Science Societies

Farmer-inspired cover crop research yields more than a decade of insights

Long-term experiment not only provides key data for understanding interactions, but also a platform for training next generation of scientists

By Laura Brenner

August 13, 2026



Research assistants, Megan Galvin, left, and Jenna Kokoskie, right, taking samples at the site of the Cover Crop Cocktails experiment at Penn State. Photo by Emma Rice.

When innovative farmers began experimenting with cover crop "cocktails," Penn State researchers set out to study their benefits. More than a decade later, the data show that carefully balanced mixtures can deliver greater stability and reveal ecological interactions that would not have been apparent in shorter studies. The project's lasting impact extends beyond the field, shaping both future farming practices and future scientists.

Check out the short video summary below!

For over a decade, the Cover Crop Cocktails experiment at Penn State has followed the lead of innovative organic farmers who began testing cover crop mixtures on their own. Researchers sought quantitative data to help farmers determine the right mix of cover crops based on their goals. Nearly 15 years later, the findings include robust datasets that answer the original hypothesis, as well as exposing some exciting trends only possible by looking back on these rare, long-term experiments.

One experiment to serve many roles

In 2012, researchers began a multi-species cover crop experiment in response to feedback from farmers. Cover crops were increasingly popular among organic farmers, but multi-species mixtures were only being field-tested among the most innovative, risk-tolerant farmers. The experiment's lead, Jason Kaye, Ph.D., is an ecosystem ecologist and soil biogeochemist. Kaye's analytical mind wanted to develop a scientific basis for farmers to make decisions around cover crop mixtures.



At the start, Kaye had little idea the experiment would continue for more than a decade. Research grants come in two- and three-year stints, but the experimental site has remained a hotbed of agronomic research throughout.

Jason Kaye, an ecosystem ecologist and soil biogeochemist, heads up the Cover Crop Cocktail experiment at Penn State.

The experiment remains true to its roots, but Kaye says over time he and other faculty have become more open to findings outside of the original premise, including experiments from other College of Ag Sciences departments. Kaye says the experiment has also proven to be a valuable asset to students and young researchers.

“Training became much more of a goal for me,” says Kaye. “As I trained many students on the project, my personal goals had a lot more to do with providing a platform for them to do their work than the research itself.”

Research technologist Brosi Bradley has worked with the project for almost the entire duration. While most researchers are likely to be introverts, Bradley shines as the outgoing coordinator of the diverse network of students, faculty, and fellows.

“It's been neat staying in touch with alumni,” says Bradley. “Actually, someone who got their master’s at Penn State and has just finished their Ph.D. at Cornell and is working at Cornell emailed to ask about collaborating on the project. That's been really neat to see the connections and offshoot projects develop.”



Research technologist Brosi Bradley (left) and Ph.D. candidate Emma Rice, Penn State, taking soil cores at the Cover Crops Cocktail experiment site.

Collaborative research is part of what keeps the Cover Crops Cocktail experiment fresh after more than a decade. Farmers also help keep the experiment aligned with real-world needs. Since the outset of the experiment, Kaye has worked with a panel of innovative organic farmers who advise and share their experiences. The farmer panel helped establish the original design and was instrumental in helping researchers make changes when necessary.

Establishing farmer-led research

In some regions, cover crops may be a nice-to-have option between nitrogen-hungry cash crops; for organic farmers in the Chesapeake Bay watershed, they can be essential.

“When we started this project, many farmers were planting monoculture cover crops, and it was becoming popular and important in the Mid-Atlantic for water quality,” explains Kaye. “To some extent, we were following some innovative farmers' leads. But also, we were trying to provide information that was going to be in demand because more farmers were trying mixtures.”



The idea with cover crop mixtures is you may be able to reduce risk by getting more consistent performance across varying weather and environmental conditions. If one species struggles, others can fill the gap. As well, a diversity of cover crop species could bring a diversity of ecosystem services, such as fixing or scavenging nitrogen, suppressing weeds, attracting pollinators, and improving forage quality and water infiltration.

The cover crops cocktail experiment at Penn State's Russell E. Larson Agricultural Research Center. Photo by Mark Horse.

The most popular cover crop at the start of the project was cereal rye. The winter annual grass establishes late in the fall, making it easy to plant after soybeans or corn. Rye overwinters well and provides an important environmental service for farmers in the Chesapeake Bay region: scavenging nitrogen from the soil and reducing leaching. The downside is its competitive nature. When mixed with other cover crops, rye tends to take over.

