Science Societies

Cover crops, sensors, and food security

Forward-thinking ideas for the USDA's Agriculture Innovation Agenda

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November 20, 2020

Cover Crops, Sensors, and Food Security, CSA News

"Food security" will be achieved when all people have access to healthy, nutritious, and safe food at all times, according to the Food and Agriculture Organization of the United Nations. In honor of World Food Day, which took place on 16 October this year, *CSA News* magazine is publishing a three-part series on food security. This is the final article in the series, which conveys the following main ideas:

- The USDA's Agriculture Innovation Agenda (AIA) aims to increase agricultural production by 40% while cutting its environmental impact in half.

- ASA, CSSA, SSSA, and members of other related societies formed a 12-person task force and contributed ideas for inclusion in the AIA.
- Here, we'll discuss two forward-thinking areas of research submitted by the task force with the potential to increase our food security: cover crops and biodegradable sensors.

Marty McFly and Doc Brown stand at the end of an unfinished bridge, dangling out over a ravine. The two had planned to use the bridge as a runway for the time-traveling Delorean, accelerating back to the future.

"Oh well, guess we'll have to wait a year until it's finished," Marty says.

"Marty, you're just not thinking fourth dimensionally!" Doc Brown says.

"Right, right, I have a real problem with that," Marty replies.

Of course, in the future, the Delorean *won't* jet off the end of the bridge—the bridge will be finished!

It's "fourth dimensional" ideas that Science Policy Manager for ASA, CSSA, and SSSA, Elizabeth Stulberg, sought when leading a task force of 12 agricultural stakeholders to think about the biggest problems confronting farmers in the United States.

From the Societies' Science Policy Office in Washington, DC, Stulberg put together a group of experts, guiding them through brainstorming sessions and compiling their

comments. The task force formally submitted comments in August 2020 (
https://bit.ly/3jD5JZx).

Steven Mirsky evaluates a cereal rye cover crop. Photo by Photo by Matthew Ryan (USDA-ARS).

The AIA's mission is to "align USDA's resources, programs, and research to provide farmers with the tools they need." By using measurable outcomes, the USDA's goal is to increase agricultural production by 40% while halving its environmental impact by 2050 (
www.usda.gov/aia).

These are lofty goals. In 2019, the National Academies of Sciences, Engineering, and Medicine published *Science Breakthroughs 2030: A Strategy for Food and Agricultural Research*, which outlines the immediate "how" of increasing production and decreasing the environmental impacts of agriculture (https://bit.ly/2TzMsgV). But the AIA will serve as a mission statement and vision for those goals—the "fourth dimensional" view of agriculture.

Here, we take a deep dive into two of the technologies put forward by the inter-society task force: cover crops and biodegradable, ubiquitous sensors. In both cases, the advances researchers can make in the next 30 years—by 2050—will help us maintain our food supply, grow food more efficiently, and care for our climate and environment. All of which contributes to greater food security.

Cover Crops

"It's not debatable, at this point: cover crops provide a whole range of agroecosystem services," Steven Mirsky says. "But there are lots of things we don't know. To what degree do they provide those services? How do we enhance them? How do services change based on your climate, your soil, your management?"

Mirsky is a research ecologist at the Sustainable Agricultural Systems Laboratory, a USDA-ARS site in Maryland. Mirsky co-leads a Coordinated Agricultural Project that includes over 100 researchers in more than 29 states, all focused on documenting cover crop use, management, and breeding.

By definition, cover crops cover soil during gaps in the rotation where the field might otherwise lay fallow. They're often worked into rotations in the winter, between cash crops, in high-yielding systems.

Aside from the aesthetic benefit of keeping the landscape green for a larger chunk of the year, cover crops are a boon to soil health and water conservation. They help capture nitrogen, preventing it from leaching into waterways. They increase soil organic matter, recycle nutrients, and suppress pesky weeds. They prevent erosion, increase soil aggregation, build soil biology, and increase water infiltration.

"Cover crops don't take land out of production, but they reduce our environmental footprint," says ASA Fellow Rob Malone, a task force member and USDA-ARS agricultural engineer. "It's exactly the kind of thing the AIA is looking for."

Typical cover crops fall into four broad categories: grasses, brassicas, legumes, and mixes (**https://bit.ly/3jyogGl**).

