The Future of Farming Takes Root

Sustainable agriculture is quickly becoming the wave of the future as global leaders grapple with the question of how to feed a world population approaching 10 billion. At the UA, researchers are looking

up for answers, in the form of vertical farming.

"Research and development leads to innovations and technology. I always knew that I wanted to go into that direction, so that I can contribute to solving some important problems facing our planet," says Joel Cuello, UA professor of agricultural and biosystems engineering. (Photo: Bob Demers/UA News)

Joel Cuello has fond memories of the small patch of dirt behind the elementary school he attended in the Philippines. Textbook lessons on germination and photosynthesis came to life as the students sowed seeds that sprouted into plants. He and his classmates learned the importance of light, carbon dioxide, water and nutrients on the plants' growth, and they saw the connection between plants and food as they harvested their crops.

No one could have guessed those early lessons in the garden would cultivate a lifelong passion. As a professor of agricultural and biosystems engineering at the University of Arizona, Cuello still grows plants in a tiny space on campus, but with a larger purpose in mind. He wants to feed the world.

A Coming Food Crisis

According to the United Nations' report "World Population Prospects: The 2017 Revision," the current world population of 7.6 billion is expected to reach 9.8 billion by 2050.

"That would be the equivalent of adding another China and another India to our planet in terms of population. That's a lot of people and a lot of mouths to feed three times a day," says Cuello, who is a member of the UA's **BIO5 Institute** and director of the Global Initiative for Strategic Agriculture in Dry Lands. "The United Nations predicts that to be able to meet the food demand by the middle of the century, we have to increase our current food production by 70 percent, and the corresponding crop production has to double. That is a very tall order."

Agricultural practices already have changed significantly throughout history in response to a growing population and changing society. During the Green Revolution of the 1960s, new technologies resulted in marked increases in agricultural production worldwide. But today, agricultural production has plateaued and, in some cases, even declined.

Agriculture faces declining land and water availability in many parts of the world while still using large amounts of resources such as land, water and energy. Traditional agriculture uses 70 percent of fresh water resources and 50 percent of the planet's land. Food production and the supply chain use about 30 percent of global energy expenditures on a yearly basis.

Lettuce is grown in a floating raft hydroponics system at the UAg Farm, which is sponsored by the UA Water, Environmental and Energy Solutions Program and Controlled Environment Agriculture Center, with in-kind support provided by industry collaborators Illumitex, HortAmericas, IndoorHarvest, Civic Farms, Enza Zaden and Grodan. (Photo courtesy of Murat Kacira)

"We can't afford to use all of these remaining resources, whatever is left, to be able to achieve that increase in food production," says **Cuello**, who became interested in sustainable agriculture while completing his postdoctoral work at NASA's Controlled Ecological Life Support Systems Division. "NASA focused my interest in the sustainability aspect of producing food. It crystallized for me the idea of, and the importance of, being able to produce food in a very sustainable manner.

"What I learned at NASA basically has been my guiding principle in my research, which is achieving sustainability and maximizing performance, meaning crop productivity per unit resource used," Cuello adds. "The bottom line is we need to be able to come up with an innovation or innovations that enable us to produce more food with less use of resources."

Enter the vertical farm.

Sustainable Agriculture for Food Production

A vertical farm, at its most basic definition, is a crop production building. Shelves are stacked, one on top of the other, full of fast-growing leafy crops such as lettuce, basil and chard. A true vertical farm is completely enclosed, like a warehouse, and can be operated year-round, independent of geography, climate or season. Inside, every resource is carefully managed and controlled, in contrast to the unpredictability of traditional agriculture, which is highly dependent on the weather.

"In terms of vegetables, or some fruits like strawberries, it's more efficient to grow them in vertical farms, where you can recycle the nutrients and use solar radiation for energy," Joel Cuello says. "Land in some cities is very expensive, but you can grow these vertical farms around cities, but at a distance that is quite manageable." (Photo: Bob Demers/UA News)

"To me, vertical farming is an idea whose time has come," Cuello says. "In the open field, because it's open to the atmosphere, the temperature, relative humidity and light radiation fluctuate over the course of a day. The productivity is not optimized or maximized, and it's also not consistent. Whereas in a vertical farm, productivity is optimized or maximized, and it's consistent. It helps tremendously in being able to help produce food to meet the demand."

