Making Agriculture Part of the Climate Change Solution

AMY MAYER

Researchers seek new ways to sustainably increase food production

Iowa State University professor Patrick Schnable and students install cameras to record time-lapse photos of plant growth. Schnable has collaborated with data scientists and engineers to develop tools to improve plant breeding. Photograph: Iowa Economic Development Authority.

The number of hungry mouths to feed keeps growing faster than predicted. A 2009 projection by the United Nations Food and Agriculture Organization (FAO) that by 2050 there would be 9 billion people on the planet may be off by a billion or so. Recently, some estimates have revised that figure closer to 10 billion.

A 2018 report by the World Resources Institute (WRI), *Creating a Sustainable Food Future*, noted that by 2050, the world will need 56 percent

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more crop calories (7400 trillion) compared with those needed in 2010, and a land mass nearly twice the size of India to grow additional crops, even after accounting for increased yields. Already, agriculture and related land use contribute close to a quarter of all greenhouse gas emissions.

But teams of plant geneticists, biosystems engineers, animal scientists, and fish nutritionists, among others, are making headway in finding ways to increase food production while potentially keeping a lid on greenhouse gas emissions. From sophisticated technologies at work in the fields to seaweed diets for cattle and agroforestry practices used by small farmers in Kenya, scientists are developing tools to make agriculture part of the climate solution.

A collaboration at Colorado State University (CSU) led to fitting this tall tractor with a robotic arm that can pull up an entire corn plant, including the roots, and another mechanism that takes soil cores. CSU Professor John McKay says the automated process will lead to more studies of roots and how they interact with the soil to sequester carbon. Photograph: Kyle Palmiscno/Czero.

Understanding plants better

Iowa State University Professor Pat Schnable knew from the time he was a teenager that he wanted to be a plant breeder. Today, his office is adjacent to a vibrant laboratory where, on any given day, researchers may be squeezing sap out of corn stalks to measure the amount of nitrogen they contain. They will compare these manual measurements to the ones taken by a nitrogen sensor that Schnable created with engineering professor Liang Dong, who devised a way to tease out just what they want to see.

“Now we can measure specifically nitrate ions right in the plant,” Schnable said, which will help speed up breeding research. It could also finally give farmers precise information about exactly where to apply nitrogen fertilizer and how much to use. Until now, Schnable said, nitrogen calculator tools developed by university extension services or other crop advisers have relied on spring soil testing, which takes about a week and cannot be done when the ground is too wet. The sensors can be used no matter the soil conditions and offer an almost immediate result. Schnable, Dong, and their partners have licensed the technology and they are launching a start-up to make these sensors available to farmers.

Midwest corn typically requires added nitrogen. Fertilizer is a huge expense. It is also a significant environmental problem. What the plants do not take up washes off fields and contributes to the hypoxic zone in the Gulf of Mexico and other water quality problems. If farmers could apply exactly the nitrogen their crops need, they would use, and lose, less synthetic fertilizer, which carries its own climate burden because most of it is made from fossil fuels.

Schnable and Dong also created a nitrogen sensor for use in water, which could allow farmers to monitor the nutrient content in the discharge from their tile drains. Across much of the corn-growing region of the middle United States, fields are underlain with large pipes that collect excess water from fields. The excess nutrients flow through these tile drains. Schnable sees a near future in which farmers can place these Bluetooth-enabled sensors at the outflows of their tile lines and then drive around the perimeter of a field to download real-time nutrient level data from the water.

Between having a clearer idea of how much nitrogen a plant needs and being able to monitor nutrient loss in real time, Schnable says farmers would be much better equipped to curb runoff. They then can target mitigation strategies such as riparian buffers, strips of native prairie plants, or the use of cover crops accordingly.

While farmers apply the technology in their fields, researchers will use it to select for varieties that use nitrogen most efficiently. The same collaborators also created a “plant tattoo” that monitors the water level in a plant. Eventually, it could allow farmers in areas that depend on irrigation to remotely monitor how much water to apply to a given field, to avoid doling out precious water when plants do not need it or cannot use it. For researchers, that information could help in the development of drought-resistant crops, which could improve yield in places where climate change is bringing hotter, dryer growing seasons.

