BRINGING THE FARM INDOORS

New technology is changing where and how some crops are grown

BY TIM SABLIK

This vertical farm, created by Freight Farms, uses energy-efficient LED lights, which help farmers have greater control over the amount of light plants receive.

On April 29, Newark, N.J.-based AeroFarms broke ground on a new farm in Danville, Va. When it opens for business next year, it will be the largest farm of its kind in the world. Yet compared to the typical commercial farm, it will occupy a tiny amount of land — just over 3 acres. Rather than planting in sprawling outdoor fields, AeroFarms will grow its crops indoors.

AeroFarms' new facility is one of many vertical farms being built in the United States and around the world. Vertical farming is a form of controlled environment agriculture (CEA), which uses a range of technologies and techniques to optimize plant growth and minimize the risks and variability found in outdoor growing. And, as the name suggests, vertical farms grow up rather than out. Racks of plants can be stacked on top of each other, allowing the farm to economize on space. That is particularly valuable for farmers looking to grow food in places where land is scarce, such as cities.

Proponents of vertical farming and CEA in general argue that it can help increase the supply of healthier, more sustainable, and more local food. But can it compete with traditional outdoor farming?

TAKING CONTROL

One of the main benefits of growing indoors is that it affords farmers much greater control over their environment.

"Mother Nature introduces all this variability and risk to yields and harvest timing," says Michael Evans, director of the School of Plant and Environmental Sciences at Virginia Tech and associate director of the Controlled Environment Agriculture Innovation Center (CEAIC). "With a vertical farm or greenhouse, you get a lot more control over the environmental conditions."

Plants in indoor farms are protected from unexpected changes in the weather, as well as from pests and many diseases found outdoors. Farmers can control temperature and airflow in the facility as well as the amount of water, nutrients, and light each plant receives. This enables farmers to grow crops year-round, regardless of season and climate, with greater consistency and predictability. That is increasingly valuable as changing climates have injected greater uncertainty into farming.

Shenandoah Growers, based in Rockingham, Va., started out as a field

IMAGE: CAROLINE KATSIROUBAS/FREIGHT FARMS

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farming operation in 1989. But around 2008, they decided to take their farming operations indoors.

"We were already seeing the disruption in growing cycles from climate change, and it was impacting our ability to be commercially viable," says Cameron Geiger, Shenandoah Growers' chief operating officer. "We wanted to be able to have more control over weather events to make sure we could continue to be a cost-effective supplier to retailers."

The control afforded by CEA doesn't come free, however. Relying on technology rather than Mother Nature to grow plants can be expensive, depending on the setup. Plants grown outdoors get their light for free from the sun, whereas those grown indoors are either partially or entirely reliant on artificial lighting powered by electricity. Controlling the temperature and airflow in an indoor farm also requires energy to power heating, ventilation, and air conditioning systems.

That said, indoor farms can be more efficient than outdoor farms in many respects. Most indoor farms grow plants in a water-based nutrient solution — a technique known as hydroponics. In addition to not needing soil, hydroponic systems typically use much less water than outdoor farms. Water can be reused instead of being lost to runoff or evaporation.

Technological advances have also helped indoor farms make strides toward improving the efficiency of their artificially supplied resources, such as light.

"The main driver that has reignited interest in growing plants indoors recently is the ability to produce light with light-emitting diodes at high intensity using less energy," says Ricardo Hernandez, a professor of horticulture science at North Carolina State University whose research focuses on light use in CEA.

The first light-emitting diode, or LED, bulbs were developed in the 1960s. They were costly to produce and not very bright, but LED technology has come a long way since then. In 2000, scientist Roland Haitz of HP Inc., formerly named the Hewlett-Packard Co., predicted that the cost per unit of light emitted by LEDs would fall by a factor of 10 each decade and the amount of light they generated would increase by a factor of 20. So far, commercial producers have met or even exceeded "Haitz's law," as the prediction came to be known. In addition to improving energy efficiency in homes and powering displays in consumer electronics, modern LEDs have prompted a resurgence in indoor farming.

"Before LEDs, indoor farms mainly used fluorescent bulbs, which are actually an ideal spectrum for growing plants but not very energy efficient on a large scale," says Hernandez. "That meant that 70 percent to 80 percent of the electricity for indoor farming was used to power the lights. Now, thanks to LEDs, that percentage has shrunk to maybe 30 percent to 40 percent of total electricity."

With LEDs, farmers also have greater control over the spectrum of light plants receive, allowing them to tweak light recipes to generate optimal growth.

The specifics of every farming operation are different, but most estimates suggest that despite these recent gains in efficiency, indoor farming still faces an uphill battle on costs compared to outdoor farming. In 2019, Peter Tasgal, a food and agriculture consultant and CEA specialist, estimated that farming in a greenhouse or vertical farm is about three to five times more expensive than farming outdoors. And upfront costs for building a state-of-the-art vertical farm can be substantial: AeroFarms is investing $53 million to build its new facility in Danville. Still, larger costs don't necessarily rule out an economic case for CEA if consumers are willing to pay more for indoor-grown food.

