AGRICULTURAL RESEARCH

Higher Yielding Perennials Point the Way to New Crops

Today, almost all of our major crops are herbaceous annuals—plants such as corn and soybeans that have to be replanted every year. But even though the costs of this constant replanting are high, in both monetary and environmental terms, few agricultural scientists have tried to replace these annuals with more long-lived perennials. That's mainly because perennials are thought to put so much energy into maintaining the sturdy underground roots they need to last through the winter that not enough is left to produce bountiful harvests of seed grains. But recent results from a few agricultural pioneers suggest that is not necessarily the case.

They have found that, in small-scale tests, it is possible to boost dramatically the seed yields of at least some perennials such as gama grass, a cousin to corn, without impairing its perennial vigor. While perennial yields are still well short of those customary for commercial crops, researchers are now starting programs to achieve better results in other plants by selective breeding or genetic engineering. Besides gama grass, whose grain tastes like corn, some candidate perennial crops include wheatgrass, whose seeds have a nutty flavor, as well as current standards like sorghum, which might be converted to perennials.

Ecologists and agricultural researchers concerned about the high environmental costs of current farming practices, which rely overwhelmingly on huge monocultures of annual plants growing over thousands of hectares, say the effort is worthwhile. "If [it] succeeds, the change will be staggering," says University of Tennessee ecologist Stuart Pimm. "Few scientific projects have the potential for such a dramatic affect on society." Perennial crops could help cut down on the soil lost to erosion, much of it as a result of fields having to be plowed up and replanted annually. And if the perennials were grown in a novel approach called "natural systems agriculture," they could have additional benefits, including reductions in pollution caused by chemical fertilizers and herbicides.

Proposed almost 20 years ago by plant geneticist Wes Jackson of the Land Institute, a private agricultural research center in Salina, Kansas, this approach seeks to mimic what happens in nature by planting diverse mixtures of perennials. This mix could include nitrogen-fixing legumes as a source of nitrogen fertilizer, other plants that provide natural insecticides such as the pyrethrums of chrysanthemums, and grain-producers.

First, though, researchers will have to show that seed production by perennials can be increased. As plant ecologist Jacob Weiner of the Royal Veterinary and Agricultural University in Copenhagen, Denmark, points out, "If you look at natural communities, perennials don't maintain high seed production over prolonged periods," apparently because so much of their energy goes to making the deep roots and other vegetative tissues needed to sustain the plants over long periods of time.

High yielder. Wild-type gama grass *(left)* produces few seeds because its flowers are mostly male. The mutant *(right)* lacks male flowers and consequently has many more seeds.

Such findings raised concerns that increasing perennials' seed yields might compromise their ability to grow and thrive.

But the results of a 5-year study by Laura Jackson of the University of Northern Iowa in Cedar Falls (Wes Jackson's daughter) and Chester Dewald of the U.S. Department of Agriculture's Southern Plains Range Research Station in Woodward, Oklahoma, show that at least some perennials can have markedly increased yields without losing their vigor. In the study, which began in the mid-1980s when Laura Jackson was at Cornell University in Ithaca, New York, the researchers worked with a naturally occurring mutant of gama grass (*Tripsacum dactyloides*), a perennial relative of corn. During the 4 years they grew the mutant in the field, Jackson and Dewald found that it produced an extraordinary amount of seed—at least four times as much by weight as normal plants. Despite this, the mutant plants grew just as rapidly and vigorously as the normal ones.

Other experiments with the mutant provide further evidence that seed production can be increased without limiting the growth of vegetative plant parts. For example, Jackson and Dewald found that clipping off the plants' vegetative shoots didn't decrease seed production, and conversely, removing the seed stalks didn't speed up the growth of the vegetative shoots. "The vegetative and reproductive parts of the plant are independent," Jackson says. Such findings offer hope that efforts to develop high-yielding perennials will succeed.