Farmers use grasses like winter rye, oats, annual ryegrass, and sudangrass to prevent erosion, build soil aggregation, and retain nutrients, reducing leaching. Many grass cover crops can also be used as forage for livestock—an immediate economic benefit. Some grass species die off over the winter, making it easier for farmers to manage them before planting their cash crops in the spring.

A late-fall cover crop consisting of spring oat, field pea, and radish continues to grow green. In stark contrast, the unprotected adjacent plot of low soybean residues is vulnerable to erosion (foreground). Photo by Keith Kohler, USDA-ARS National Lab for Agriculture and the Environment.

Legumes, with their nitrogen-fixing capabilities, are suited for summer, winter, or even perennial or biennial cover. However, farmers must remember to inoculate legumes with nitrogen-fixing bacteria, and bacterial species are crop specific.

Producers are increasingly incorporating brassicas like mustard, rapeseed, forage radish, and canola into their rotations, particularly in specialty crop production.

Finally, there are the mixtures, in which farmers combine two or more cover crop species for specific outcomes. A mixture provides much the same advantage as a diverse ecosystem: if one species struggles, there are others present to fill the gap. Each species in a mix brings different benefits to the soil, but mixtures can be difficult to seed and manage.

Those are just some of the choices a farmer faces in selecting a species of cover crop. There are unique management questions for each, too. But with these challenges, come great opportunity.

Benefits and Breeding

As Mirsky pointed out, researchers don’t have a complete grasp on the *degree* of benefits provided by cover crops. Often, cover crops are tested in two- or three-year-long studies, and information is swayed by the weather.

“You could have one year that's wet, and one that's dry, and you just won’t be able to detect any differences even if you have a bunch of treatments,” Mirsky says.

Mirsky's team, co-led by Chris Reberg-Horton (ASA, CSSA, and SSSA member) at North Carolina State University, is piloting collection methodologies and wrangling data from longer-term, on-farm studies across the United States. They’re trying to quantify the benefits cover crops can offer, learning from farmers versed in their management. The team was awarded a five-year grant from USDA-NIFA in 2019.

At the same time, researchers are confronting gaps in knowledge about cover crop breeding. From locally adapting certain varieties to designing blends of seeds for a farmer's specific needs, the field is wide open for further research.

“Cover crops are messy—they don’t always behave like you want them to,” Mirsky admits. “They’re very responsive to their environment, and there's been little improvement to their genetics. We can make big strides in very little time, just because there's been so little focus on them.”

Here's an opportunity for the AIA to increase awareness and interest in decreasing the environmental footprint of agriculture through cover crops.

Corn silage harvest involves near-total residue removal, resulting in an extended period of barren soil surface, devoid of biological activity. The foreground plot has an established cereal rye cover crop, protecting the soil from erosion and providing a host of soil biological services. Photo by Keith Kohler, USDA-ARS National Lab for Agriculture and the Environment.

Cover Crop Adoption

The National Cover Crop Survey has been collecting data about cover crop use and management since 2012. The number of acres planted with cover crops of all kinds has increased 50% between 2012 and 2017 (**https://bit.ly/3msnlJw**).

Even with that year-over-year increase, it's still only a tiny fraction of America's farmland. In 2017, cover crops were planted on only 15.4 of the 395 million acres farmed in the U.S.—a mere 3.9% (**https://bit.ly/3e693en**).

What's keeping farmers from using them?

“You don’t just wake up one day and say, ‘I’m going to grow cover crops!’” says Eileen Kladivko, an ASA and SSSA Fellow. Kladivko, Professor of Agronomy at Purdue University, is a founding member of the Midwest Cover Crop Council. “There's site-specific selection, there's getting the right crop, there's managing it, and there's the economic aspect, too.”

Economic benefits to farmers aren’t immediate, and they aren’t always found in increased yield. After a farmer shells out for seeds, spends time and energy planting in the fall, and either terminates or plants into the crop in the spring, the costs can be daunting.

But Kladivko cites potential benefits in reduced herbicide use and decreased inputs as ways to offset those initial costs.

“Cutting back on inputs isn’t something that happens in a single year, either,” Kladivko says. “I remind farmers that for every 10 or 20 lb of nitrate they keep from going into a tile drain, that's building organic matter.”

