Do POLYCULTURES HAVE A ROLE IN MODERN AGRICULTURE?

by Madeline Fisher

As a rangeland ecologist, Oklahoma State University professor Sam Fuhlendorf has always had one foot in agriculture and the other in ecology. He belongs to the Society for Range Management and the Ecological Society of America (ESA). He holds awards for meritorious research in agriculture and for best wildlife publication. And while he loves the science of ecology, he knows what it takes to grow crops. That's why when he and his Kansas State University colleague, ASA, CSSA, and SSSA member Bob Gillen, attended the ESA meetings in 2001, they were amazed to see ecologists making inferences about agriculture from experiments on random assemblages of plants in small, carefully tended plots.

"They were interesting," Fuhlendorf says of the studies, which aimed to test how species diversity related to productivity. "But most of them were

just completely unrealistic from an agronomic perspective."

Sensing a research niche to be filled, the pair soon launched their own experiments in two Oklahoma locations, comparing the productivity of mixtures, or polycultures, of prairie species, with monocultures of plants like switchgrass and big bluestem. Later, they teamed up with Oklahoma State agricultural economist Francis Epplin, who evaluated the two cropping systems based on their biomass yields and production costs. The main finding of their paper, published in the May–June 2011 issue of *Agronomy Journal*: Economics favored the monocultures, at least for the locations and conditions of their three-year study. "My perspective still stands," Fuhlendorf concludes. "There are lots of reasons to have diversity. It just so happens that growing biomass may not be one of them."

To many agronomists, that should be the last word on the subject. But in the meantime, the concept of "diversifying" the farm landscape with perennial species and polycultures has taken root in the scientific literature, fueled by the push toward cellulosic bioenergy crops, such as switchgrass, miscanthus, and prairie plant mixes. Proponents argue that while today's simplified agricultural systems excel at producing corn, cotton, and other vital commodities in massive amounts, they come at the price of degraded water quality, vanishing wildlife habitat, and increased pesticide use. Sowing plant diversity back into farmlands, they say, could reduce these costs by providing ecological benefits, such as natural pest control, carbon storage, and nutrient retention. Others see diversification as crucial to agriculture's future resilience.

Most agronomic scientists don't disagree; rather, it's the expense, risk, and difficulty of growing such crops that makes them wary. Still, studies like Fuhlendorf's that used to appear exclusively in ecological journals are being published more frequently in the agricultural literature, as well. And what they're showing is that while growing polycultures *is* hard and economically impractical right now, these systems do hold potential that should perhaps be further explored.

To do things right, however, an equally tough but promising effort must also get underway: Agronomists and ecologists need to work together to address important questions, such as the one at hand: Are monocultures all we should grow? Or do polycultures have a place, too?

"I think [more collaboration] sounds wonderful," Fuhlendorf says. "But," he adds with a wry laugh, "it's a really big challenge."

Photo credits: *page 4, clockwise:* Matt Wisniewski, Great Lakes Bioenergy Research Center (GLBRC); Kathy Eystad; David Tilman, University of Minnesota; Craig Sheaffer, University of Minnesota; and Michael Casler, USDA-ARS, U.S. Dairy Forage Research Center; *page 5, left vertical panel:* Andrew Leakey; *page 5, right vertical panel:* John Durling, USDA-NRCS, Rose Lake Plant Materials Center; *page 5, middle horizontal panels,* from top to bottom: Gregg Johnson, University of Minnesota; Scott Bauer, USDA-ARS, Bugwood.org; and Matt Wisniewski, GLBRC.

Ecologist's Paper Sparks Agronomic Research on Polycultures

If the challenge was already big, University of Minnesota ecologist David Tilman likely made it bigger when he published a paper in *Science* in 2006. An expert on prairie ecosystems, Tilman has for years examined the relationship between productivity and species diversity in restored prairies on extremely nutrient-poor sites in central Minnesota. His work had little to do with agriculture—until biofuels came barreling along. Suddenly everyone wanted to grow perennial grasses and in Tilman jumped with his paper, reporting that mixtures of 16 native grasses, legumes, and forbs yielded 238% more bioenergy than did monocultures after a decade of growth. The plots were also unfertilized and watered only during establishment, suggesting high-diversity polycultures would be more environmentally friendly than corn ethanol or soybean biodiesel.

The paper drew intense criticism from agronomists, however. Some argued that Tilman's small, hand-weeded research plots held little significance for commercial agriculture. Others questioned his methods; for example, his practice of burning his stands returned nutrients to the soil, critics said, whereas harvesting biomass at season's end would obviously remove nutrients and reduce productivity over time. Iowa State University agronomy professor Ken Moore also notes that plant diversity naturally depends on soil conditions, and rich soils are more likely to let single species dominate than are nutrient-poor sites like Tilman's. Five years later, Moore still holds strong opinions about the work. "I would state," says the ASA and CSSA Fellow, "that studies that artificially create and maintain diversity have no relevance to the real world."

