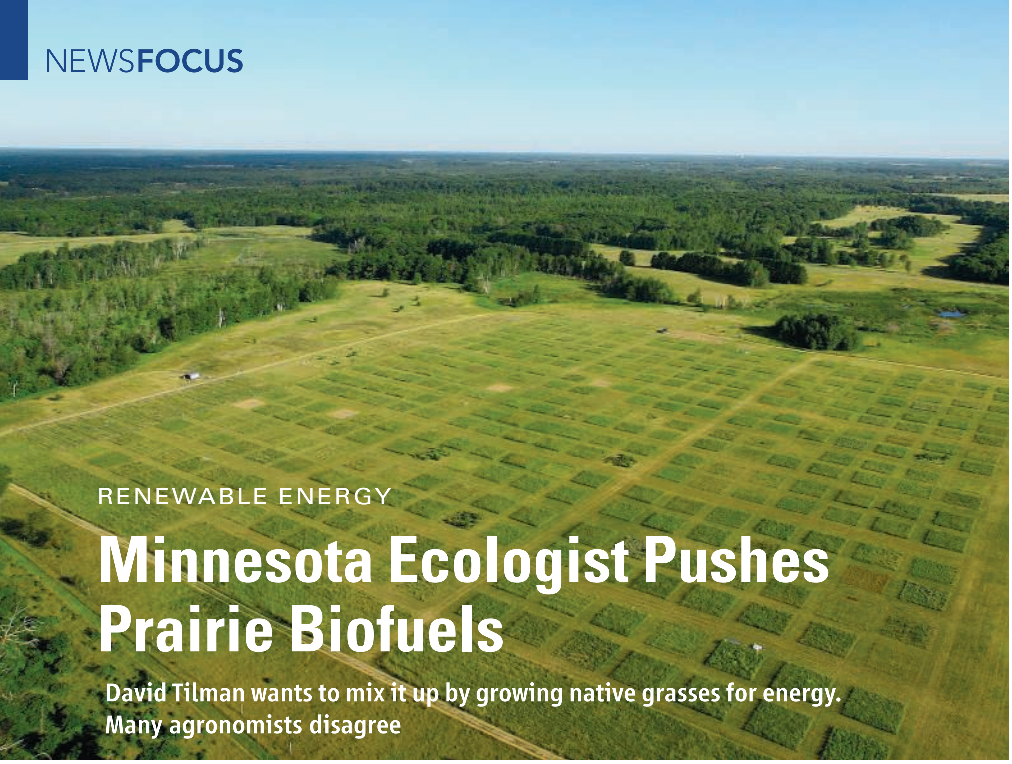


RENEWABLE ENERGY

Minnesota Ecologist Pushes Prairie Biofuels

David Tilman wants to mix it up by growing native grasses for energy. Many agronomists disagree

Plots thickened. Scientists are examining the potential for biofuels of various prairie grass combinations.

EAST BETHEL, MINNESOTA—Over the past 3 decades, David Tilman has set up thousands of field experiments here, 70 km outside of Minneapolis, probing some of the most fundamental questions about prairie ecosystems. So, the University of Minnesota (UM), Twin Cities, ecologist never imagined he'd undertake the considerably more practical task of developing new climate-friendly crops for biofuels—that is, until 2005, when he realized he'd done it inadvertently, as part of a long-term ecological study at Cedar Creek Ecosystem Science Reserve.

On one 11-m-×-11-m square plot was a healthy stand of switchgrass, an abundantly growing perennial that the U.S. government is promoting as an alternative to corn as a feedstock for ethanol. Nearby was a plot of switchgrass mixed with 15 native perennial grasses that tend to grow less verdantly each year. Neither plot received irrigation or fertilizer. Yet, when Tilman and colleagues analyzed 12 years' worth of data, the mixed plots delivered more than twice the yearly biomass per hectare—suggesting a potentially much more efficient biofuel source with a much smaller "carbon footprint." "We expected higher productivity—maybe 50%. But nothing like the 238% we now see," said Tilman during a recent walk through his 121 hectares of field sites.

To Tilman, the findings suggest that for producing biofuel feedstocks, the mixtures are "more stable than monoculture, more reliable than monoculture, and more productive than monoculture"—and more environmentally friendly. Because different species occupy different ecosystem niches and perform different functions—say, adding nutrients to the soil or resisting drought—mixtures of prairie grasses can thrive on marginal lands without energy-intensive inputs such as fertilizer and irrigation. In addition, they can boost biodiversity and replenish depleted soils. "This is bigger than just biofuels," Tilman says.

