Land Report

Number 110, *Fall* 2014 · *The Land Institute*

About The Land Institute

MISSION STATEMENT

When people, land and community are as one, all three members prosper; when they relate not as members but as competing interests, all three are exploited. By consulting nature as the source and measure of that membership, The Land Institute seeks to develop an agriculture that will save soil from being lost or poisoned, while promoting a community life at once prosperous and enduring.

OUR WORK

Thousands of new perennial grain plants live year-round at The Land Institute, prototypes we developed in pursuit of a new agriculture that mimics natural ecosystems. Grown in polycultures, perennial crops require less fertilizer, herbicide and pesticide. Their root systems are massive. They manage water better, exchange nutrients more efficiently and hold soil against the erosion of water and wind. This strengthens the plants' resilience to weather extremes, and restores the soil's capacity to hold carbon. Our aim is to make conservation a consequence, not a casualty, of agricultural production.

LAND REPORT

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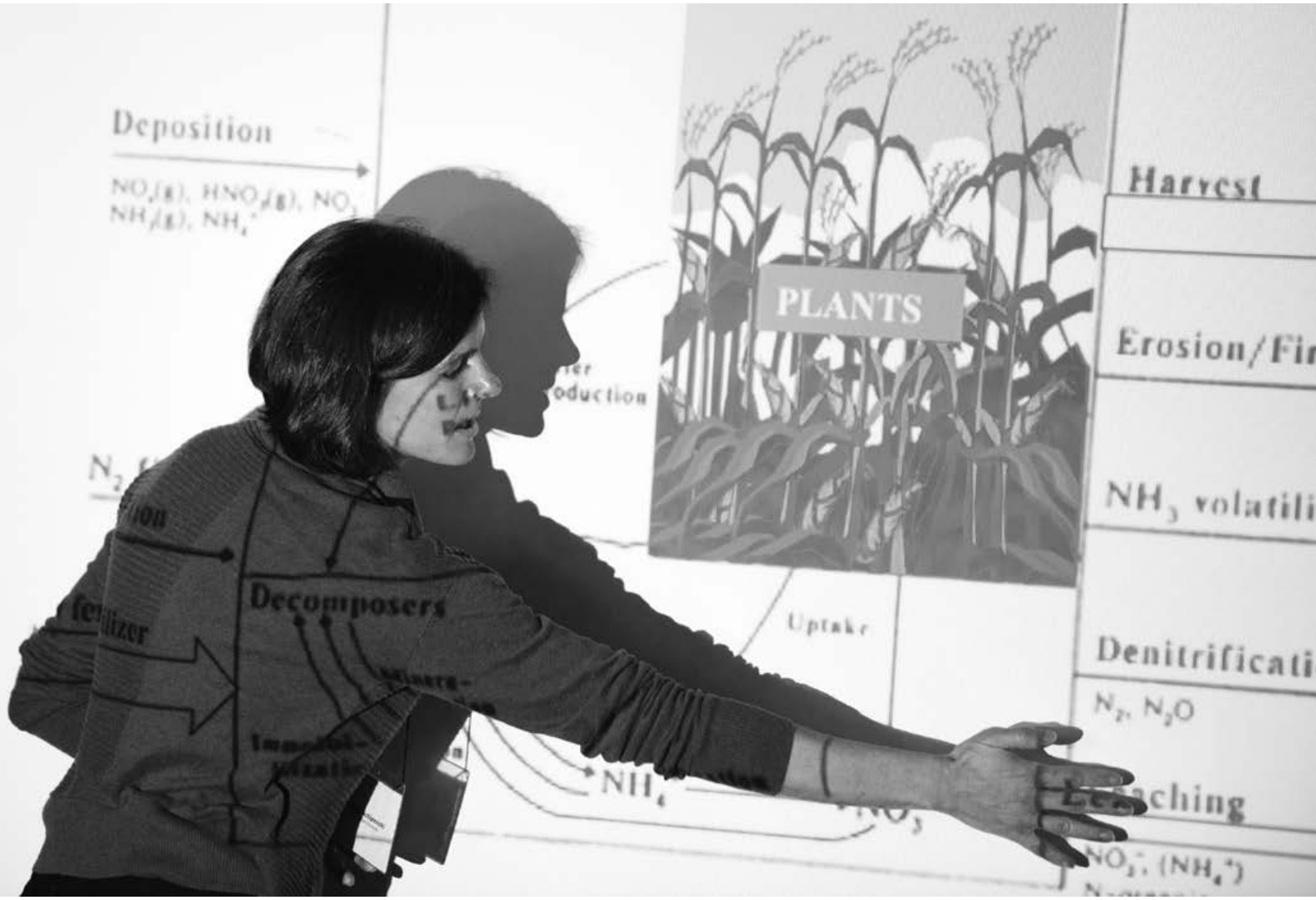
Cover

Claire Trail, a student at Marlboro College in Vermont, helps cut and bag hybrid wheat plants this summer at The Land Institute. Each plant is evaluated for breeding to develop wheat that is perennial. In October, scientists from around the world gathered to discuss transforming grain agriculture, from annuals grown alone as species to perennials in mixtures. For the whole story begin on page 4. The passage about wheat is on page 19. Scott Bontz photo.



Meagan Schipanski talks about nitrogen and plant growth at a Land Institute conference called "New Roots for Ecological Intensification." Ecological intensification of agriculture means doing less ecological damage than conventional farming, but sustaining production of food. Researchers from 10 nations talked about how to do this by developing perennial grains, and growing them in species mixtures. Enthusiasm was high. Scott Seirer photo.

Perennial grains draw world interest

A cosmopolitan, youthful meeting to develop them, and to grow them together

SCOTT BONTZ

Late this October, The Land Institute and a fledgling organization called Estes Institute brought to a historic hotel in the Rockies researchers from five continents. The congregation, mostly biologists, but also social scientists, was asked to huddle over advancing globally The Land Institute's goal, development of perennial grains grown in species mixtures. Two days into the four-day meeting, longtime observers of work toward the goal told participants that they sensed a watershed. Never had so many – more than 50 – from so many nations – 10 – gathered around the idea of perennial grains. Not until the past decade had there developed the biological insight and know-how necessary for the work's success. Not until the past few years had the worlds of science and funding paid it as much attention.