At the same time, some agronomists decided to launch their own studies of polycultures, one of whom was forage agronomist and ASA and CSSA Fellow Craig Sheaffer. A colleague of Tilman's at the University of Minnesota, Sheaffer credits the ecologist with sparking agronomic research on the subject. "We wouldn't be having this conversation right now without his work," he says.

Like Fuhlendorf, Sheaffer's goal wasn't to investigate whether diversity was correlated with productivity, however, but to find the cropping system that offered the highest, most reliable yields of biomass at production scales. To this end, he and his colleagues, Don Wyse and Margaret Mangan, launched a series of experiments in eight sites in Minnesota that span a range of ecoregions. At each location, they established stands of 1, 4, 8, 12, or 24 species of native, tallgrass prairie plants and followed them for two years without applying fertilizer.

As reported in the March–April 2011 issue of *Agronomy Journal*, the most productive plots were either monocultures or ones containing an eight-species mixture of grasses and legumes. Indeed, an increase in species from one to eight boosted yields by an average of 28%, suggesting that a strategic combination of a few species might achieve the highest biomass during the establishment phase, Sheaffer says. Seeding more than





eight species offered little additional benefit, though, and Sheaffer wasn't surprised to see something else happening in the mixtures, as well: On average, a single, dominant species accounted for 75% of the biomass.

"What we report in our paper is not that unique from an agronomic perspective," he says. "If you seed 30 species on the landscape, you're not going to get 30 species growing." That's why farmers focus on simple mixtures, he adds, such as alfalfa–grass mixes that include one or two grasses. "There aren't 26," Sheaffer says, "because we know enough about the species that will persist and be productive."

That point may be patently obvious to him, but it's one that ecologists often fail to get, says Matt Liebman, who is both an ASA Fellow and ESA member: Rather than going for the maximum number of species, agronomists are willing to sacrifice some diversity for the merits of certain plants. "There's a reason we grow corn and soybean in Iowa," says Liebman, the Wallace Chair for Sustainable Agriculture at Iowa State University. "It's not that we're hell bent on eliminating diversity. It's that those species are very well-adapted here."

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Still, crop diversity matters greatly to Liebman, and he's spent his career studying its impacts on factors such as weeds, soil fertility, and long-term productivity. Unlike Sheaffer and Fuhlendorf, however, when he and his former graduate student, Valentín Picasso, compared monocultures and polycultures in a 2003–2005 study, they sowed not only prairie plants, such as Maximilian sunflower and Illinois bundleflower, but also agronomic species including alfalfa and orchardgrass. This may be one reason why their findings differed, as well: In their experiments, published in 2008 in *Crop Science*, polycultures of two to six species clearly outyielded monocultures under all conditions—on average by 73%.

Like the other studies, though, species in Picasso's plots that produced the most biomass in monoculture also dominated any polyculture in which they were present, with other species contributing relatively little to yield. Moore adds that this kind of shift can

happen even in very simple grass–legume mixtures, which his group has been investigating as a way to reduce costly nitrogen fertilizer applications to bioenergy crops.

"Given its [way], the plant community will transition to a quasi-equilibrium state different from the initial one," he says. "It takes careful management to maintain a beneficial equilibrium."

Why Mixtures?

It seems a fair question, then: Why mess with mixtures at all? Although he is an unabashed fan of plant diversity in agricultural systems, rangeland ecologist Randy Jackson understands the concern, having experienced the pitfalls of polycultures himself. Three or four times during the last decade, explains the University of Wisconsin–Madison (UW-Madison) agronomy professor, prairie plants seeded by his group for agronomic experiments have failed to take, forcing a costly replanting effort.

"So, it's a dicey proposition," says Jackson, who is currently comparing polycultures and monocultures of biofuels crops as part of the U.S. Department of Energy-sponsored Great Lakes Bioenergy Research Center (GLBRC) based at UW-Madison and Michigan State University. "People know how to grow corn everywhere. But growing switchgrass or diverse prairie, you've got to be in it for the long haul and willing to throw some money at it, because it's expensive right now. And it's risky."

Even so, these crops have one critical advantage, he adds: The ecological benefits they offer, also known as "ecosystem services." As forage agronomists well know, for example, deep-rooted perennials easily outperform annual, row crops at preventing erosion, retaining nutrients, and sequestering carbon. Diversity in farmlands can also boost natural pest control: Some of Jackson's GLBRC colleagues have shown that insect predators such as ladybeetles devour more soybean aphids and other crop pests when feeding in fields nestled within woodlands, grasslands, and croplands than in those surrounded by a monotony of corn. Even aesthetics is considered an ecosystem service, with people valuing grasslands not only for their plants, but also the wild birds they attract.