FEEDING DEMAND

Demand for organic food has been growing steadily year over year. According to the latest Census of Agriculture from the U.S. Department of Agriculture (USDA), sales of organic crops grew 38 percent from 2016 to 2019. And early indications are that the COVID-19 pandemic may have accelerated this trend. The Organic Trade Association reported that organic food sales jumped by nearly 13 percent in 2020.

While indoor farms don't necessarily need to grow organic crops, they are well suited for it. Having a controlled environment naturally protects plants from pests, allowing indoor farmers to use fewer or even no pesticides. And growing plants without soil eliminates exposure to many types of plant diseases and removes the need for traditional fertilizers.

"Customers are savvier now. They don't want pesticides and fertilizers sprayed on their food," says Scott Lowman, director of applied research at the Institute for Advanced Learning and Research in Danville. In 2000, he co-founded a farm in Lynchburg, Va., aimed at meeting consumer demand for local and organic food. Now, he oversees the newly constructed CEAIC in partnership with Virginia Tech and the Virginia Seafood Agricultural Research and Extension Center in Hampton, Va.

Studies suggest that consumers are willing to pay extra to eat organic food, which could offset some of the costs associated with indoor farming. In a 2008 article, researchers at the USDA and the University of Georgia found that U.S. consumers were willing to pay premiums of 15 percent to 60 percent for organic produce. Moreover, chemicals, fertilizers, and seeds made up one of the highest spending categories for traditional farms in 2019, according to the USDA — so relying less on pesticides and fertilizers could also help indoor farms keep their prices competitive.

"We do not want to perpetuate a disparity where only wealthy people can afford to eat healthy," says Geiger. "Our goal is to make it possible for our retail partners to sell organic produce to consumers at the same price as nonorganic so that the customer can make the choice."

Currently, there are some limitations on what indoor farmers can profitably grow, however. While it is technically possible to grow any plant indoors, some crops require more space and resources than others.

"There are lots of crops that either because of the acreage or the energy required and their value, you are never going to grow them in a greenhouse or a vertical farm," says Evans. That list includes most "agronomic" crops like wheat, rice, corn, and soybeans

Vertical farms, like this one at the Controlled Environment Agriculture Innovation Center in Danville, Va., use a range of technologies to optimize growth and minimize risks.

IMAGE: CONTROLLED ENVIRONMENT AGRICULTURE INNOVATION CENTER

that form the bedrock of the world's food supply. For now, most vertical farms focus on leafy greens and herbs because they are high-value and grow well in small spaces. But as CEA expands, scientists are looking at ways to adapt more crops to indoor growing.

"A lot of current vertical farms are using genetics for plants that were designed to grow in the field," says Hernandez. "We are looking into using gene-editing technology to produce plant cultures that will excel in a vertical farm environment."

Evans says that at the CEAIC they are experimenting with growing micro tomatoes that were originally developed for ornamental agriculture. Their smaller size makes them well suited to fitting in vertical farm racks. And Geiger says that while Shenandoah Growers is currently focused on organic herbs and leafy greens because that is their core business, they are exploring expanding into other crops as well.

The technology for indoor agriculture can be used to grow more than just plants, too. The CEAIC partners with the Virginia seafood extension center because indoor aquaculture uses many of the same technologies as indoor agriculture. Lowman explains that early efforts to combine the disciplines ran into problems because growing plants and fish in the same water resulted in cross-contamination. But modern aquaponic systems treat and reuse water for both the plants and fish, allowing farmers to keep them separate but grow both in the same facility and conserve resources.

RETHINKING WHERE WE GROW

In addition to increasing the overall supply of food, vertical farms also create opportunities to grow food closer to consumers. Because they aren't limited by available arable land, vertical farms can theoretically be built anywhere.

The biggest markets for food in America are in cities. More than 80 percent of Americans live in cities or metropolitan suburbs. That share is expected to continue rising despite some questions surrounding the future of cities in the aftermath of the COVID-19 pandemic. (See "Has the Pandemic Changed Cities Forever?" *Econ Focus*, First Quarter 2021.) But most food consumed by urbanites is imported, either from farms in rural America or other countries.

That wasn't always the case, but throughout the 19th and 20th centuries, farms became larger and more industrialized thanks to advancements in technology that generated economies of scale. As farms grew, it made more sense to locate them away from cities where land was cheaper and more abundant. At the same time, advancements in transportation technology made it easier and cheaper for cities to import food. While the early 1900s saw some attempts to continue farming in suburbs close to cities, those efforts dwindled as cities expanded.

Thomas Wheet grew up in Washington, D.C., where he currently manages the Bertie Backus Food Hub for the Center for Urban Agriculture and Gardening Education at the University of the District of Columbia. Although having healthy food was always important to his family, he didn't think much about where that food came from. In that respect, he says he was like most city dwellers.