The scientists, many of them young, several of them former Land Institute graduate school fellows, came to Colorado from university posts, government agriculture departments, and an arm of the United Nations. They met Land Institute researchers who have been on the perennial grains track for more than three decades. Talk covered technique, results, and coordination of efforts, along with curiosities like the high altitude disrupting sleep, and elk grazing in yards. The conversation about a new agriculture stretched beyond scheduled morning and afternoon sessions, to drinks, to meals, and to after meals. "It was fantastic to see the people I have been working with from around the world on wheatgrass finally getting to meet each other," Land Institute breeder Lee DeHaan said. "It was great to see them interacting and generating ideas, which would have been nearly impossible without this meeting." Institute President Wes Jackson later said, "I sensed congeniality, and collegiality. It was 'What can we do about making the great transformation?'" Jackson, who founded the institute 38 years ago, said, "It was maybe our finest hour."

Here are sketches of the scene.

The goal of Estes Institute is conservation. It works from Estes Park, a small city at 7,500 feet and entrance to Rocky Mountain National Park. Overlooking the scene from a granite rise spreads the neoclassical Stanley Hotel, built in 1909 by F. O. Stanley, who also manufactured the Stanley Steamer automobile, one of which stands in the lobby. During a stay at the Stanley, Stephen King conceived his horror novel "The Shining." But it is a bright place, with generous south windows in three stories of wood painted white. Melinda Merrill likes it for staging Estes Institute conferences.

A former schoolteacher and the daughter of a prosperous miller, Merrill directs the institute for no pay, with help from a handful of other volunteers. She also travels to Wilson, Kansas, to manage the family farm.

She met Jackson a year and a half ago, and found in The Land Institute an ideological partner. "Everything that The Land Institute stands for, I believe in," she said. Institute scientists invited the participants and organized the presentations in October, but Merrill conceived the event, pushed it, made arrangements with the Stanley, and, through her institute, paid for it.

The conference was called not "Perennial Grains 2014," but "New Roots for Ecological Intensification." Ecological intensification is about getting more with less, about raising grain yields by bringing plants to work nearer their potential while also cutting harmful consequences such as water pollution, soil loss, and soil nutrient exhaustion. For the conferees Land Institute Research Director Tim Crews traced this idea to a 1999 paper by Kenneth G. Cassman, of the University of Nebraska. Cassman advocated an agriculture that better uses nitrogen fertilizer, lowers greenhouse gas emissions, and regulates pest populations. The means would continue conventional agriculture's reliance on approaches extrinsic, from outside the crop ecosystem itself, such as using GPS satellites to precisely fit fertilizer application to soil needs that vary across a field. Thinking about intensification was not yet in terms of a natural ecological system, where the solutions are intrinsic.

That came with argument to breed the annual grain crops so they improved processes like pulling more water from soil and losing less to air. But this did not look beyond solitary species. And neither path led away from annuals grown in monocultures.

Crews observed that almost all of nature is made up of polycultures, species growing not alone, as in most of industrial agriculture, but in mixtures, and that the plants involved are mostly perennials, which do not require yearly soil disturbance by planting and tillage, as in grain agriculture, where annuals reign. A new level of ecological intensification comes with those species mixtures. They make community. Different plants fill different niches and use different resources, or use the same ones in different ways. Different plants also uniquely support groups of soil organisms that can improve soil fertility and prevent plant disease. Put together, the different species lose less and grow more. Also, because many plant predators and pathogens attack particular species, multiple species in one space can brake losses. Even agroecologists working with annuals have for some time recognized the good of diversity, Crews said, both in place, as with polycultures, and in time, as with crop rotations.

A final level of intensification comes with perennials. They are the usual destination, after disturbance by disaster or plow, for the natural course that ecologists call succession. Through competition and tighter use of resources, perennials resume command. Using data from University of Washington geologist David Montgomery for rates of soil formation and loss around the world, Crews questioned whether soil can even form under continuous annual cropping. Montgomery shows that in no-till agriculture, where farmers use chemicals rather than mechanical force to control weeds, and so better shield with crop residue the loss of soil to wind and water, erosion under annual crops can still exceed the rate of soil formation by a factor of five. Under the tradition of plow and cultivator, still used on 95 percent of cropland globally, erosion may exceed formation by 90 times. "It's very difficult to form soil under annuals," Crews said. Perennials make soil by tapping parent rock and mineral under the topsoil and adding great amounts of organic

matter via roots. Annual agriculture appears to fundamentally rely on soil capital accrued under perennial vegetation. Crews showed a National Geographic photo of a trench at The Land Institute exposing side-by-side annual wheat and the deeper, thicker roots of perennial wheatgrass. He said, "This is where erosion will stop." If the photo showed the wheatgrass roots intermingled with those of a perennial legume, he might say this is where farming will at last be ecologically intensified and sustainable.

To change farming, change farm policy

Ken Bagstad is a research economist with the US Geological Survey in Denver. He studies ecosystem services. This is an economic term for how people benefit from nature, such as with clean air and water, crop pollination, and recreation. The services are often ignored, but people depend on them for prosperity. A natural, functioning ecosystem typically provides more services than a system designed to provide just one thing, as with an annual monoculture. Converting grasslands or forests to agriculture not only drives out wild species, it can reduce economic benefits. What the Estes conference-goers were interested in, farming of perennial polycultures, would at least partly fix this.

Ecosystem services are affected by agricultural policy, and changes in policy could speed adoption of perennial grains. For policy to work like a market, with incentives and disincentives, it needs accurate measure of the services. Several US Department of Agriculture programs pay farmers to take cropland out of production and plant perennial cover, aiming for soil conservation. Accurate measure of services could improve the programs by ensuring that payments go for the greatest actual gains. Ecosystem services need easy, consistent measurement so policymakers can design for their conservation, Bagstad said.

These reckonings entail both private costs and social costs. Private costs include what farmers pay for fertilizer, pesticides, and irrigation water. Social costs include the effects of fertilizer or pesticides on water, soil, wildlife, and human health. These costs farmers do not figure into their books, but instead "externalize." Government policies may attempt to reduce social costs. These can be hard to measure, and finally prove high, as when fertilizer pollutes drinking water and cities must build new treatment plants. To internalize what had been treated as external cost requires a change in public policy. Farmers could apply less synthetic nitrogen fertilizer, but see yields fall – a higher private cost. Policy could provide economic incentive for farmers to reduce fertilizer application, and improve water quality.