Tilman's proposal to grow the mixtures as ethanol feedstocks, published in the 8 December 2006 issue of *Science* (p. 1598), won plaudits from top ecologists and inspired the U.S. Congress to include prairie biofuels in a $100 million national biomass-planting program. The Minnesota legislature kicked in roughly $3 million for state studies of prairie grasses. But Tilman's idea drew a firestorm of criticism from many agronomists, who said it overstated the potential climate benefits. They charged that Tilman's methodology exaggerated the productivity of mixed grasses and underestimated the expense and difficulty of scaling up test plots to commercial size. "Most people don't believe [his idea] could be practical," says agronomist and geneticist Stephen Moose of the University of Illinois, Urbana-Champaign.

Prairie home companion. Dave Tilman has studied the ecology of grasses in Minnesota since 1976.

The upbeat, fast-talking ecologist concedes that several questions must be answered before his strategy goes prime time. "I'm not one to believe we've found the be-all and end-all of biofuels," Tilman says. But he thinks it is worth a try. And so do a handful of ecologists and agronomists in seven Midwestern states; like Tilman, they are starting larger trials to test his concept under different conditions.

A mixed bag

Tilman's proposal contrasts sharply with the recent thrust of biofuels research. Today, U.S. farmers produce some 29 billion liters of ethanol a year from corn. But corn-based ethanol is no longer seen as a relatively cheap, environmentally friendly alternative to petroleum-based fuels. Experts say it's too carbon-intensive. Fertilizing, harvesting, and refining corn into fuel takes a lot of energy, and the sugar-conversion process wastes most of the plant's biomass, primarily cellulose. Using prime farmland to grow biofuels not only contributes to rising global food prices but also leads indirectly to cutting down trees for farmland overseas—and that, in turn, releases more carbon.

In search of a substitute for corn ethanol, President George W. Bush launched a $150 million, two-pronged federal research program in 2006 to identify cellulose feedstocks for biofuels, such as switchgrass, as well as the enzymatic and microbial methods to convert plant cellulose into fuels, an equally daunting challenge. Last year, the U.S. Congress passed a law requiring refiners to produce an estimated 61 billion liters of cellulosic biofuels by 2022.

In terms of potential new feedstocks, the part of the challenge on which Tilman is working, the U.S. departments of Energy and Agriculture have focused so far on switchgrass, waste-plant material from farms, poplar trees, and a tall European perennial grass called *Miscanthus*. Their emphasis has been to grow these crops as monocultures on large plots of prime farmland, using conventional high-input agricul-

CREDITS (TOP TO BOTTOM): UNIVERSITY OF MINNESOTA; TIM RUMMELHOFF tural techniques. Tilman, by contrast, advocates growing biofuel stocks with minimal or no fertilizer on some of the nation's more than 5 million hectares of marginal soils—farmland with nutrient-depleted soils, worn-out hayfields, or on the edges of streams or highways, "using mixtures of plants which will grow there anyway," says ecologist Clarence Lehman, a research partner of Tilman's at UM.

The soils on Tilman's experimental plots are about as marginal as they come in the Midwest. They were too sandy for general farming to begin with, and then, in 1993, Tilman and his colleagues scooped off the top 15 centimeters of soil to ensure that each plot had roughly the same depleted levels of nutrients such as nitrogen and phosphorus. They measured the output of hundreds of mixed-species plots, publishing a string of high-profile papers that demonstrate the stability and productivity of biodiverse ecosystems.

Although Tilman didn't realize it at the time, he was also creating an ideal laboratory to test potential feedstock crops for biofuels that could grow on the world's 700 million hectares of degraded land. These days, that lab is abuzz with activity. Since 2006, the researchers have expanded the fieldwork to examine the agricultural and environmental implications of growing prairies for biofuels. They maintain test plots planted in various monocultures of prairie species, six-species mixtures, and 60-species mixtures. As Tilman reported in 2006, the mixed prairie grass plots produced the equivalent of 1500 liters of ethanol per hectare in net energy yield as opposed to 620 liters from switchgrass. (The net energy yield reflects the total amount of fuel produced minus the energy used to produce it, including energy required to make fertilizer and to run farm equipment.)

To gauge productivity, Tilman's team measures aboveground growth from samples cropped close to the ground. Obtaining accurate data requires a platoon of several dozen summer students, who spend hours a day sifting through thousands of kilograms of dried soil, leafs, and twigs to separate bits of each species for weighing. Others obtain underground biomass samples at various depths. "It's not easy," laughed Andrew Chua, a University of California, San Diego, undergraduate, who had removed his shirt as he pounded a steel probe through dry soil one afternoon in late August. The elbow grease will pay off in the winter, says Tilman, when full results from this fall's harvest will be available.