"I think there was a general feeling in cities that you could just show up at a grocery store and expect there to be avocados in December without really thinking about where they came from or how they got there," says Wheet.

Like the demand for organic food, demand for more locally grown food has been steadily increasing, and COVID-19 seems likely to accelerate this trend. For decades, most food has been produced on large farms and shipped to restaurants and grocery stores across the country. But during the pandemic, many of those supply chains were disrupted. (See "Unpacking the Meat Industry," *Econ Focus*, Fourth Quarter 2020.)

"People in cities realized that building resiliency into the supply chains is essential to make sure that we continue to have access to the foods that we take for granted," says Wheet.

Wheet adds that, historically, urban agriculture has tried to apply outdoor growing techniques to city spaces through projects like community or rooftop gardens. Although such gardens are valuable, the cost of land in cities makes it unlikely that such approaches could reach the scale to fully meet the demand of urban consumers. Wheet and others believe that vertical farming presents an

opportunity to get closer to meeting that demand for local produce.

Richmond, Va.-based Babylon Micro-Farms Inc. started as a project at the University of Virginia in 2016 to find food solutions for refugee camps. But CEO and co-founder Alexander Olesen says they quickly saw an opportunity to make food more accessible for everyone by developing small-scale vertical farms that could be installed directly inside a food service space.

"Modular solutions represent a more accessible alternative to the big, utility-scale farms that are prominent today," says Olesen. "Our farms can be built in or close to the point of consumption, allowing the food service operator to increase their self-reliance for a lot of their highly perishable and often very high-value ingredients."

Olesen says that their clients are willing to pay a premium to have access to those items year-round at peak freshness rather than rely on importing them from distant farms where they might lose flavor and nutrition in transit. Babylon's team automates all of the growing decisions for their clients' farms via the cloud, which means food service providers don't need to have any farming expertise to grow their crops on-site.

Freight Farms Inc., founded in 2010 in Boston, Mass., has also taken a modular approach to farming. They build and sell vertical farms in storage containers, allowing people to have their own farm installed virtually anywhere. Their customers include entrepreneurs looking to start their own farming business, as well as institutions like schools that use the container farms as classrooms and to augment their cafeteria's supply of fresh local greens.

"Because the farm is in a container, you can put it right next to the need," says CEO Rick Vanzura. Freight Farms reports that it has sold about 400 farms to customers in 49 states and U.S. territories and 33 countries, and on average its farms are no more than 20 miles away from the end consumer, providing both convenience and nutritional benefits.

"The average age of produce sitting on grocery shelves is about 12 days postharvest," says Vanzura. "In that time, you lose a lot of texture, flavor, and nutrition. Over half of the nutritional value of plants is lost by the ninth day."

LOOKING AHEAD

In addition to shortening supply chains and boosting urban agriculture, many proponents of vertical farming tout the environmental benefits of growing and consuming more food locally.

But the evidence on that remains unclear. In a 2015 report, the USDA estimated that transportation only accounts for about 11 percent of greenhouse gas emissions from conventional agricultural production, and the mode of transportation matters more than the distance crossed. Large farming operations can take advantage of economies of scale in transportation, using water and rail shipping that generate fewer greenhouse gas emissions than trucking.

While food grown in smaller vertical farms like those produced by Babylon Micro-Farms or Freight Farms can be harvested very close to consumers, larger vertical farms still need to transport their products to customers, possibly using less environmentally friendly methods such as trucks. Additionally, indoor farms consume electricity that may be generated from fossil fuels to power their LEDs and other environmental controls, although many are exploring ways to get more of their energy from renewable sources. So the ultimate environmental impact of a shift toward more indoor farming is, so to speak, up in the air.

Outdoor farming is unlikely to ever be completely replaced, though. Because of economies of scale, there will still be a need to grow some crops outdoors in rural areas where land is plentiful. But the tools and techniques being developed in CEA can benefit outdoor farming as well. Sensors used to monitor indoor plant growth have migrated to the field, and field farmers can use the controlled environment of indoor farms as a laboratory for testing different growth recipes for plants. At N.C. State, Hernandez and his colleagues grow young plants indoors where they can be protected from pests and diseases, giving them a head start before transplanting them to fields.

"Vertical farming is just another tool of food production," says Hernandez. "We need field production, we need indoor production, we need all kinds of production to feed our growing population."

Expanding that production will require investments in both technologies and skills.

"How do you find engineers who are used to working with plants? Or data scientists who are used to working with plant scientists?" says Lowman of Danville's Institute for Advanced Learning and Research. "The controls behind these systems are very complex, so they require a unique skill set."

Cloud-based growing solutions like those offered by Babylon Micro-Farms and Freight Farms allow customers to operate small-scale vertical farms without specialized skills. But as the industry grows, the skills needed to be a commercial farmer are likely to continue evolving.

"It's hard to predict," says Lowman, "but I think we're just barely scraping demand with the amount of vertical farming outfits available now." **EF**

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