In a vertical farm, all of the resources plants need to thrive are supplied in optimal amounts, resulting in a high level of sustainability. Instead of soil, crops are grown hydroponically in nutrient-rich water. Sunlight is replaced by efficient LED lighting. The temperature and relative humidity are controlled, and in many cases, the carbon dioxide content of the air is enriched to promote photosynthesis. And it's all done with the help of artificial intelligence.

Murat Kacira, one of Cuello's colleagues in the **Department of Agricultural and Biosystems Engineering**, conducts research in the 750-square-foot Urban Agriculture Vertical Farm Facility, or **UAg Farm**, located at the College of Agriculture and Life Sciences' Controlled Environment Agriculture Center north of campus. One of his focuses is on improving air flow distribution systems in vertical farming operations.

Undergraduate student Robert Swartwout (left) and biosystems engineering graduate student Brian Caplan evaluate experimental crops in the UAg Farm. (Photo courtesy of Murat Kacira)

"If crops like lettuce, commonly grown in vertical farms, are not able to transpire properly due to lack of proper or dynamic airflow, they are not able to take up calcium, and that in turn results in a crop disorder called tip burn, which prevents the marketable potential of the crop," explains Kacira, who has used experimental and computer modeling-based studies to develop alternative system designs to distribute air uniformly through each shelf, creating a desirable environment for crop growth.

Kacira also is researching monitoring systems that track all of the key variables in a vertical farm environment, including air temperature, humidity, light intensity, carbon dioxide, pH and electrical conductivity. Using artificial intelligence, he hopes to perfect a system in which the plants actually teach the computers what they need to thrive.

Brian Caplan and Murat Kacira examine one of the environmental sensors in the Urban Agriculture Vertical Farm Facility. Part of Caplan's graduate research revolves around examining plant responses to light and airflow. (Photo: Bob Demers/UA News)

"We are working on camera systems where we can monitor a plant as it grows by looking at crop growth related features," Kacira says. "Later on, we would like to also study crop health by using the camera and other sensors, and use that information as a feedback to control, for example, the artificial lighting system, rather than operating our lighting in an on-and-off mode. The idea here is basically having crops actually manage their growing environments in a smarter and resource-conserving way."

Putting It Into Practice

As researchers such as Cuello and Kacira work to improve the technology behind vertical farming, private companies are slowly starting to enter the vertical farming space commercially. The Japanese company Mirai Co. Ltd. was one of the first. Mirai (which means "future" in Japanese) opened its first vertical farm in 2004 and posted some impressive statistics.

Basil grows under flourescent lighting in a prototype of the V-Hive Green Box, which Joel Cuello patented with the help of Tech Launch Arizona. They are now working together to commercialize the V-Hive. (Photo courtesy of Joel Cuello)

At one of its "plant factories," Mirai produced 10,000 heads of lettuce per day in a facility less than half the size of a football field, using less than 1 percent of the water typically used to grow vegetables and 40 percent less energy. The resulting product is pesticide-free, herbicide-free and 95 percent edible.

By optimizing resources to maximize plant growth, growing time is also shortened. At the UAg Farm, lettuce is grown from seedling to harvest in just 28 days, versus 60-70 days in an open field. At the completion of the experiments, each crop of approximately 1,800 heads of lettuce is harvested by students and donated to local food banks, including the Campus Pantry, or given to student clubs to sell at farmers markets.

In New Jersey and New York, shoppers can buy "**Dream Greens**" vertically farmed by **AeroFarms**, which claims to operate the largest vertical farm in the world in Newark, New Jersey. "Large" in vertical farm terms can be a misnomer, though, when it takes just 1 percent of the land required by conventional farming to achieve the same harvest volume. AeroFarms boasts water savings of 95 percent over field-farmed food while harvesting up to 30 times a year.

A shipping container in the heart of campus serves as the home of the Arizona Green Box, Joel Cuello's vertical farm laboratory at the UA. The UA Green Fund and Cats in the Green Box sponsor the facility, which is one of two vertical farming operations at the UA. (Photo illustration by Bob Demers/UA News)

Investors are taking note. In San Francisco, Plenty Inc. is making headlines thanks to a $226 million investment by people such as Amazon's Jeff Bezos and Eric Schmidt of Alphabet. Several food banks, including Surrey Food Bank, the second-largest food bank in British Columbia, and the Community Food Bank of Eastern Oklahoma, also are testing the vertical farming waters in an effort to deliver fresh produce to those in need.