Sheryl C. Hosler, Ph.D., knows almost as much as anyone about the Cover Crops Cocktail Experiment, despite not having lived in the Keystone State until 2024. Hosler is a postdoctoral researcher with a background in statistical analysis. She was recruited to the experiment for her knack for turning big datasets into meaningful information.



When mixed with other cover crops, cereal rye tends to take over. Photo courtesy of Edwin Remsberg and USDA-SARE.

"[Cereal rye] was kind of causing a problem because, well, if our experimental design is not being realized, then it's harder for us to actually ask questions about how different cover crop treatments work if all of our mixtures look like cereal rye monocultures," says Hosler.

The first version of mixtures didn't live up to the goal—they were dominated by cereal rye so that other species weren't playing much of a role in the mixture. So researchers worked with the farmer panel to tweak the species mixture. After they found success with their Version 2 mixtures, researchers didn't look back at the data to track changes. It wasn't until recently, when Hosler joined the experiment, that looking back at trends became feasible.

Finding diversity's sweet spot

Cereal rye was replaced with triticale, and researchers swapped out or reduced meek red clover for more assertive crimson clover. In addition to the species changes, the seeding rate was reduced to match the control, monoculture seeding rate.

In both Version 1 (2012–2015) and Version 2 (2015–2019) of the research design, six cover crop species were planted in individual monocultures and three mixtures. Researchers tested a three-, four-, and six-species mixture. In Version 2, a five-species mix was established to include both red clover and crimson clover. By Version 3 (2019–2025), red clover was eliminated entirely.



In Version 2 of the Cover Crop Cocktails experiment at Penn State, cereal rye was replaced with triticale, and researchers swapped out or reduced meek red clover for more assertive crimson clover. This resulted in more even stands with higher legume biomass.

These adjustments resulted in the intended changes to final biomass composition. The plots showed a shift in community expression; the mixtures were more even and contained higher legume biomass compared with the original design. For example, a six-species mixture initially composed of 81% grass (cereal rye) and 14% legume saw its composition shift to 25% grass and 65% legume.

Plant communities were quantified three times each year: stand counts two to three weeks after seeding, fall biomass before a killing frost, and spring biomass immediately prior to cover crop termination. Species evenness was measured using Pielou's evenness scale. Pielou's evenness is an ecological metric that measures how evenly individuals are distributed across species in a community. It compares the observed Shannon diversity index against the maximum possible diversity if all species were perfectly equal in abundance.

In a research letter published in the journal *Agricultural & Environmental Letters*, Hosler writes, "We show that by replacing two species and adjusting seeding rates, we successfully altered the community expression of three cover crop mixtures to better meet goals determined by a farmer advisory panel."

With the benefit of more than 10 years of hindsight and data, Hosler is able to see trends and slow-moving patterns that most two-year research experiments aren't able to capture.

“What's been most exciting and interesting to me is looking at the dynamics in these multispecies mixtures and sort of looking at how the cover crops responded to environmental variation over all of the years of the project,” says Hosler. “The coolest part is that each species responded to different components of the environment. That means that when there's a bad year for some species, other species do okay, and vice versa. They're all compensating for one another.”

Hosler describes her paper in *Agricultural & Environmental Letters* as a side quest. As in, it was not part of the original plan and research strategy to look back at a decade of data and hunt for additional meaning. But that’s exactly what she’s doing. She has two more forthcoming papers related to long-term analysis of how cover crops responded to the environment and how they affect a variety of important ecosystem services.

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For Kaye, these side quests are part of the magic of long-term university research. “We know things like organic matter accrue slowly, but we actually don't know a bunch of the other interactions that can only be illuminated by continuing to collect quality-controlled data. So we can actually do a little bit of a fishing expedition, which isn't a popular thing to say in science. We need to mine our data to discover what the interactions are,” he says.

Kaye’s spent the past decade of his career shepherding this experiment and its many contributors toward meaningful ends. As he’s matured in his position, he’s striking a more even balance between his interest in developing novel research and in developing future researchers.

Dig deeper

Hosler, S. C., Murrell, E. G., Arrington, K. E., Baraibar, B., Barbercheck, M. E., Bradley, B. A., … & Kaye, J. P. (2025). Managing cover crop mixtures over a decade via species replacement and seeding rate adjustment. *Agricultural & Environmental Letters*, *10*, e70029. https://doi.org/10.1002/ael2.70029

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