So could perennial grains grown with nitrogen-fixing legumes. Perennials also could vastly cut the cost of planting and tillage, lowering both private and social costs. That alone could win farmers over. But this new, more ecologically intensive system is a radical rethinking of agriculture. It is not yet well known – not by the public, which stands to benefit from its ecosystem service benefits, not by policy makers, who could dramatically accelerate its adoption, and not by farmers or agricultural corporations. As with other people, Bagstad said, for farmers perhaps more important than the cost of

perennial agriculture is its message and the messenger. The message must come from sources that farmers trust.

For effecting policy Bagstad presented environmental law specialist Jim Salzman's "five P's": Prescription – making an action illegal. Penalty – allowing choice but imposing costs for those that are socially damaging. Persuasion – changing social norms. Payments – financial rewards. Property

Scientists from Canada, Argentina, and the US plan how to achieve perennial oilseed crops. Scott Bontz photo.

rights – their redefinition. For understanding when and how policy paradigms can shift, Bagstad cited political scientist John Kingdon's work. Kingdon said this takes timely confluence of three streams: a problem is recognized by the public, the media, and politicians; policies for addressing the difficulty are publicized; and political will and power are found. For example, the Dust Bowl of the 1930's spurred the creation of the Natural Resources Conservation Service to reduce soil erosion under President Roosevelt. Bagstad described today's vicious cycle as intensified farming of annuals in monocultures leading to land degradation, which leads to more fertilizer and pesticides, which intensifies policy support for annual monocultures. To turn this around would require introduction of perennial grain crops, which would lead to enhanced ecosystem services, with wide understanding of their social and private benefits, which could lead to policy that internalizes ecosystem services value.

For this, Bagstad recommended research in three areas: In science and economics, to predict and measure the ecosystem services of perennial crops. In social science, for communicating the benefits to farmers, the public, and policymakers. In policy, for the most effective and feasible means to support sustainable agriculture.

Bagstad said he thought much headway has been made in understanding how nature provides values underpinning economic prosperity. But he said more than nine of 10 economics textbooks still fail to recognize the relationship between the economy, sustainability, and biological limits. We need a shift in our economics that will help farmers make better decisions for all of us in the long term, he said.

Plants feeding plants feeding people

For the same amount of nitrogen reaching their roots, perennials take up more to make proteins and build stems, leaves, and seeds. They let far less escape to runoff and groundwater. With annuals the norm for loss of nitrogen fertilizer is about 50 percent. Herbaceous perennials commonly lose less than 10 percent. Even better might be if, instead of reliance on synthesized nitrogen, with its water pollution plus energy-intensive costs to farmers and in greenhouse gases, perennial cereals got their nitrogen from other plants. This would be the legumes, which work with bacteria around their roots to take an otherwise unusable form of the gas from air and "fix" it. Before nitrogen synthesis was invented a century ago, farmers devoted up to half of their land to growing legumes, in rotating monocultures – the fixers mingling with grain crops was not in space, but over time. At Estes Park one group discussed how legumes could do the job while growing with the grain.

But they began one session with this question: Isn't attaining perennial grains challenge enough? Why throw in legumes and complicate matters with a polyculture? Erik Steen Jensen, a Danish agronomist working at the Swedish University of Agricultural Sciences, said that for a new kind of farming system, it could make sense to build in legumes from the start. Other participants assembled a list of what that inclusion would bring. As mentioned, less synthetic nitrogen and its costs to farmers,

soil, and water. Also, less fossil fuel burned. Better soil organic carbon, which makes for better plant growth. Mixed species thwarting advance of pests and diseases, though also risking disease to the legume. Species with different needs or abilities going after different resources, or the same resources in different ways, so together they produce more. Without all resource gathering in one basket, more resilience to climate change. One field bringing multiple products and ecosystem services.

Legumes in a polyculture would not necessarily be eaten. Taking their seed protein means taking away nitrogen. Farmers without synthetic fertilizer often leave the whole legume plant to feed the annual crops that follow. Unknown about perennial polycultures, with their tighter roots and cycling, is how much nitrogen they will need, and whether legumes in the mix will provide enough, in their decaying roots and residual stems and leaves, so that they can spare to feed people with their seed. Tim Crews, the Land Institute research director, suggested making the legume neither a seed crop like soy, nor a forage crop like alfalfa, but a cover crop like vetch, purely for adding nitrogen. Matt Ryan, from Cornell University in New York, thought it better if both the legume and the cereal made a product.

Legume and cereal also likely will compete, unless, like modern corn, they are bred to grow congenially, shoulder to shoulder. Competition may waste growth for something like height, to hog sunlight, at the expense of edible seed. This is another big challenge for attaining perennial polycultures. Perennial wheatgrass planted in fall outcompeted several added legumes, said Steve Culman, a former Land Institute fellow and now the soil fertility specialist for Ohio State University. Sieglinde Snapp, from Michigan State University, said that if the planting ratio is shifted enough, the plant that comes out on top can be "queen of the forages," the legume alfalfa. Ryan said vetch is very competitive.

A system might cycle: when soil nitrogen falls, legume population rises; when legumes raise soil nitrogen, the grain population rebounds. Studies so far show mixed results, with some combinations of legume and grain leading to domination, and others maintaining balance for years. But this is a young field, and there may be profitable paths among the many as yet untested combinations of species, their planting times and space, and management of their growth.

Steen Jensen said competition can be used as a tool. Maged Nosshi, an Egyptian at the University of Kansas who is conducting his doctoral research at The Land Institute, noted for example that crabs gnawing on mangroves at particular elevation in the trees can boost their growth by aerating roots. Net outcome depends on context. This is called the stress gradient hypothesis, and the gradient makes a bell curve. At the peak of this one would be the right number of crabs in the right place.

Jennifer Blesh, a former Land Institute graduate school fellow and now an assistant professor at the University of Michigan, said that resource gradients can be manipulated through proper farming. Use of sun, soil nutrients, and water might be staggered by planting together species that grow at different rates, said Meagan Schipanski, another former Land Institute fellow and now a faculty member at Colorado State University. But she said that left to its own, any combination would eventually fail to keep the legume plentiful enough for the optimum nitrogen dividend. She said the farmer must manage the system to keep the legume.