Like a certificate of deposit, farmers can’t cash in on soil nutrient benefits right away. Over time, the inputs begin to recycle as soil microorganisms release them in forms that plants can use.

The reason a farmer turns to cover crops is usually not the same reason a farmer *keeps* planting them. At first, a farmer might be looking for an immediate fix for soil erosion or a solution for earlier cash crop planting in the spring, but long-term benefits have surprised early adopters.

“I’ve heard a lot of farmers talking about how cover crops have added to their enjoyment of farming,” says Rob Myers. “They like figuring out how to use them in different fields; they like keeping their farms greener.”

Myers, the director of USDA's North Central Sustainable Agriculture Research and Education (SARE) program, says that farmers are innovating faster than some researchers can keep up. Myers encourages researchers to keep track of the latest innovations farmers are using—something SARE keeps abreast of by asking questions about management in its National Cover Crop Survey.

All this to say that the key to unlocking the benefits that cover crops offer is communication and coordination across stakeholder groups. With the visibility the AIA brings to agricultural research interests, a new cohort of scientists and farmers can confront issues facing a crop whose function is not to feed, but to increase the resiliency of our fields and keep the ground green.

Biodegradable Sensors

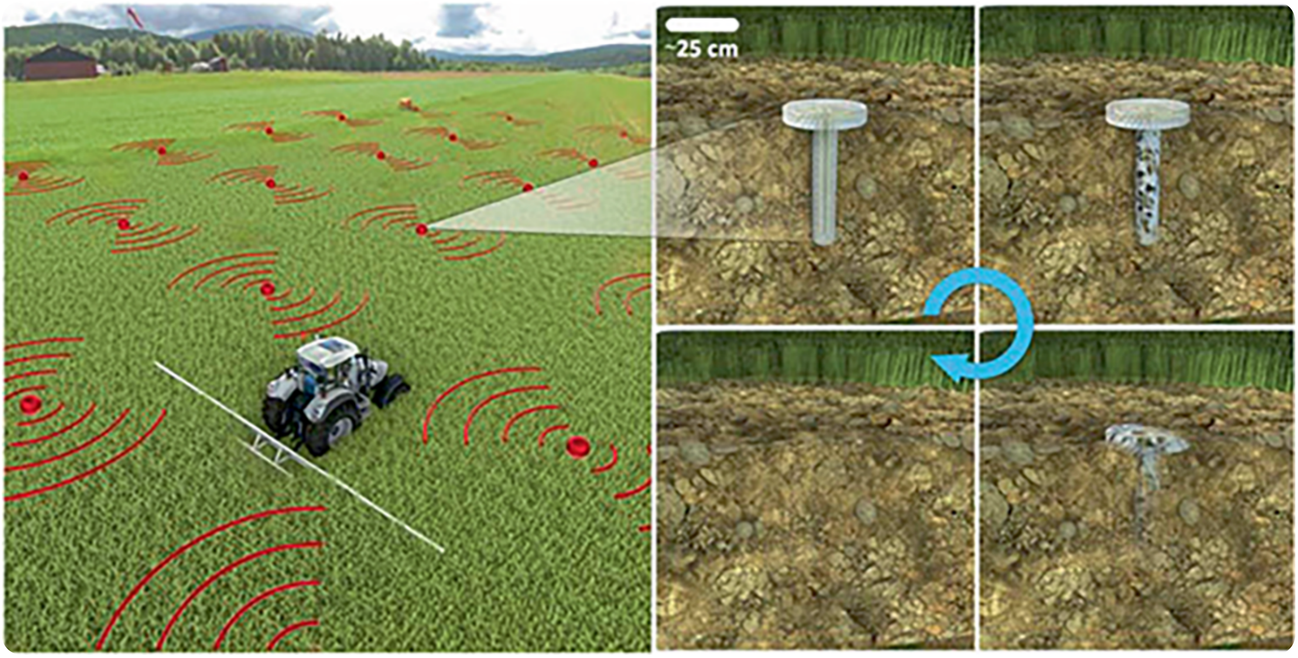
Picture an object about the size of a dollar coin. It's made of beeswax, or wood, or biodegradable plastic—it's not built to last. You have a pile of these little gadgets, and you’re going to scatter them across your field.

