Land Report

Number 114, Spring 2016 · 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

The latest perennial wheat from breeding winter durum wheat, an annual, with intermediate wheatgrass, a perennial. Whole plots of these plants survived both last summer and this winter, a first at The Land Institute. Wheat researcher Shuwen Wang continues to search for the complex genetics behind whether and how wheat regrows to make a perennial grain crop. Scott Bontz photo.

How can The Land Institute's intermediate wheatgrass be grown so that year after year it profitably makes grain? How close should the plants be? Which legumes can help by fixing nitrogen between wheatgrass rows, and without one species crowding out another? Researcher Jake Jungers, here at a field day for interested farmers, is trying to answer these questions in Minnesota, where wheatgrass grain yields can triple those at The Land Institute in hotter, more arid central Kansas. Photo by David L. Hansen, University of Minnesota.

Under new management

Perennial grains demand different culture, so research is seeking what works best

SCOTT BONTZ

Lee DeHaan grew up on a farm near Albert Lea, Minnesota. His family, and their neighbors, planted corn and soybeans in spring, and harvested in fall. For the rest of the year nothing occupied the ground for these annual crops: the soil and its nutrients were left vulnerable to wind and rain. Nearby pastures and alfalfa fields weren't like this. These plants were perennials. Even though grazed and hayed, their roots lived on to hold soil through all the year, and neither disc nor plow razed the protective stubble.

Young DeHaan noticed another interesting difference: by the time the soil in southern Minnesota was warm enough for farmers to plant corn, they could already take their first hay crop of alfalfa. With the perennial there was no wait for the plant to build from the scratch of seed. The yearlong roots jumpstarted spring growth.

In the 1980s Wes Jackson came up from Kansas to speak at Rochester. DeHaan's father, Roger, drove 60 miles to hear the geneticist talk about a revolution for grain crops. Jackson wanted to make them perennials. Forest, grassland, tundra, and desert coat the earth with perennials. For reasons dating to prehistory, the agriculture that gives humanity most of its calories, grain agriculture, replaced them with annuals. Kipling might have substituted "perennial and grain" for "East and West" when he said never the twain shall meet. Jackson saw that with evolutionary biology and statistical tools amassed in the century since, they could. Roger DeHaan and his three sons pondered this possibility for years.

"I was thinking about perennials from the time I was a kid," Lee DeHaan said. Jackson's idea made obvious a missed opportunity. Perennial grains would not just better control soil erosion, they would also cut the tremendous amount of energy that farmers like DeHaan's father expended on planting and tilling the earth. "The more that I thought about it, the more that I thought it was a great idea."

But growing a field of perennial grain – let alone developing the plant itself, which despite decades of work by Soviet scientists in the mid-20th century had not seen a commercial contender – would be different than growing perennial pasture, perennial hay, perennial orchards, or even seeds for the pasture plants. And though DeHaan, now a researcher at Jackson's Land Institute, feels he's on track for the goal set in 2010 to have by decade's end a perennial that makes a profitable mass of grain, he can't yet answer for farmers this crucial question: how do we keep the field making that much grain year after year without falling back to that burdensome and costly tillage?

"We don't really know how to manage for optimum sustained yield," DeHaan said. "We really need to get on these management questions."

"Breeding is a more elegant solution by far." *Lee DeHaan*

This work proceeds in Minnesota. There the scale of precipitation versus evaporation won't limit what is possible with DeHaan's new grain crop, intermediate wheatgrass – it can make two or three times as much seed as in Kansas. The Land Institute enlisted the help of Jake Jungers, a researcher at DeHaan's doctoral alma mater, the University of Minnesota. In 2014 Jungers and colleagues planted wheatgrass from 6 to 30 inches apart, by itself and with a variety of legumes to supply nitrogen, and with some of it fed various portions of nitrogen fertilizer. Over three years of study Jungers will try to find the "sweet spot" among these variables for the best sustained yield. Since a perennial's growth habit changes with age, the trials might take even longer. But 2015 gave the first round of results.

Previous work had shown that nitrogen fertilizer increases wheatgrass grain yields. It also leads to lodging – plants topple before harvest. The plants use some of the nitrogen to build longer stems for leaves to grab more light. Rows planted more distant from one another might relieve the plants of sensing encroachment that triggers such skyscraping. In the past, most wheatgrass was sown in spacing similar to wheat, from 6 to 12 inches apart. This allows for more plants in a field, which should increase grain yield – if not for lodging.

At Roseau and Roosevelt, in far northern Minnesota, Jungers fertilized with 0, 20, 40, 60, and 80 kilograms of nitrogen per hectare. (This is close to pounds per acre.) He was somewhat surprised to see that fertilizer did not boost yields. Nor did he see much lodging. But this soil was already fertile, and for the plants that extra nitrogen might have been excess. Or, as first-year perennials, they might have emphasized building roots rather than stems and leaves. Jungers expects that as the stands mature and mine nitrogen from the soil, the effects of fertilizer will grow. Anecdotal evidence suggests that lodging becomes worse in the second and third years.