Snapp suggested using low-growing annuals for "understory" to cover soil until taller but slower perennials grow to height.

Richard Hayes, a research agronomist from Wagga Wagga, Australia, described a study of intercropping perennial wheat hybrids and forage legumes – both perennial and reseeding annuals – in three arrangements and ratios. Two of the combinations did not significantly cut yield. One yielded less grain than a monoculture, but in the second year produced the most overall aboveground growth, which could benefit a crop meant not only for grain, but also for grazing. Two species grown together appeared to produce more grain than when grown alone, Hayes said. His photo showed that intercropped wheat was greener, probably from the legume nitrogen.

How plantings of species together tend to play out, and how they call to be managed, will change as their combination and perennial presence in once annually tilled soil remakes the soil microbe community, and restores useful soil carbon and nitrogen levels to nearer those of natural systems. Snapp said achieving that equilibrium might take a decade.

The work beyond the breeding and ecology

On the second full day of the Estes Park conference, after one group of scientists talked about legumes, and others about sorghum, wheat, and oilseed crops like sunflower, all regrouped for how to scale up and fund worldwide development of perennial grains. This meeting is where the description "watershed" was used, by Land Institute President Wes Jackson, institute board Chairman Angus Wright, and Ted Lefroy, the Australian who in 1997 organized the first international conference for agriculture to mimic nature. They were part of a panel of half a dozen who argued to the assembled plant and soil scientists for what work was needed outside labs and test plots.

Lefroy advocated high-level publication of the effort, affiliating authors from around the world, in professional journals and in popular magazines like Britain's New Scientist. He said, "To me, it's a wonderful story." He also said The Land Institute's concept of patterning agriculture after the native Kansas vegetation of prairie should be adapted to other natural ecosystems around the world. It should be brought to those places, but not imposed on them. "It has to have grass roots," he said.

The Land Institute is already sending plants and trading notes with sorghum researchers in Africa. In February its oilseed crop candidates will expand to Uruguay. Institute wheat plants are being evaluated in several nations around the world.

Ricardo Salvador led off those on the panel arguing that radical change to agriculture demanded a radical change to politics and economics. Salvador is an agronomist who lobbies members of Congress as director of the Food & Environment Program of the Union of Concerned Scientists. This group was founded in 1969 to study government policy for science and technology, steer it away from military development, and solve social and ecosystem problems. Perennial grain polycultures could be a solution. Salvador said those working toward them should beware of co-option

by an economic system that accrues wealth to a select few, but which operates a shell game to present the agricultural system as benefitting all. "The majority of us experience agricultural chaos," he said. Those who believe in need for an ecological agriculture and economy see the current system's limits. "If we believe in the future, we must believe that this system will fail," he said. Disasters loom with water, oil, and land, he said, and that gives opportunity for the system's remake. A template is natural ecosystems. Avoid recreating the old boss, Salvador said, and assure benefits go equitably to a large set of stakeholders. He also urged recognition that even funders of perennial grains science are behind the shell game.

For a sociology doctorate at the University of Kentucky, Alicia Hullinger is studying how the new agriculture's success relies on development of a network, a "movement of movements." Convergence of labor, justice, ecology, and food security can make a society just and sustainable, she said. Hullinger cited Jackson for seeing social justice as deriving from the ecological perspective. For the scientists at Estes Park, her suggestion was to be mindful of the importance of language. Even among these precise professionals she saw communication gaps. To get the message to the public, she said, it should first be clear among the pioneers.

Bridging gaps is Lennart Olsson, who founded the interdisciplinary Lund University Center for Sustainability Studies, in Sweden. His education was in geography and social anthropology. At Estes Park he followed on Salvador with how to avoid co-option of perennial polycultures – as he put it, to make sure they are not taken over by the wrong people. Olsson said he studies transformation. Transformation to this radically new agriculture will not evolve by itself, but must be planned. That makes it harder, he said. Its benefits will not come quickly. Advocates cannot call on venture capital to promote common good. The program also might initially have trouble competing with established techniques. What must change is not just the new plants and how they are grown, Olsson said, but the rules of the game. The new agriculture will find itself up against a system controlled by strong interests. The large majority of the world food seed market lies in the hands of three or four companies. Seed that a farmer does not need every year, and is developed by nonprofits who want to keep it in public domain, is not what these corporations want. "They will not be passive if this is a technology that challenges their interests," Olsson said.

To plan, he suggested analysis of strengths and weaknesses, opportunities and threats. In the work toward perennial polycultures he sees strength in a visionary idea, necessity, and increasing scientific support. Its weaknesses are research that is geographically scattered, lack of a coherent vision, and lack of social dimensions – he said there might be need for a completely different rural society. Opportunities are awareness of the work, instability of the current food system, and new kinds of funding. Threats to the idea are its dismissal as radical or utopian, co-option, an inability to quickly answer needs, and drift from the core concept of perennial grain polycultures.

Seth Murray, a maize breeder at Texas A&M University, challenged Olsson about what he meant by "the wrong people." To answer, Olsson noted how microcredit designed to give the poor affordable loans has been co-opted by big lenders. Murray responded that he wants to see

perennial grains benefit the ecosphere and society regardless of who promotes them. Assuming moral authority to divide "us" and "them" often misses a large common ground, he said, and there is no reason for drawing lines in the sand over a technology that does not yet exist. To support Olsson, The Land Institute's Jackson pointed to how Monsanto presents itself as caring for the devastated population of monarch butterflies east of the Rockies with advocacy for planting milkweed, sole food of the insect's larvae, while the corporation's herbicide glyphosate continues to be sold and kill the plant. "The industrial mind will have its way," Jackson said. In conversation later, Jim Anderson, a breeder at University of Minnesota, said the important thing is to get the ground covered with green, whether the crop is from a nonprofit or a global corporation like Monsanto, which is now interested in pennycress, a wild annual that Minnesota is developing to cover ground in winter and produce oilseed. Steve Culman, of Ohio State, said he saw the agricultural revolution as distinct from the economic and so-

Perennial grains might be managed with grazing. At the Stanley Hotel, elk grazed lawn. Scott Bontz photo.

cial one. He said attaining the former will be hard enough without distraction by the latter, far more difficult challenge. Nature does not care, he said. Another former Land Institute graduate school fellow, Jennifer Blesh, now at the University of Michigan, and who has studied land reform as well as agroecology in Brazil, said one change must come with the other. She said The Land Institute's ecological vision had advanced, but without enough ideas for social change. She appreciated the Estes Park forum venturing there. Institute sorghum researcher Stan Cox said that without socioeconomic reform, perennial polycultures can succeed in development, but not in the market, even if they appear superior in big-picture analysis. Current policy and corporate infrastructure have other interests. The seismic economic and social shifts that could make way for perennial polycultures will take time, he said, but that is all right, because so will development of perennial grains and perfecting of polycultures.