Over the course of a growing season, these sensors will send you data every 30 minutes, hour, or day. They’ll document soil moisture and nutrient levels like nitrate, and record if pests or weeds threaten your plants. You can precisely manage inputs, applying them just to parts of the field you know need them.

You check your sensor data, looking at a map that visualizes moisture levels across your fields. You start watering, and as your center pivot irrigation makes its way across the field, the map changes. Over a day or so, you see soil moisture increasing and pivot applying a little less water to the areas of your fields that retain more water. You do the same for nitrogen inputs as the data integrates with technology already installed on your precision-input tractor.

At the end of the season, there's no need to go on a scavenger hunt for sensors—they degrade in the soil. With the money you save on fertilizer, herbicide, pesticides, and water, you buy another set for the next year.

This is the vision of Raj Khosla, a task force member, Fellow of ASA and SSSA, and Professor of Precision Agriculture at Colorado State University. His team is developing sensor technology specifically aimed at measuring moisture and nutrient levels in the soil.



A schematic of a biodegradable sensor network (left) and a sensor node (right). The node degrades over time as is shown clockwise in the four blocks on the right. Photo courtesy of Raj Khosla.

“You can’t manage what you can’t measure,” Khosla says. “We have the tractors, the applicators, and the sprinklers to apply the right inputs at the right time, in the right place, in the right amount, in the right manner, down to a square foot level. But we have to collect data in high density from the field to take advantage of what precision technology offers.”

Like Doc Brown, Khosla sees past the unfinished business of the present. The sensors of today are expensive, bulky, metal-made, and battery-operated machines.

“It's a major limitation,” admits Subash Dahal, a post-doctoral researcher in Khosla's lab and an ASA, CSSA, and SSSA member. “We can’t put them at a spatially dependent scale to capture all the variability in the field.”

Other means of monitoring, from GPS technology to drone-based images, do not give direct measures of in-field variables.

Wub Yilma assessing the damage to the biodegradable sensor candidate after 90 days of maize growth in a greenhouse pot as Huma Tariq looks on. Both are Ph.D. students in the Khosla Lab at Colorado State University. Photo courtesy of Raj Khosla.

“It's an indicator, not a measurement,” Khosla explains. “If you go to the doctor, they don’t take a blood test and say, ‘Maybe you’re diabetic.’ No! They diagnose you, given their measurements of your blood. Right now, we can’t measure nitrogen, phosphorus, or potassium with sensors. We’re always using surrogate measures.”

With only indicators to go on, farmers cannot manage fields in real time, and they definitely can’t catch signs that sensors could. For example, precision technology of the future could measure pest infection before physical indicators of infection appear and spread. With this kind of forewarning, farmers can prevent yield losses or disease spread long before they can even see it happening.

If cover crops get at the heart of environmental challenges facing agricultural systems in the United States, then precision technology addresses issues of efficiency.

“We have to use our resources efficiently because those resources are limited,” Dahal says.

Challenges for Sensor Technology

There's one drawback: sensor technology is a high-risk, high-reward area of research.

“I’ve been involved with smart agriculture since its inception,” Khosla says. “The first 20, 25 years were an uphill battle. It created challenges and issues and conundrums for farmers because we didn’t have the answers. It's slowly but surely gaining attention because we’ve advanced the technology, and we have the data to show it can make a difference.”

For example, a farmer applying fertilizer at an average rate for a given field may lead to over- or under-application of nutrients more than 90% of the time, according to Khosla. With a “net” of sensors scattered in a field, farmers can apply more precisely—just the right amount of fertilizer to meet the needs of an individual section of a field.

For now, the team is trying to find ways to create biodegradable sensors that supply accurate measurements for the course of one growing season but still break down.

“They’re not encased in metal—they go in the soil where there's microbes and herbicides and fertilizers; they can be trampled by tractors or penetrated by roots,” Dahal says. “There are so many things that can go wrong, and we have to control for so many factors to get this to work.”

Regardless, we could be nearing a breakthrough. Dahal estimates that biodegradable soil moisture sensors could be manufactured at scale within two or three years. Nitrate sensors will take a little longer.

The other major challenge?

“The talent pool,” Khosla says without hesitation.

Finding researchers with the right combination of agricultural savvy and computer science acumen is difficult. And with the sheer amount of data generated by a whole interconnected web of sensors, managing those data becomes a difficult task.