At the same northern sites, Jungers compared yield from rows 6, 12, 18, 24, and 30 inches apart. Yields were highest in the narrow rows, probably because there were more plants in a given area, and without much lodging. But in plots to the south, at St. Paul, heavy lodging in the 6-inch rows canceled any yield gains. There was no significant difference in yields among row spacing of 6, 12, and 24 inches. The wider spacings gave more seed heads per row. They also lodged far less.

After DeHaan joined The Land Institute in 2001, he first grew intermediate wheatgrass in 30-inch rows, like the farmers who raise it to sell seed for planting pasture and hay fields. The history of wheatgrass as a forage crop is long, and for that kind of seed production there's already much data. But forage wheatgrass is bred for lots of nutritious leaves. Plants making lots of big, nutritious seeds might prefer a different neighborhood. DeHaan wants a new arrangement regardless, because the wider rows leave more space and light for weeds, which demands tillage, which half defeats the purpose of making grains perennial. The perennial roots still anchor and use the soil much better than annual crops, and as long as the rows run along slope contours, erosion is negligible. But DeHaan had to burn fossil fuel pulling tillage machinery between his 30-inch rows up to five times a years. "I got very tired of the time it was taking," he said.

He switched to "solid seeding," with 7.5-inch rows, like wheat is sown in Kansas, a spacing too narrow to drive over, but where mature wheatgrass chokes out weeds. Unfortunately, as the plants age their yields fall. Jungers is trying to find out why. The plants appear to sense their neighbors as crowding them, and respond by sending up more, thinner stems, with smaller heads and seed, and more prone to lodging.

If this is the heart of the problem, then wheatgrass plants oblivious to their neighbors should keep strong stems, and make plentiful, good seed. Breeders have achieved this imperturbability with corn, a giant grass once planted 36 inches apart and now sown in rows as tight as 15 inches. DeHaan has found among his wheatgrass plants some standouts less sensitive to neighbors. "So I know there's genetic diversity for this," he said. He hopes to capitalize on the trait to plant tightly and end tillage. "Breeding is a more elegant solution by far," he said.

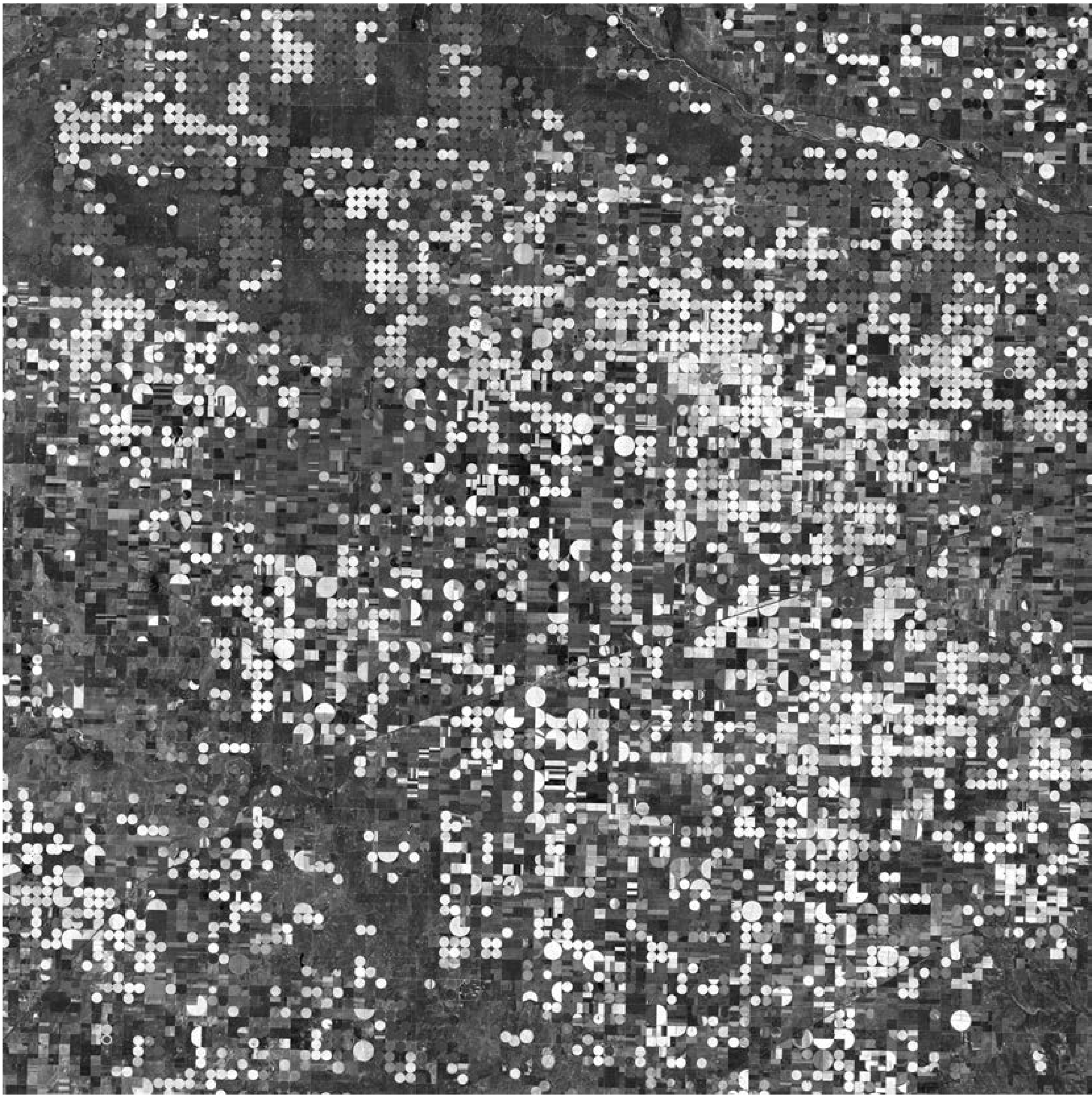
This will take more time and money, however, and DeHaan said, "It's not what we can do right now." He can select wheatgrass plants for better grain yield every generation. He can select for yield sustained over five years only by watching and waiting five years – a slow path to progress. He hopes to eventually find genetic markers for the desired neighborliness. Then he will be able to gauge a plant before it even makes its first seed, and so speed selection for breeding.