Families own about 90 percent of the world's 570 million farms, and care for about 75 percent of agricultural land. This includes spreads of hundreds and thousands of acres in the industrial West. But most families raise food on less than 5 acres, a square under 470 feet wide. Many of these smallholders grow multiple crops. They are already at The Land Institute's aim of diversity, said Caterina Batello, who works from Rome for the United Nations' Food and Agriculture Organization. Most smallholders also have a working intimacy with their land, including with its wild species. "They have ecological knowledge that's not science, but it's in practice," Batello said.

Their weakness is in lacking not only science, but also policy support. Many work in closed circles, using few products from outside. In turn, the outside lacks information about their market workings, their conservation methods, how the farmers affect ecosystem services, and their crops' nutritional value. To fill this out the FAO would like an information network. It also would like farmers involved in testing the new perennial crops and methods, Batello said. The FAO could promote this with organizations like The Land Institute. It especially wants research adapted for developing countries to address land degradation and climate change. Erik Steen Jensen, from Swedish University of Agricultural Sciences, said farmers with new technology can fail for lack of know-how. Managing perennial polycultures will take more expertise than sowing and cutting an annual monoculture. Their introduction should be made with care, he said.

For the scientists involved, Angus Wright suggested a Web portal with links to their work and other valuable findings for development of perennial polycultures. The site could also present polemics. It would primarily be scientific, Wright said, "But within that we have debate about the science." Wright appraised that the Estes Park meeting's dynamic of communication in person had built a community to work with the ideas. "Firsthand contact is powerful," he said. The Internet is not enough, but Wright said it could enrich face-to-face encounters.

Wright also asked if the banner that the effort flies should bear the words "ecological intensification" or something else. Organizer Tim Crews said the conference was not called Perennial Grains 2014 because the goal is not just another alternative crop, but a wholly new way of agriculture. He said strategic conversation about food security has converged on not being able to solve agriculture's problems without a wholly

new way. "When you look under the hood as to what we have to offer … annuals cannot meet the demand," Crews said. "There's not enough there." The farmer in Uganda does not have the luxury of saving his crops with more synthetic fertilizer. Crews said farmers urgently want another system, one of ecological intensification.

Bongani Ndimba, from the University of the Western Cape in South Africa, suggested the name "sustainable intensification." Jackson said those who are looking far enough ahead to solve the problem with a complex solution like perennial polycultures probably are a minority. "And that's something we have to overcome." Ndimba asked what would trigger this. What makes sense for a poor person? There the session for promoting and funding perennial polycultures ran out of time.

Malawi farmers test legumes amid maize

Sieglinde Snapp teaches at Michigan State and conducts research in Africa. She told of a study involving farmers in Malawi. There, crops are mostly annuals, and with a seven-month dry season that leaves soil bare and erodible. The total amount of plant growth is in decline. The fertilizer response of the main crop, maize, is falling. Fertilizer subsidies are consuming 15 percent of the nation's gross domestic product. "It doesn't look like a Green Revolution to me," Snapp said, referring to the late 20th century development of crops that produced more grain, but paid for them partly with dependence on more fertilizer. Along with many other smallholders in Africa, Malawians face risks of degraded soil, climate change, and inequity. Their farmers want more than yield. They want protein, profitability, better ground cover, and more effective fertilization. For this their government still needs political will, Snapp said.

But the three-year-old study in which farmers participate encourages her. Growers plant with their maize two crop legumes, one of them peanut, the other pigeon pea, a perennial. With the legumes fixing nitrogen, compared with straight maize this mix cuts the added fertilizer to one-fourth. Some plots produce more food than the same plants would if grown in monocultures. Spreading among species the constant risk of changing conditions from year to year, the polyculture also makes for more dependable combined yield.

To harvest grass and grain from one plant

Farmers can grow more than one crop in one field. They also can put one crop to more than one use. Kansas farmers seed wheat in fall, and after the plants are established let cattle graze a bit before winter. Come spring the wheat can still make a good haul of grain. Steve Culman wants to see how this works with Kernza, The Land Institute's trade name for the perennial intermediate wheatgrass. He has lined up small plots at nine sites in seven states. For this preliminary study he

Conference-goers break from talk about ecological intensification, for a visual record outside their meeting place, the Stanley Hotel, in

Estes Park, Colorado. Scott Seirer photo.

will not use livestock, but what he called "nerdy" defoliation – mowing. That will make easier management for the participants, all of them volunteering their space and time. It also will make treatments more consistent. Culman wants to compare not different methods, but different conditions. Mainly he wants to see if grazing affects grain yields. Grazing might also help control a species prone to dominate others sown with it, and so preserve the intended polyculture.

Kernza has long been grown to feed animals nutritious leaves and stems. Beginning decades ago, it has been bred with wheat to introduce disease resistance. Now it is one of the leading species in attempts to instill wheat with the genes for perenniality. The Land Institute is also taking Kernza directly to domestication as a grain crop. Culman, a former graduate school fellow for the institute and now soil specialist for Ohio State, will use in his study those improved plants.

The species does not regrow quickly. Culman's Kernza band will do their simulated grazing in spring or fall, well before summer grain harvest. Measured will be weight both of the seed and of cut plant. Compared will be the seed yield with that of plants not grazed.

Culman e-mailed invitations to participate in the pilot. Takers are two sites in Ohio, two at The Land Institute, and at Cornell University in New York, Michigan State, Colorado State, Iowa State, and the University of Minnesota. After two or three years of study, Culman will pursue grant money for a larger test, with livestock. He would like to give farmers seed and guidance. They will also want something profitable.