And researchers are now exploring several ways of achieving that goal. At the Rodale Institute in Kutztown, Pennsylvania, for example, plant breeder Peggy Wagoner has a breeding program aimed at increasing the productivity of perennial wheatgrass (*Thinopyrum intermedium*), a wild ancestor of wheat that produces a highly nutritious seed with a protein content of about 20%—roughly 65% higher than that of ordinary wheat. Currently, wheatgrass seed yields are moderate, about 560 kilograms per hectare during the first year, although less in following years. To achieve economically worthwhile production, Wagoner says she wants to increase the yield to a sustained 700 kilograms per hectare.

An alternate strategy is to breed established annual crops into perennials. In one such effort, botanist Jon Piper and plant breeder Peter Kulakow of the Land Institute crossed the annual grain, *Sorghum bicolor*, with *Sorghum halepense*—a perennial weed commonly known as Johnson grass. The resulting hybrid, grown without the benefit of fertilizer, pesticides, or selection, had 62% of the yield of commercial sorghum cultivated with every industrial advantage. The hybrid was only a marginal perennial, however, because most plants could not survive the Kansas winter, although Piper says that further breeding might improve this.

Recent molecular discoveries might also help out in this regard. In work reported in June 1995 in the *Proceedings of the National Academy of Sciences*, plant molecular geneticist Andrew Paterson of Texas A&M University in College Station, Texas, and his colleagues mapped the chromosomal location of the genes that cause Johnson grass to make plant structures called rhizomes, enlarged underground stems that help the weed to survive the winter. This finding might help breeding and selection because the hybrids could be screened to find plants having a good dose of the genes, or once the genes are cloned, they might be introduced into sorghum or other plants by genetic engineering.

Other genes might have the converse effect, turning wild perennials into domesticated crops. Paterson's team has mapped the genes responsible for the domestication of sorghum, maize, and rice (*Science*, 22 September 1995, p. 1714). The genes code for such traits as large seed size and shatter-resistant seed clusters, and Paterson predicts it will be "very possible to use these genes to create other domesticated perennials."

Other recent work shows that perennial yields can be beefed up by cultivating mixtures of the plants—the same approach that would be used in natural systems agriculture. The Land Institute team has found that several perennial mixtures can significantly outyield their respective monocultures—"the first time that such an effect has been shown for seed yield" by perennials, says Wes Jackson.

Despite these recent advances, Jackson is the first to concede that perennial polyculture agriculture has a long way to go. He says the research is currently in the "Kitty Hawk stage of development," requiring 25 or more years of basic research and field work before full flight can be realized. And there are no guarantees that perennial agriculture will get off the ground, cautions University of Minnesota ecologist David Tilman. Still, as he says, "perennial crops may allow sustainable soils, sustainable yields, and much lower pollution," and that makes investing in them "a worthwhile gamble."

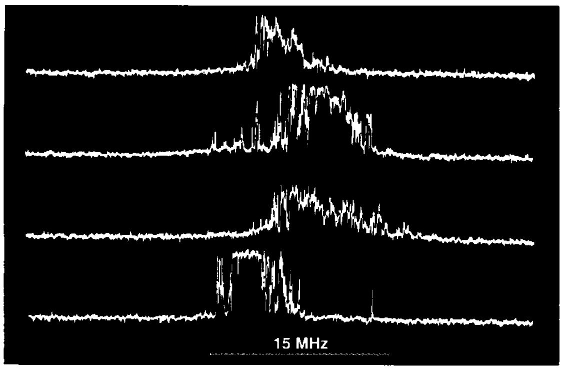
–Anne Simon Moffat

CHAOS

Astronomers Tame a Workhorse Laser

"Chaos is not what you think it is," remarks Gordon Chin of NASA's Goddard Space Flight Center in Greenbelt, Maryland. Unlike ordinary noise, chaotic behavior isn't total anarchy: It has constraints. Those constraints mean chaos can be tamed—and now, it seems, even put to work.

That's the message of research reported on page 1498 of this issue, in which Chin and his colleagues have exploited techniques for controlling chaos to tame fluctuations in the frequency of a tunable infrared semiconductor laser. It's not the first demonstration of chaos control, or even of chaos control applied to a laser. But it may be the first example of chaos control to move out of the laboratory into practical application.