Farmers in eastern Colorado already are facing dry conditions for longer periods. Another collaboration between plant breeders and engineers, at Colorado State University, is aimed at improving the understanding of plant roots, specifically looking at rates of decay and genetic traits related to drought tolerance.

To better scrutinize plants, a large tractor, tall enough to travel down rows of mature corn, gets fitted with a robotic arm that pulls up plants and soil cores. "The idea is that the technology in the field allows us to look at thousands of plants and hundreds of genotypes," said Colorado State Professor John McKay. "The engineering part is to automate this root sampling as well as automate taking a soil sample at the precision plot level."

That means amassing more information faster, which will jump-start lab work on both identifying gene function and breeding. McKay says looking at the corn roots and the soil around the plants gives his team the raw material for exploring the genetic controls of drought resistance and carbon sequestration. Ideally, McKay says, he would select for varieties whose roots decompose more slowly and keep carbon in the soil longer. At the same time, he recognizes that farmers will be interested in corn varieties that can better withstand dry conditions. He is hoping to identify, and ultimately breed for, both characteristics.

McKay chose corn for the study because it is the largest seed grain crop in the United States, and if its ability to sequester carbon increased significantly, that gain would be multiplied across millions of acres. Similarly, if advances lead to less reliance on synthetic fertilizer, the climate implications could be significant.

Currently, after the corn kernels, or grain, are harvested for food, feed, or fuel, the biomass from leaves, stalks, and cobs is mostly an untapped resource. Some is left on fields to reduce erosion and help regenerate soil organic matter. But some researchers see potential for that biomass.

Researcher Santanu Bakshi of the Bioeconomy Institute at Iowa State University has found that biochar in the lab will absorb phosphorus and then slowly release it. If that holds true in the field, biochar could present an alternative to synthetic fertilizer. Photograph: Christopher Gannon/Iowa State University.

After grain ethanol took off, the 2007 Renewable Fuels Standard expected a second generation of biofuels would emerge. Cellulosic ethanol produced from biomass waste such as corn stover (stalks and leaves) was among those advanced biofuels. Several companies developed cellulosic technology, but it has not taken off as anticipated. DuPont built a commercial-scale plant, but shortly after merging with Dow, the company announced that it was getting out of cellulosic, and the Iowa plant would be shuttered. The landscape was left

University of California, Davis, animal science Professor Ermias Kebreab conducted research with 12 dairy cows to find out whether adding a small amount of seaweed to cattle feed reduces methane emissions. A small amount of macro red algae, a type of seaweed, is mixed with molasses and added to the cattle feed. Promising preliminary results prompted a second, larger study in beef cattle. Photographs: Gregory Urquiaga/UC Davis.

dotted with stacks of baled corn stover DuPont had purchased and no longer wanted.

Santanu Bakshi, a researcher at the Bioeconomy Institute at Iowa State University, works on biochar, which is the solid coproduct of putting biomass such as corn stover through pyrolysis to extract bio-oil.

He was surprised to discover that the biochar acts as a kind of phosphorus sponge. If what he has seen in the lab pans out in the field, Bakshi says biochar could become a sort of time-release phosphorus fertilizer. After absorbing the nutrient, the biochar then releases it gradually over time. That would reduce both the need for synthetic phosphorus fertilizer and the amount of phosphorus lost to runoff.

"We have a plan to explore nitrogen in the same way we are working with phosphorus," Bakshi says. He adds, though, that nitrogen behaves differently in the soil and any shift from synthetic to biochar fertilizer may be quite a ways off, especially for nitrogen.

While reducing the carbon footprint of existing crops is essential, plant breeders also want to increase the amount of food produced. In the past few decades, corn and soybean yields have increased, largely thanks to genetic engineering. Wheat has lagged behind. An international team of researchers suggests in a review article in *BioMed Research International* that the complex wheat genome may partially explain why. But they say the CRISPR/Cas9 gene editing technology could give wheat a boost, and they cite several groups working with it.