A world underfoot, and underused

In the 1966 film "Fantastic Voyage," an assassination attempt has left a crucial Cold War scientist comatose. To excise a clot from his brain, a submarine and crew are shrunken to one micrometer and shot into his blood. They must wield their laser and exit within an hour, before their return to size kills him. Movie going voyeurs see, by perspective of scale and insertion, a world that is the body. Now imagine taking the same kind of journey through the world that is soil. It would be more complexly fantastic than Hollywood fabrication, with microscopic bacteria, fungi, and nematodes teeming in a jungle of roots through boulder-size granules of sand, silt, and clay. This community of millions of lives per teaspoon is increasingly revealed by science as plants' lifeblood. It also is as variable as world geography.

Matt Bakker, a plant pathologist for the US Department of Agriculture in Ames, Iowa, and a former Land Institute graduate school fellow, explored for the Estes Park audience how important soil microbes will prove for agriculture. He said corporations including Monsanto, BASF, and startups are exploring the field. Its understanding might be crucial for success of perennial grain polycultures. Microbes can do things that plants cannot, Bakker said. They make novel enzymes, increase a plant's access to nutrients, enhance root growth, render toxins benign, and help the plants resist disease, heat, flooding, drought, and predators. In turn, plants are major drivers of soil microbiology. Different plants favor different microbes, which cascades to different communities and their workings. The affect is greater among microbes living amid plant cells, but extends to around the roots.

We cannot expect plants to consistently rearrange soil microbiology regardless of location, Bakker said. Also shaping community are soil minerals, particle size, climate, and random variables. But an online publication that Bakker recommended, "How Microbes Can Help Feed the World," tells how even before science began to understand what was happening between plants and microbes, farmers inoculated ground with soil hauled from fields that grew better crops. As the complexity and capacity of what is involved are revealed, people may nudge a microbial community to their benefit, by means far less crude and invasive than synthetic fertilizer and herbicides. Bakker said microbiological intercept of pathogens with potential for epidemic can have huge monetary consequence. For another example, a soil might bear loads of the major nutrient phosphorus, but lock it in molecules that plants cannot open. Microbes could prove the key.

When fields of annual crops are converted to mixtures of perennial grains, lack of tillage may leave soil undisturbed for years. This will see the microbial neighborhood made over. Bakker, who had presented his information carefully, said his gut feeling here is for an effect much bigger than when traditionally rotating annual crop species. He expects fungi to attain prominence. The community should have more life. Study also has shown that, contrary to how diversity aboveground can slow pests and pathogens, microbe competition and its suppression of plant disease is higher in monocultures. The ecologists of the new agriculture face this challenge along with that of selecting microbes and putting the to work around the world in soils and climates of great variety.

The long, hard challenge of wheat

To make wheat perennial was the widest draw to Estes Park: scientists came from China, Sweden, Australia, Italy, Canada, and the United States. Wheat is the most widespread crop in the world, and makes more protein for human food than does any other plant. It also may now be the most challenging crop to make perennial. The Soviet Union's attempts through the middle of the 20th century failed to achieve anything that could both live for several years and grow grain in plenty. Land Institute scientist Shuwen Wang has advanced, but his progeny from crossing wheat by perennial wheatgrasses regrow after harvest in a way that proves fatal during blazing Kansas summers. Encouraging is that some of these hybrids have survived in milder Michigan, and two lines tested in Australia have produced grain for a fourth year. Today's plant breeders also have knowledge and know-how far beyond that of the Russians, and technical means at far less cost than just a few years ago.

Most plants in the Australian study originated at The Land Institute and Washington State University. After rigorous quarantine, the imports that grew and survived can be considered pure, said Richard Hayes, an agronomist from New South Wales. This played into his idea of sending seed back overseas, to see how the same genetics perform in different conditions. Sites include Britain, South Africa, Nepal, Britain, and the Netherlands. The trial is young, and comparison has not been made all around. A site in Turkey has just finished its first year. But an older site, a 2011 planting in Italy, had pulled results for sharing in Estes Park.

The presentation was not about how the plants grew, but about how their grain quality would serve for food. Laura Gazza, from the Agricultural Research Council's Cereal Quality Research Unit of Rome, said thick roots and competitive yields are not enough for perennial wheat's success. It also must win the hearts of cooks and eaters. Gazza warned against "the triticale risk." Plant scientists in mid-20th century crossed wheat with rye to get triticale. They wanted wheat's grain with rye's vigor and hardiness. Triticale served protein aplenty, but proved inferior for baking, and the little grown in North America mostly feeds livestock.

Gazza tested lines from Hayes for dough quality key to baking, for kernel texture, and for nutrients. Protein was high, superior to that of the hard spring wheat valued for bread. A lab measure of protein quality, called sedimentation volume, scored the perennial wheats relatively low. Gazza said this means only mediocre bread making. She called the hybrid nutritional quality superior, which for a small market might make up for baking shortfalls. More breeding and selection are needed to improve the protein. She proposed a different annual wheat parent than the Chinese Spring variety so often used now only because of its relatively high success in the chancy cross with a distant perennial relative.

The ability to look far enough back in wheat's ancestry might reveal a perennial. Now all plants in the *Triticum* genus are annuals. Researchers trying for long-lived wheat have crossed it with many perennials of different genera. A favorite is intermediate wheatgrass. The Land Institute is also domesticating this plant directly – no crossing with other species – and has for it a more marketable name, Kernza. So wheat breeder Wang has the benefit of continual

Jesse Poland, far left, of Kansas State University, prepares to explain his work on the genetics of intermediate wheatgrass, which is being developed as a perennial grain. Scott Seirer photo.

improvement of seed and yield from his perennial parent stock. But he thinks that side of his hybrids' parentage matters less than work with the annual. Wheat chromosomes typically make three-fourths of the hybrid genome, and bring almost all that he wants in his plants. Almost the only thing needed from the perennial is perenniality.

That appears to be associated with genes that determine when wheat plants flower. Wang is investigating. Wheat and other grasses vary between growth habits called winter and spring. Spring wheat is planted after Canada's cold winter. Winter wheat, in Kansas, gets a head start in fall. The habit is not just about planting season. A perennial with winter regrowth habit leafs anew after cutting in summer, but it does not send up stalks again until after another winter. A perennial with spring regrowth habit will keep trying to flower and reproduce through summer. Wang found that after their first year, nearly all of his perennial wheat lines showed spring regrowth habit, even when the crosses used strong winter wheat. Something strange must occur during the regrowth stage. For a crop this would confound harvest and waste food energy – wet, recently flowered heads contaminating dry, ripe heads in the combine. In further mystery, it also brings Wang's hybrids to die, at least in a Kansas summer. Wang wants to fix the flowering time genes. "If the association of wheat flowering time genes with perenniality is confirmed, then we can focus on the selection of these genes with less trouble in playing with wheat and wheatgrass chromosomes," he said. "The high grain yield of current lines will be retained while perenniality is improved."