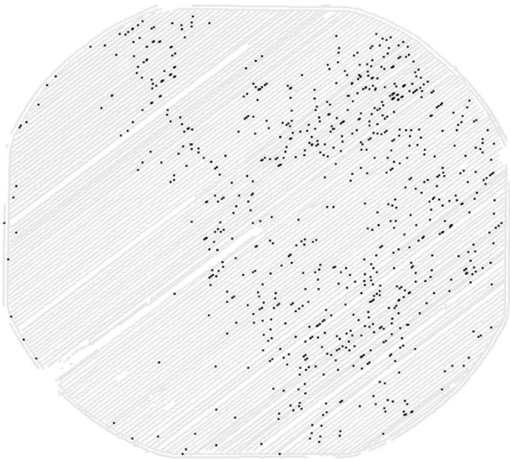
The next frontier for much of agricultural research is finding ways to create clever, efficient means of managing data. Whether it's using artificial intelligence to generate prescriptions for water or nutrient application, or creating neural networks that help farmers predict what's going to happen in their fields tomorrow based on data from today, we need researchers with an agricultural education and knowledge of programming and statistics.

Dahal, who was just hired in Khosla's lab this year, offers advice for young researchers.

"Don't just focus on the field you're working on—try to gain some knowledge and expertise of the fundamentals of statistics and computer science," Dahal says. "Big data is everywhere, no matter which field you're in."

Thinking Fourth Dimensionally

"These are wicked problems," Khosla says. "We can't keep doing the same thing and expect different results…We need to harness the intelligence and expertise of different disciplines. We need to be willing to invest dollars that bring, and continue to bring, different disciplines together to look at the same problems."



An average irrigated corn yield map in Colorado, highlighting only 2% of the field yield pixels matching with the average grain yield of this field. Figure courtesy of Raj Khosla.

Undergirding the AIA is the idea that collaboration is the way forward, but to collaborate, researchers need funding.

According to the Farm Bureau, public funding for agricultural research and development has decreased by 30% in the last 10 years—not to mention, the USDA receives less funding earmarked for research than the Departments of Defense, Health and Human Services, Energy, NASA, and the National Science Foundation (**https://bit.ly/2Tz9eFC**).

Karl Anderson, Director of Government Relations at the Societies' Science Policy Office, advocates for agricultural research interests on Capitol Hill. He likens the federal budget to personal finance.

"You've got to pay the mortgage, the utilities, buy food," Anderson says. "Then you're left with a little bit of cash, and you have to decide: how do I invest for the future? It's that last little bit that's like discretionary funding, and Congress has to decide how to spend it."

The timing is right to position agriculture as part of the solution for the issues facing our environment and a changing climate.

"There's a lot of interest in things like soil health, water quality, and the environmental footprint of food production," Anderson says. "That's the biggest opportunity for us to show what our members are doing to help solve those issues."

With investment—in time, talent, and research budgets—we can look out over the unfinished bridge and see where we'll be in 30 years.

In January, the USDA plans to release the synthesized comments from its Request for Information for the AIA. With ASA, CSSA, and SSSA members working on so many cutting-edge technologies with such great potential, the USDA is smart to endorse agricultural research as a means of caring for our climate and ensuring food security for the people of the United States and the world.

Dig deeper

Interested in food security? Our podcast, *Field, Lab, Earth*, recently released a series of episodes relating to this topic. You can find the podcast at **https://bit.ly/3bGyMc5** or through your favorite podcast provider. Subscribe for free to never miss an episode. CEUs available.

Rafi Qamar, Sundas Ashraf, Hafiz Muhammad Rashad Javeed, undefined Atique-ur-Rehman, Muhammad Yaseen, Bilal Ahmad Khan, Tasawer Abbas, Farhan Saeed, Mazhar Ali, Regenerative Organic Farming for Encouraging Innovation and Improvement of Environmental, Social, and Economic Sustainability, Regenerative Agriculture for Sustainable Food Systems, 10.1007/978-981-97-6691-8_6, (175-216), (2024).

Everald McLennon, Biswanath Dari, Gaurav Jha, Debjani Sihi, Vanaja Kankarla, Regenerative agriculture and integrative permaculture for sustainable and technology driven global food production and security, Agronomy Journal, 10.1002/agj2.20814, **113**, 6, (4541-4559), (2021).
