planting to picking) could be harvested three to four times annually. In addition, dwarf corn plants, developed for NASA, take up far less room than ordinary corn and grow to a height of just two or three feet. Dwarf wheat is also small in stature but high in nutritional value. So plants could be packed tighter, doubling yield per acre, and multiple layers of dwarf crops could be grown per floor. "Stacker" plant holders are already used for certain hydroponic crops.

Combining these factors in a rough calculation, let us say that each floor of a vertical farm offers four growing seasons, double the plant density, and two layers per floor—a multiplying factor of 16 ($4 \times 2 \times 2$). A 30-story building covering one city block could therefore produce 2,400 acres of food (30 stories $\times$ 5 acres $\times$ 16) a year. Similarly, a one-acre roof atop a hospital or school, planted at only one story, could yield 16 acres of victuals for the commissary inside. Of course, growing could be further accelerated with 24-hour lighting, but do not count on that for now.

Other factors amplify this number. Every year droughts and floods ruin entire counties of crops, particularly in the American Midwest. Furthermore, studies show that 30 percent of what is harvested is lost to spoilage and infestation during storage and transport, most of which would be eliminated in city farms because food would be sold virtually in real time and on location as a consequence of plentiful demand. And do not forget that we will have largely eliminated the mega insults of outdoor farming: fertilizer runoff, fossil-fuel emissions, and loss of trees and grasslands.

The second question I often receive involves the economics of supplying energy and water to a large vertical farm. In this regard, location is everything (surprise, surprise). Vertical farms in Iceland, Italy, New Zealand, southern California and some parts of East Africa would take advantage of abundant geothermal energy. Sun-filled desert environments (the American Southwest, the Middle East, many parts of Central Asia) would actually use two- or three-story structures perhaps 50 to 100 yards wide but miles long, to maximize natural sunlight for growing and photovoltaics for power. Regions gifted with steady winds (most coastal zones, the Midwest) would capture that energy. In all places, the plant waste from harvested crops would be incinerated to create electricity or be converted to biofuel.

One resource that routinely gets overlooked is very valuable as well; in fact, communities spend enormous amounts of energy and money just trying to get rid of it safely. I am referring to liquid municipal waste, commonly known as blackwater. New York City occupants produce one billion gallons of wastewater every day. The city spends enormous sums to cleanse it and then dumps the resulting "gray water" into the Hudson River. Instead that water could irrigate vertical farms. Meanwhile the solid by-products, rich in energy, could be incinerated as well. One typical half-pound bowel movement contains 300 kilocalories of energy when incinerated in a bomb calorimeter. Extrapolating to New York's eight million people, it is theoretically possible to derive as much as 100 million kilowatt-hours of electricity a year from bodily wastes alone, enough to run four, 30-story farms. If this material can be converted into useful water and energy, city living can become much more efficient.

Upfront investment costs will be high, as experimenters learn how to best integrate the various systems needed. That expense is why smaller prototypes must be built first, as they are for any new application of technologies. Onsite renewable energy production should not prove more costly than the use of expensive fossil fuel for big rigs that plow, plant and harvest crops (and emit volumes of pollutants and greenhouse gases). Until we gain operational experience, it will be difficult to predict how profitable a vertical farm could be. The other goal, of course, is for the produce to be less expensive than current supermarket prices, which should be attainable largely because locally grown food does not need to be shipped very far.

HURDLES

Several roadblocks could stifle the spread of urban farms, but all can be solved.

- Reclaim enough abandoned city lots and open rooftops as sites for indoor agriculture.
- Convert municipal wastewater into usable irrigation water.
- Supply inexpensive energy to circulate water and air.
- Convince city planners, investors, developers, scientists and engineers to build prototype farms where practical issues could be resolved.

Desire

It has been five years since I first posted some rough thoughts and sketches about vertical farms on a Web site I cobbled together (www.verticalfarm.com). Since then, architects, engineers, designers and mainstream organizations have increasingly taken note. Today many developers, investors, mayors and city planners have become advocates and have indicated a strong desire to actually build a prototype high-rise farm. I have been approached by planners in New York City, Portland, Ore., Los Angeles, Las Vegas, Seattle, Surrey, B.C., Toronto, Paris, Bangalore, Dubai, Abu Dhabi, Incheon, Shanghai and Beijing. The Illinois Institute of Technology is now crafting a detailed plan for Chicago.

All these people realize that something must be done soon if we are to establish a reliable food supply for the next generation. They ask tough questions regarding cost, return on investment, energy and water use, and potential crop yields. They worry about structural girders corroding over time from humidity, power to pump water and air everywhere, and economies of scale. Detailed answers will require a huge input from engineers, architects, indoor agronomists and businesspeople. Perhaps budding engineers and economists would like to get these estimations started.

Because of the Web site, the vertical farm initiative is now in the hands of the public. Its success or failure is a function only of those who build the prototype farms and how much time and effort they apply. The infamous Biosphere 2 closed-ecosystem project outside Tucson, Ariz., first inhabited by eight people in 1991, is the best example of an approach not to take. It was too large of a building, with no validated pilot projects and a total unawareness about how much oxygen the curing cement of the massive foundation would absorb. (The University of Arizona now has the rights to reexamine the structure's potential.)

If vertical farming is to succeed, planners must avoid the mistakes of this and other non-scientific misadventures. The news is promising. According to leading experts in ecoengineering such as Peter Head, who is director of global planning at Arup, an international design and engineering firm based in London, no new technologies are needed to build a large, efficient urban vertical farm. Many enthusiasts have asked: "What are we waiting for?" I have no good answer for them. ■

MORE TO EXPLORE

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