Breeders are testing new approaches. Wang has made many crosses between different wheat and wheatgrass species. Until now his most perennial hybrid is by winter durum wheat. Because winter durum has two-thirds as many chromosomes as bread wheat, the hybrids have a higher proportion of chromosomes from the wheatgrass parent. Wang has sent seeds for selection by the other breeders, including Jamie Larsen, in Lethbridge, Alberta. Western Canada grows mostly spring wheat, especially durum, used for pasta. Larsen said that ordinary winter durum does not survive winter. He is working to develop a winter-hardy winter durum and will make crosses with wheatgrass.

Throughout the week in Estes Park, Larsen pushed for the other wheat breeders to share their results – to send seed from their perennials for testing in different climes and soils around the world. "The best stuff you got goes in that nursery, and everybody can get at the best stuff," he said. To this the other wheat breeders agreed.

A grain seen as nearest the perennial goal: rye

Rye planted in fall already can take western Canada winters. It also produces on soil too poor for wheat. Breeder Jamie Larsen thinks the crop has great potential as a perennial grain. He thinks too that of all prospects for achieving a perennial grain, rye has the shortest distance to get there. In fact, rye has already been bred and released as a perennial, although primarily for grazing and hay. For that it does well. It was also promoted as a cereal, but before it was perfected, and there it failed. Echoing Gazza on the lesson of triticale for perennial wheat, Larsen empha-

sized attaining confidence in the genetic stability and dependable production of a new perennial cereal rye – not to be confused with perennial ryegrass for lawns – before taking it to market. "We can't let something get out before we know a lot about it."

Unlike wheat, rye has perennial kin within its own genus. Crosses are not so tricky. Larsen already knows that his hybrids would need from the perennial parent only three chromosomes. The rest of the genome can come from annual rye, a crop refined since prehistory. Hybrid seed size already nears that of annual rye. Hybrid yields are 20 to 40 bushels per acre, near the average for annual rye – though the hybrids are fertilized, and with annual rye on lesser soil, Canadian farmers often do not bother. In fall the hybrids are bushy. Larsen said might let it double as a forage crop.

There are hurdles beyond competitive yield. Like most plants before domestication, the hybrids shatter, dropping seed as soon as ripe rather than holding on until harvest. And in threshing the new seed does not easily shed its hull – another common problem for domesticators.

The outstanding problem for perennial rye, as for annual rye through most of its history, is high susceptibility to ergot. This fungus grows in place of seeds, and though small parts are used in medicine, large ingestions can cause hallucinations and injury. Canadian law allows infection of 0.33 percent. Larsen said the perennial rye shows 10 to 20 percent. But ergot can affect all perennial grasses, and as with other plants that humans have taken far from their wild form to domestication, Larsen said, problems can be overcome by breeding and selection.

He does not think perennial rye got a fair shake. He says researchers need to try again. He wants a rye not aimed at forage, but which pays that bonus after serving people with grain for bread. Rye is not nearly as popular worldwide as is wheat, nor is as widely planted as rice or maize. It occupies a fair amount of western Canada, however, on marginal, sandy land, generally without additions like fertilizer. It remains significant in northern and eastern Europe and in Russia. It also goes to make US whiskey. "I think there is a fit," Larsen said.

For climate change near the arctic, a new barley

The best fit in northern Sweden now is annual barley. Barley, rye, and wheat are placed taxonomically in the tribe called *Triticeale* – tribe being the level just above genus. Before humans began writing, they domesticated these three grasses as grains, and from origins in southwest Asia spread them widely. Anna Westerbergh, a geneticist and plant breeder at Swedish University of Agricultural Sciences, said barley already seems more adaptable than wheat to trials by weather in a region reaching into the arctic. She thinks perennial barley will be more flexible yet, to fluctuations expected with climate change. These might include longer stretches of extremes, and more rain, with added stress from waterlogging.

As a postdoctoral scholar at the University of Minnesota, Westerbergh studied annual and perennial species of teosinte, relatives of maize. In Vietnam she studied cassava, a perennial shrub grown as an annual for its starchy, tuberous root. "All of

this kept me thinking that we need to think out of the box as breeders," she said. In 2009 she started discussion of making barley a perennial grain. Seed companies were not interested then. But by this year, from one company she secured partial support. Another help to her is the recent complete read of crop barley's DNA sequence.

One perennial species crosses with crop barley. The perennial's common name is bulbous barley, and it is of the same genus as the crop plant. What might have been the first attempt to develop a perennial grain, by German Gustav Bestehorn in the late 19th century, used these species. Before Westerbergh started, bulbous barley already had been used to give the annual genes for disease resistance. Westerbergh is evaluating these lines for perenniality. Plants go both to the field and into the phytotron, a building where temperature, humidity, and, with artificial lighting, even day length is controlled. Last winter in the field was extreme, with repeated melts and freezes. "This was very hard for them," Westerbergh said. The barley cultivars that were used for disease resistance are not good over cold winters. Westerbergh and colleagues are now making their own crosses with cultivars and bulbous barley lines better adapted to cold and high altitude. They also replanted the original crosses, and she said that in their first season they looked good. More impressive was growth in the phytotron. "The plants are quite vigorous," she said. "They don't look weak in the first season."

Westerbergh saw various amounts of regrowth. Her team will take the most promising plants and cross them. They also will try through genetic mapping to find signals for perenniality. Breeders of all would-be perennial hybrids desire these signs, so they can be spared growing plants a year or more to answer the primary question.

After the meeting in Estes Park, Westerbergh drove east and spent most of a week at The Land Institute to learn more for her work that is just beginning. "For me these two weeks have been so inspiring," she said. "I've learned so much, and made so many contacts."