Still, why mixtures exactly? Can't monocultures of switchgrass provide these services just as well when sown on the landscape amid row crops? It's a key question, Jackson says, and a key reason why his team is comparing not just the productivity of various bioenergy cropping systems, including continuous corn, switchgrass monocultures, and native prairie, but the level of services they offer, as well. The idea is that because different species presumably occupy different ecological niches, mixtures can better retain nutrients, or resist drought and disease, than any one species can on its own. Even if this hypothesis is supported, however, it's unclear whether these benefits will outweigh the downsides.

"We haven't really done the full accounting yet," Jackson says. "Okay, the diverse system is less productive, but what does it do for greenhouse gas emissions, carbon accumulation, and nitrogen retention? Are we seeing





extra benefits there? Or is a switchgrass monoculture just as good on all those accounts as a diverse prairie," especially on rich soils?

Liebman has documented better weed suppression in polycultures than in monocultures. But ecosystem services aren't the only reason to consider mixtures, he emphasizes: The resilience of agricultural systems is also critical. As Picasso's work showed, he says, picking the best-adapted species for a given set of conditions leads to high yields in monocultures. But imagine you don't know the exact conditions or the best-adapted species. In this case, including a full set of possible species, from which the winner can emerge, makes sense.

"It's context dependent, obviously. If you're in a world with a stable climate and cheap fertilizer and perfect moisture conditions, you can probably pick the winning species," Liebman says. "But if you don't operate in that kind of a world or the cost of inputs is becoming limiting for profitable production, then you begin to look at forms of biological diversity not just as ways to hedge your bet, but also to maintain productivity in the face of economic and biophysical challenges."

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Nick Jordan, Sheaffer's and Tilman's colleague at the University of Minnesota, agrees, noting that a 2010 study led by Bruce Dale at Michigan State University suggests perennial, biomass crops could be grown profitably for animal feed and biofuels on roughly 50 million U.S. hectares that today produce annual crops for feed and export. Such a transformation of our agricultural land base, Jordan says, would not only provide useful goods and substantial environmental benefits, but could also help buffer U.S. agriculture against the wider variability in weather that's being forecast for the future.

"The prediction, at least, is that we're talking about significant differences in the distribution of rainfall, so that we have more big storms and drought," he says. "So we need to invest in 50 million hectares of perennials in a way that will be resilient to

that kind of variation, or at least we should consider it."

'Lab Land' Concept

Considering it is one thing, however; getting there is quite another. Answering agronomic questions can help in this regard, of course. But for Jackson, those questions aren't the main ones.

"We have to do this work to understand the agronomic limitations, the best practices, and that sort of thing," he says. "But the real leverage points are how people behave, what choices they make, how society incentivizes these things. We can understand everything there is to know about whether a diverse prairie is more productive or not, but if people aren't going to plant it, then it isn't going to matter."

A means to make that societal shift has thus become another research focus of Jackson and Jordan. "Clearly, creating these unprecedented systems—blends of perennial and annual agriculture on unprecedented, landscape-wide scales—we have no idea how to do that in advance," Jordan says. "The only way to figure it out is to try to build pilot-scale landscapes that we can learn something from, without betting the farm on them."

To this end, the pair has been developing a "Lab Land" concept, with their colleague Doug Landis of Michigan State University. It comprises, first of all, spatial decision support tools that would allow stakeholders, such as farmers and land managers, to "turn the dials" on a watershed or other landscape, Jackson says—adding to fields of corn, for example, strips of diverse prairie plantings or streambank buffers of switchgrass or willow. The tools would then let them see not only how factors such as productivity, water quality, greenhouse gas emissions, and wildlife habitat would be affected, but the actual look of the new farmlands, as well. Another ingredient are mechanisms for bringing multiple stakeholders together to design supply chains, markets for ecosystem services, and other needed infrastructure to make the new landscapes lucrative. And the final ingredient, Jordan says, is policy.

"If we've got a landscape people can agree on and a supply and value chain that looks promising," he says, "then what kind of policy environment do we need to support them?"

The Land Lab isn't the only possible solution, of course, but the larger point is that we need *some* way to move forward. Otherwise, it will remain tough to bridge the divide between the benefits of diversity that ecologists see and the need for profitable production that agronomists know—even when both sides are willing to cross it.

"Here at Minnesota, at Iowa State, at Wisconsin, we're studying these native plants [as crops] because we are aware of the importance of ecosystem services," Sheaffer says. "But I also like to think that as agronomists, we pretty much have our feet on the ground in terms of the reality of the situation."

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