Fickle frequency. The frequencies of a tunable diode laser are shown for 0.01-second intervals. During each interval, the laser jumps between many narrow frequencies.

SOURCE: D. E. JENNINGS

Astronomers like Chin use tunable lasers to study how cold gases resembling the atmospheres of the outer planets absorb infrared light, allowing them to build a database for interpreting observations from space probes. Sharpening the laser's frequency output could make it even more useful. "I think this is a big achievement," says Ira Schwartz of the Naval Research Laboratory in Washington, D.C. "A real application hasn't come out [of chaos control] as yet, and this is probably a good one."

Chin and his colleagues John Hillman of Goddard and William Blass and Larry Senesac of the University of Tennessee, Knoxville, focused on the lead-salt laser—a decades-old device that has a distinct advantage over most other lasers: Researchers can tune the infrared light it emits, dialing up any frequency over a 1-micrometer window simply by adjusting the laser's temperature or the current that energizes it. But the frequency of the beam is not as narrow as calculations suggest it should be. In 1984, Don Jennings, whose office is just down the hall from Chin's at Goddard, discovered that the laser gives off light at many closely spaced frequencies, hopping between them so fast that the net output is just some smeared average of many sharply defined signals.

Chin and his colleagues wanted the narrowest possible light source for their spectroscopic studies of planetary atmospheres, so he and his team set out to find out just why the lead-salt laser's output is so fuzzy. That meant tracking the frequency changes. But because they come so rapidly, the frequency would have to be sampled about 50 million times per second, and nobody knew how to do that.

What Schwartz calls "the new idea here" was to pass the light through ethylene gas and tune the laser so that its frequency was just at the edge of one of the gas's absorption peaks—a frequency at which ethylene absorbs light. That way, even a slight change in the laser's frequency, by shifting it either closer to the absorption peak or farther away, would result in a big change in the intensity of the transmitted light. "We've moved the problem from that of measuring frequency, which was difficult to do, to that of measuring amplitude, which was simple," says Chin.

The sampled output passed all the standard mathematical tests of chaos, meaning that its evolution could be predicted exactly in principle but not in practice, because it is so sensitive to tiny perturbations. When the researchers compared the frequency change during one time interval to the change during the next equal interval, they saw the signature of chaos. If the frequency excursions had been random, a plot of the differences would gradually fill with scattered points. If they had been periodic, the plot would consist of a closed curve. Instead, the plot showed a multitude of distinct paths lying close together but never repeating.

Such chaotic behavior probably emerges from the competition among many slightly different frequencies within the lasing medium. But even without knowing the exact cause of the chaotic fluctuations, Chin and his team could control them by exploiting a feature of chaos: In the very short run, a chaotic system is predictable. Via the frequency-to-amplitude trick, the electronics could spot when the laser frequency was drifting chaotically and apply a correcting pulse to the laser current approximately every microsecond—an implementation of "occasional proportional feedback," a chaos-control technique devised in 1991 by Earle Hunt of Ohio University. Making it all work "is just staggeringly simple," says Chin. "We got success in the first try." His measurements showed that the strategy reduced the frequency variation by a factor of 15.

"I think it could be used in lots of systems," says Schwartz. Besides aiding laboratory studies, the sharpened laser might also serve as a "local oscillator," providing a reference signal with which infrared light from an astronomical detector could be compared for extremely high-resolution spectroscopy.

Others need a little more convincing before they join the party. "The question for me really is whether the instantaneous linewidth gets narrowed that much or not," says physicist Rudolf Schieder of the University of Cologne in Germany. Schieder's own team has found ways of stabilizing lead-salt lasers without resorting to chaos control, but he acknowledges the simplicity of Chin's method. "I'm going to visit his lab in early December, and we agreed that we'll have a look at it," he says.

Chin, however, is already planning to put the newly stabilized laser to work. "We're going to try to use it immediately and see how much better we can do."

–Andrew Watson

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