Feeding cows seaweed to reduce methane

One of agriculture's major contributions to global warming comes from livestock. According to the FAO, livestock globally account for 14.5 percent of all anthropogenic greenhouse gas emissions. Methane accounts for about 44 percent of livestock emissions, and cattle contribute the most.

The idea of beef and dairy cattle burping their way to the top of the list of greenhouse gas contributors periodically grabs the public's attention and is part of the reason some environmentalists advocate eating less meat. Although reducing the global cattle herd would lower methane emissions, several groups hope to find other ways to mitigate the ruminants' contributions. One of those may rely on a particular seaweed, *Asparagopsis taxiformis*.

Researchers at the Australian government's Commonwealth Scientific and Industrial Research Organization (CSIRO) and James Cook University showed that combining the macroalga with a bovine feed ration has an antimethanogenic effect. Recently, collaborators at the University of California (UC), Davis, published results of an *in vivo* study of dairy cows fed the seaweed-laced feed.

"In animals it worked better than in the lab and usually it's the other way around," says Ermias Kebreab, who led the project at UC Davis. He found that with just 1 percent of the seaweed in the cows' normal feed, their methane emissions went down 60 percent. "We were very surprised by the magnitude of the results."

Researchers also evaluated protein and fat composition of the milk from the cows who ate the altered ration and did not find any differences. (They tasted the milk and thought it was fine, but did not conduct formal studies on taste.)

With the surprise success in dairy cows, Kebreab is now working on a longer trial with beef cattle. This time, the experiments will include testing whether the seaweed diet affects the taste of the beef, "and I don't believe it will, but we have to do the work," says Kebreab.

The Australian collaborators have provided the harvested seaweed to the California researchers, but if it proves to be a viable pathway forward to reducing methane emissions from cattle, seaweed would need to be farmed, Kebreab says. Groups around the world are exploring that possibility, and Kebreab says there should be minimal environmental impacts to growing and harvesting the potential dietary supplement.

But he cautioned that if the seaweed changes feed efficiency—the amount of feed it takes to get the beef to market, "then we have a problem." It is unlikely farmers and ranchers would welcome a hit on profit, no matter how great the climate gains.

In Kenya, the **Croton megalocarpus** *(Croton) tree grows near homes and crops. Collecting and selling its nuts provides an additional income stream to farmers and an incentive to keep the trees, which help reduce the overall carbon footprint of growing food crops. The nuts are used in oils, biofuels, and animal feed. Photograph: Michael Jacobson.*

Planting trees near farms

A July 2019 paper in *Science* made a bit of a splash in the general news media with its declaration that adding trees to some 0.9 billion hectares that are suitable and appropriate for them could store 205 gigatons of carbon, making trees the most promising climate change mitigation strategy readily available. The models that Jean-François Bastin and colleagues used in those calculations did not consider current urban and agricultural lands as potential locations for new trees. But around the world, the agroforestry movement aims to increase the ways trees and agricultural lands coexist to help reduce the overall carbon footprint of agriculture, without reducing food production.

"Trees are obviously the low-hanging fruit for carbon sequestration," says Michael Jacobson, a professor of forest resources at Pennsylvania State University. They are inexpensive and reliably sequester carbon. Trees also can offer a number of benefits to agricultural systems. What types of trees make sense and what additional benefits they bring varies. In fact, Jacobson says "agroforestry" can mean different things in different places, but "with climate change, people are beginning to realize that we're going to have to not just cut all our trees," to grow more food. Rather, he says, people will need to "make them more efficient in our systems."

Workers sort croton nuts at a factory in Kenya before moving them on to shelling and pressing. Michael Jacobson of Pennsylvania State University says the young industry shows a lot of promise. Photograph: Michael Jacobson.

In an analysis of more than 50 studies, Jacobson and his colleagues looked at how transitioning from agriculture to agroforestry impacted soil organic carbon. On average, it increased 34 percent.

For smallholder farmers in Africa, Jacobson says the term "agroforestry" can mean planting a few fruit or nut trees that will provide food, shade, and possibly fire wood, while also reducing the overall greenhouse gas emissions from adjacent crop cultivation.