Still, commercialization of vertical farming has not been without its challenges. One of the largest vertical farms in the U.S. was forced to close its doors, and rumor has it that another will be following in its footsteps in the coming weeks.

"For vertical farming to really flourish requires technology, but it also requires a business model that will work," says Cuello, who **patented the V-Hive Green Box with help from Tech Launch Arizona** and believes in the viability of minimally structured, modular and prefabricated vertical farms, such as the **Arizona Green Box**. A group developing an urban farm on a 20-acre site in Camden, New Jersey, is currently consulting with Cuello on the application of that type of vertical farm.

"The business model works when you have an ecosystem — you have your production facility, you've got your supply chain, you've got your market," Cuello says. "Typically, that ecosystem is built most effectively when there is a public, private and academic partnership."

Planning for the Future

As scientists at the UA continue to research and develop vertical farming technologies and businesses venture into the commercial space, governments around the world are stepping up the plate, as well.

"It's only 30 years until we reach 2050," Cuello says of the looming deadline the agriculture industry faces to increase food and crop production. "There are countries now that have problems with food security, even the rich countries in the gulf, like Saudi Arabia, Qatar and the UAE. They are food insecure."

Joel Cuello and biosystems engineer senior Adrian Valois examine basil growing in the Arizona Green Box. Cuello hopes to use robotics to automate many of the systems in the vertical farm operation. (Photo: Bob Demers/UA News)

Three years ago, Cuello visited Qatar, a country that imports more than 90 percent of its food, to talk to officials at the Qatar National Food Security Program about vertical farming as they considered methods to reduce their country's food insecurity. The global outreach gives Cuello a unique perspective as an educator in a senior/graduate level course he teaches on globalization, sustainability and innovation.

"For globalization to continue on, you need both innovation and sustainability," Cuello says. "The government in Saudi Arabia is proactively looking for technologies and innovations that would help them with their food security. They are establishing not just the R&D, but a demonstration facility for their entrepreneurs and farmers to encourage them to get into this space in a commercial sense. My approach in all of this, as a professor of the University of Arizona, is really to help them have the capacity building for these technologies for their benefit."

As vertical farming gains a foothold with governments and businesses, Cuello and Kacira believe it is even more important that research universities such as the UA continue to focus on developing the technology to drive the industry forward.

"We can keep designing things so that vertical farming can become more resource efficient — more water efficient, nutrient efficient, energy efficient," Cuello says. "When we do that, it's not only becoming environmentally sustainable, but also economically feasible."

"Research and development to improve labor and energy-use efficiency through technology and automation will be important to address industry viability and profitability," Kacira adds. "Furthermore, controlled environment agriculture-based research and educational programs can help address the industry's critical demand for success by providing a skilled work force who understand both the biology and engineering of crop production in controlled environments."

One of the technological advances that could contribute to the success of vertical farming is robotics.

If artificial intelligence can be combined with robotics, Cuello envisions an AI-complete vertical farm where sustainability is optimized. While vertical farming isn't there yet, Cuello says it is only a matter of time.

"There has to be economic sustainability, environmental sustainability and social sustainability," Cuello says. "When those things are met, the vertical farming system becomes not only feasible, but it flourishes and becomes robust and sustainable in the long run."

Fast-growing leafy green plants, such as chard, are ideal candidates for vertical farming. "At this point, I'm not recommending production of grains in vertical farms, because grains need really large land areas," Joel Cuello says. "They're more energy intensive." (Photo: Bob Demers/UA News)

When it comes to sustainable agriculture, Cuello is definitely in it for the long run, dating back to that small patch of dirt at school many years ago. He recalls how when school opened in the mornings, he and a few classmates would head straight to their food garden, excited to see how much their plants had grown overnight.

"I was definitely fascinated and taken by the idea that plants grew at certain rates, though subject to fluctuations caused by the environment, and I still very much am today," Cuello says. "I am delighted that with vertical farming, we now have the practical means to enable plants to maximize their growth and production, not only consistently, but in a resource-efficient manner. And that's a truly propitious beginning for an effective solution to help feed our hungry world."