The improved view of a proposed marriage

Wes Jackson told those gathered in Estes Park that 25 years ago, about 25 people from around the country came to The Land Institute for a conference called "The Marriage of Ecology and Agriculture." Among attendees was corn breeder Major Goodman, who with Jackson had been a doctoral student at North Carolina State University. Goodman said that what Jackson proposed would be a shotgun wedding, one made in poverty and bound for divorce. Goodman himself was on the fringe of corn science, Jackson said, seeking genetic diversity for the vulnerable king of crops in the upper Midwest by combing material from the tropics. He could do this because he had tenure. And he was not opposed to the marriage for which he had dim forecast. He did not see biology as the problem. That lay in status quo social nature and politics. At the gathering in Kansas, Goodman gave his blessing. "It ought to be done," he said.

In the quarter-century since, including through the recent recession, The Land Institute has grown, with a new research

building, one greenhouse rebuilt, a second one imminent, more scientists and more support crew, and with them, youth. Papers by Land Institute scientists make roads in peer-reviewed journals. Stories about their work make the popular science press – National Geographic, Smithsonian, Scientific American. There are new funding sources, with an expanding foundation world, Jackson said. And around the world more researchers are joining work that Jackson thinks will be more important than the Copernican revolution. That did not change how people treated the earth. He told the scientists at Estes Park, "My view is things are different now."

Shuwen Wang of The Land Institute conducts conference scientists working on perennial wheat. Scott Bontz photo.

Land Institute shorts

Purchase adds 70 acres, nearly doubles largest research space

The Land Institute effectively doubled its largest single ground for development of perennial grains, buying 70 acres across the road from its 72 acres just south of the city of Salina. The new land is within city limits, and had been zoned for industrial development. The addition prevents loss of prime, river plain farmland to development, and secures more space for research that has expanded to largely fill the old farm. It puts buildings that house the institute's large field equipment at the operation's center. Also at that center are two houses for institute workers. The combined spread is bisected by Ohio Street, which a short drive north becomes one of the main north-south roads through Salina. It is a mile and a half west of the institute office and science building.

Dozens of plants will show off their roots in nation's capital

Former Land Institute scientist Jerry Glover visited in November and shipped some 80 plants, roots and all, for display at the US Botanic Garden in Washington, DC. "Exposed: The Secret Life of Roots" will show February 21 through October 13. The garden plans to display at least 60 plants. More than 40 will hang so visitors look up at them, as if from deep underground. Panels will show more roots closer and at eye level. The garden is just southwest of the Capitol. Glover, who now works for the US Agency for International Development, seven years ago began growing plants in 10-foot-long tubes filled with growth medium that can be washed off to reveal intricate root structure. The project has allowed The Land Institute to impress upon people the difference between the roots of annuals and perennials, and how perennials could change grain agriculture. The Botanic Garden display is in connection with the International Year of Soils, which is aimed at communicating how soils are crucial for food.

Acreage added in Minnesota for Kernza food research

Businesses contracted for another 50 acres in northern Minnesota to grow The Land Institute's Kernza grain for development as a commercial food product. Patagonia Provisions and Ventura Spirits, both of Ventura, California, already had acreage planted to Kernza. The field manager in the first arrangement is with the University of Minnesota. The new contract is with three members of RL Growers Cooperative, which specializes in producing grass seed. In total, Patagonia Provisions has 120 acres, and Ventura Spirits has 20. Kernza is The Land Institute's name for the perennial intermediate wheatgrass. Patagonia Provisions is a food products venture by the outdoors clothing company Patagonia. It is still in research and development with Kernza. Ventura Spirits is a distiller using local plants such as prickly pear and native herbs, and devoted to restoration of distilling as waste-not end user in the agricultural chain.

Seeds from the perennial called stiff sunflower, and what was pressed from them: oil and high-protein solids that could feed livestock. The oil tastes much like annual crop sunflower oil. Scott Bontz photo.

Many apple calories once were saved in hard cider. Ventura Spirits is making vodka with local strawberries that remain viable but did not make the cosmetic cut for produce shelves. It also wants to use perennials. Co-founder Henry Tarmy said the company is putting Kernza spirits in barrels this fall. It will age for at least a year.

Historian and philanthropist Levy-Church joins directors

Kenneth Levy-Church, a New York City philanthropist and historian of central Eurasia, this fall joined The Land Institute Board of Directors. He also spoke at this year's Prairie Festival, about agrarian revolution in pre-Soviet Georgia. Levy-Church earned a bachelor's degree in philosophy from Dartmouth, built passive-solar adobe homes in New Mexico, then studied history and languages to earn a doctorate at the University of Michigan. He taught at St. Lawrence University, then left academia for philanthropic work, first with the JEHT Foundation, focusing on criminal justice. He went on to found what is now called Fair Food Network, for healthful food for America's inner cities.

Seed from perennial sunflower gets first pressing for oil

Visiting his plots at Organic Valley's research farm in Wisconsin this summer, Land Institute scientist David Van Tassel for the first time had his developing oilseed crops pressed for oil. The result shown on the facing page is from stiff sunflower. The oil is golden. It tastes much like crop sunflower oil. The same oil quality report came for another of Van Tassel's plants, silphium. Appearing beside the oil in the photo are pressed solids, which could make an animal feed high in protein. The press used for the oil travels by trailer among members of the farmers' cooperative Organic Valley, based in La Farge, Wisconsin.

Perennial rice in tropical China produces grain competitively

Colleagues in China have in four successive years harvested from the same experimental perennial rice plants about as much grain as would come from annual commercial rice, Land Institute Research Director Tim Crews said after visiting in September. Yunnan Academy of Agricultural Sciences in southern China enjoys a tropical climate. Its rice sprouts anew from the plant base instead of building rhizomes, the underground stems that would make for stronger perenniality. Researchers under Hu Fengyi are breeding for rhizomes. The academy has brought Land Institute scientists to trade notes with Hu in Yunnan each year since 2008.

Video of Berry, Jackson, Bittman can be viewed online

Land Institute President Wes Jackson and writer Wendell Berry traveled to New York in April for an interview with New York Times writer Mark Bittman before an audience in the historic Cooper Union school. Video of the event is on YouTube. A link is on the Facebook page of The Land Institute Web site, landinstitute.org.

Correction

The caption on page 16 of the summer Land Report erred in telling how much carbon dioxide results from burning 1 pound of carbon. The correct amount is 32/3 pounds.

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Scientists from 10 nations around the world met at a Land Institute conference for how to develop perennial grains, and how to grow them in mixtures. This group focused on the latter. The story begins on page 4. Scott Bontz photo.