In Kenya, he says, nuts from the croton tree are valued for the oil they contribute to biofuels and the tree is naturally occurring. "It's all over the place," he says, and when locals can gather the nuts and sell them for fuel, they are incentivized to keep the trees rather than cutting them down for wood. Jacobson says croton nuts show a lot of potential and points to Eco Fuels Kenya (EFK), a croton-processing business that produces oil, seed meal, and fertilizer from the nuts.

In the United States, Trees Forever, an Iowa nonprofit organization, is working to bring more trees back to farmland. Although it emphasizes the trees' ability to reduce snow drift and improve neighbor relations by shielding barns from view and containing animal smells, the trees also have a climate impact.

Corey Hillebo farms near Polk City in central Iowa. He grows corn and soybeans and raises pigs, which are not the greenhouse gas powerhouses that cattle are. Still, hogs generate copious amounts of manure, their barns consume a fair amount of energy because the temperature has to be controlled throughout the year, and even just the labor to clear snow in winter adds an expense and more emissions from fuel use.

Hillebo has a plan for mitigating some of those concerns while also pursuing a possible new income stream: aronia berries. The 6 to 8 feet tall bushes are native to the area and produce a berry that is high in antioxidants but low on the radar of most consumers.

Interest in aronia has waxed and waned over the past decade or so, and Hillebo recognizes the fruit is "obviously a gamble." But whether his bushes ever become a profit-generator, they contribute to reducing his farm's carbon footprint.

The aronia bushes are planted around the hog barns, an area "that's got living roots in it all year round," says Hillebo. That helps prevent erosion and keeps nutrients from washing off the fields and into the nearby Big Creek watershed.

"Top soils are our livelihood and the nutrients that we put on, our inputs, are very expensive," Hillebo said, "and we don't want to lose them."

Joe Sweeney, CEO of Eagle's Catch, a tilapia farm in Ellsworth, Iowa, hopes to someday source the protein for his fish feed from Iowa soybeans. Photograph: Amy Mayer/Iowa Public Radio.

Eating more fish that eat plants

Eagle's Catch tilapia is farmed in a 4-acre greenhouse in Ellsworth, Iowa, that CEO Joe Sweeney says he designed to use as little energy as possible. Blowers and fans circulate air and water through the fish tanks, and filtration allows him to recirculate water so that as little as 1 percent is lost. But the fish eat a commercial feed that Sweeney procures from Louisiana. The feed contains a significant amount of soy protein, and Eagle's Catch is practically surrounded by soybean fields.

"As time goes on, I look forward to feeding them that Iowa product," Sweeney said, noting that at full capacity, his operation will require 60,000 bushels of soybeans annually.

Aquaculture is a booming segment of food production around the world thanks to the increasing demand for protein in the human diet. The WRI report projects a 58 percent increase in fish consumption between 2010 and 2050.

But the wild supplies of small fish that once made up the bulk of commercial aquaculture feed now are under strict regulation to prevent overharvesting. Paul Brown, a professor of fisheries at Purdue University, says that after seeing the inevitability of a capped supply for fishmeal, he and others began in about 2001 to search for other protein sources to supply aquaculture with plant-based feed.

Brown says the variety of fish and crustacean species grown for human consumption is far greater than the number of terrestrial animals, which complicates the challenge of developing nutritionally sound diets. But, he says, the huge amount of soybeans grown in the United States offers protein potential for both domestic and worldwide aquaculture.

In his lab, Brown says that they have used proteomics (the large-scale study of how sets of proteins behave) and metabolomics (the biochemistry of the tiny molecules that control metabolism) to understand more intricately the different nutritional needs of various species.

"I'm seeing more and more of the 'omics' types of technologies being applied to nutrition in general," Brown says, "and it offers a much broader view of what's going on physiologically and biochemically in the target animal." He recognizes that some find these approaches too crude, but he likes that they open up many paths for future inquiry simultaneously.