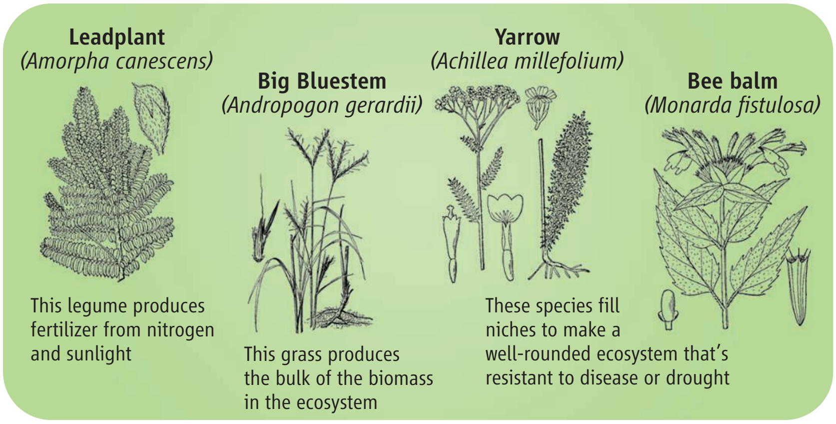
A question of benefits

But Tilman has a long way to go to convince mainstream agronomists. His critics say that his experiments inflate biomass yields, suggesting that prairie grass biofuels would be more carbon efficient than they actually are. And critics see big expenses to boot.

To maintain the correct mixture of species, Tilman's team hand-weeds the plots each year. Each autumn, they remove biomass for measurement from small sections of certain plots, which are burned in the spring. But burning may be giving the grasses an artificial advantage, allowing nutrients such as phosphorus and potassium to be incorporated back into the soil, says agronomist Kenneth Cassman of the University of Nebraska, Lincoln (UNL). A farmer seeking to sell biomass to an ethanol refinery, in contrast, would harvest the entire crop each year, removing the nutrients with a resultant decline in overall productivity, he contends. Tilman concedes that his test plots may be benefiting from conserved nutrients, although he notes that the amount of inputs required are nonetheless minimal.

Leading switchgrass proponent Kenneth Vogel of UNL and the U.S. Department of Agriculture takes aim at the most salient finding of Tilman's 2006 work: that mixed grasses were more than twice as productive as switchgrass per hectare without inputs for either. Mixed species may have won out in Tilman's small plots, says Vogel, and watering and fertilizing switchgrass fields may require more energy. But with inputs, switchgrass monocultures have a higher net energy yield, he asserts. In work published this year in the *Proceedings of the National Academy of Sciences*, he showed that tests of switchgrass on full-scale plots on 10 Midwestern farms, treated with the standard 60 to 100 kg per hectare of nitrogen fertilizer each year, delivered net energy yields of between 2250 and 3300 liters of ethanol per hectare—more than twice the net benefit Tilman's mixtures provided.

Tilman is quick to point out that Vogel's soils were mostly richer than his, providing an inherent advantage, although he acknowledges that switchgrass could potentially offer net benefits. Large head-to-head experiments using the same soil are now under way to settle the question, with results expected next year. Vogel's team has grown mixed-species plots in recent years, and Tilman is comparing watered and fertilized plots of switchgrass with his mixtures.



We are family. These four plants are representative of the dozens of species that make up naturally biodiverse prairies.

SOURCES: USDA-NRCS PLANTS DATABASE/N. L. BRITTON AND A. BROWN; USDA-NRCS PLANTS DATABASE/A. S. HITCHCOCK

Prairie grass mixtures will be expensive initially for farmers, Tilman acknowledges: The seeds can cost between two and 10 times more per kilogram than switchgrass. But he expects costs to fall as demand increases, and he hopes other environmental advantages will give mixtures a fair shot.

To pin down the biodiversity benefits of managed prairies, the state of Minnesota is supporting research on roughly 800 hectares of marginal lands across six sites to compare the effects of different harvesting techniques on game birds, insects, and other wildlife. Lehman is studying whether the grasses' root systems might take up excess chemicals that leach in from nearby agricultural fields. The U.S. Geological Survey is funding experiments using chemical tracers on several of Tilman's test plots to measure the uptake of nitrogen, endocrine disrupters, and antibiotics.

Although many agronomists remain skeptical, the overall environmental advantages of prairie grass biofuels have inspired some to test Tilman's approach. When the 2006 paper appeared, "people were saying this ecologist is doing a lot of talking but he doesn't have the data behind it," says UM agronomist Craig Sheaffer. But now he's setting up large-scale field trials of the mixtures himself. **–ELI KINTISCH**