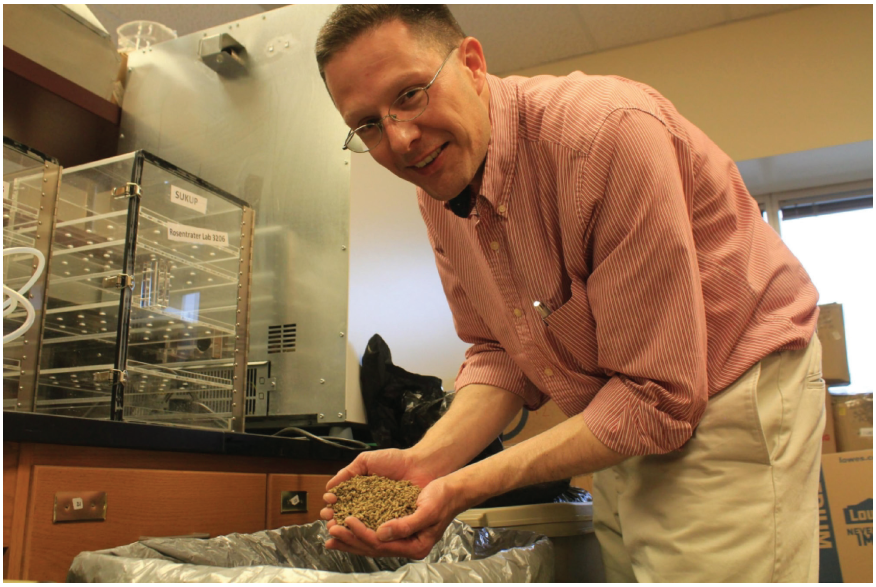
Brown says that while specific details can still be teased out among the different species, the basic dietary needs for farmed fish are understood, including how to reduce or even eliminate traditional fishmeal ingredients.

"It's simply a matter now of the feed mills and their interaction back with their clients and what tolerances and expectations they have," Brown said. He notes that he has heard murmurings of businesses in the Midwest looking into fish feed production, which would help reduce the overall food miles, or carbon footprint, of operations such as Eagle's Catch.

In addition to soybeans, Brown says there are myriad other plants around the world that people are exploring as possible sources of protein for aquaculture diets. "My goodness, it's lupins, it's pea proteins, it's any potential commodity that can be further processed into a high protein ingredient."

As with the Midwest soybeans, aquaculture businesses will need to factor in the climate implications of their feed as part of their overall carbon footprint.

"We have to consider capital, we have to consider operational costs, and then we have to consider the emissions," says Kurt Rosentrater, Iowa State University agriculture and biosystems engineering professor, to calculate a life cycle assessment for climate impact. But aquaculture does have a few things going for it. As animals go, fish are the most efficient at turning their feed into the food people eat.



Kurt Rosentrater of Iowa State University says that Midwest corn and soybeans are helping to feed farmed fish, which are going to be an increasingly important source of protein in the global human diet. Photograph: Amy Mayer/Iowa Public Radio.

"If we are talking utilizing feed ingredients, and getting the most bang for our buck, so to speak, or the least emissions for our buck… I think fish have great potential for that," he says.

New developments in crop processing could also expand corn's potential as a protein contribution to fish feed. The ethanol industry has spawned many byproducts including dried distillers' grains (DDGs), which are often used in livestock feed. Now, Rosentrater says, researchers have found ways to harvest protein from those DDGs, potentially generating more revenue for farmers and processors and higher quality feed ingredients that could be appropriate for aquaculture.

"What we're doing is expanding our possibilities for our corn and our soybean crops," he says, "which ultimately, I think, that's going to help with the sustainability of agriculture in general."

The sustainability of life on Earth may, in fact, rest on the ability of humans to sustainably feed themselves. That urgency will continue to drive innovation in agricultural systems for years to come. The challenge now, especially for wealthier countries, may be giving up some luxuries that have become commonplace—such as buying fresh fruit all year round. Rosentrater says such eating comes with a price that can no longer be ignored. "It's great from a consumer side, but at the same time there's always a penalty, there's always a cost and, unfortunately, I think the environment is one of the aspects that always pays a penalty."

Amy Mayer is the agriculture reporter at Iowa Public Radio.