Until then, though it does not fit The Land Institute's long-term vision for sustainability, weeding between perennials will still be better for soil and water than weeding and replanting annuals. "Even with tillage this gets us a long ways," DeHaan said. One approach would be to plant narrow rows, and after a few years cull some for wider spacing. Another route would be to plant between the rows of wheatgrass rows of legumes, which would add nitrogen to the soil. Jungers is testing alfalfa, white clover, the prairie plant called Illinois bundleflower, and Canada milk vetch. Land Institute researcher Tim Crews is running similar tests with alfalfa and clover.

When Jungers finds among all of these tests how to keep wheatgrass fit, productive, and economical, farmers can begin to transform farmland and farming.

His first year of study saw this added attraction: the same wheatgrass plots not only made both seeds for humans and leaves for livestock, but those that were cut in spring for forage beat the uncut plots when both were harvested for grain in summer. They also made more forage in a fall cutting. Jungers and DeHaan suspect that spring cutting stimulated growth of more stems – sort of like trimming a hedge to make it "full." This effect appeared greatest with 6-inch spacing. It's not clear if these gains offset grain losses to lodging. "It will be very interesting to see how year two grain yields respond to year 1 forage harvest," Jungers said.

During a field day last year in Roseau he met interested farmers and explored grazing experiments on working farms. "We are excited to be testing methods for managing intermediate wheatgrass as an integrated crop-livestock system," he said, "because it can reduce the economic risks related to farming a new perennial grain crop."



Hundreds of center-pivot irrigation wells around Garden City, Kansas – and thousands more across the Great Plains – draw from the Ogallala Aquifer. Over much of its expanse they draw it down. When the water becomes too costly to pump, the semiarid region will need to return to dryland farming – if it can still economically farm at all. This kind of place, among many others around the world, will be in greatest need of new crop plants, especially perennials, that can weather drought and climate change, and protect soil. Each of the small white dots above is a half-mile-wide circle of land that has been harvested and left without live cover to protect the soil. Land Institute researchers led the writing of a comprehensive plan for how to domesticate new crops. US Geological Survey photo.

To domesticate crops: a strategy

For progress toward perennial grains, researchers offer lessons and a plan

From the East Coast to Nevada, and from Mexico to Canada, Illinois bundleflower ranges far beyond its namesake. The 2- to 4-foot-tall member of the mimosa family grows finely ferny leaves that fold for the night, small white flowers like starbursts, and loads of flattish, red-brown seed. For years it attracted attention as a potential food crop. It is a perennial and would not require replanting every year. Its long-lived roots beat those of annual grains at holding soil and tapping water and nutrients. Because it is a legume, in consort with friendly root bacteria it moves nitrogen from the air to the soil and makes it useable for plants, reducing need for fertilizer. Compared with other herbaceous – not woody – wild perennials, it makes abundant seed. Researchers find in the species ample genetic variation for traits such as seed size and yield. For all of these reasons it seems a prime candidate to become one of the world's first perennial grain crops.

But Illinois bundleflower's blossoms have tiny parts, which make handling by breeders troublesome. It doesn't do well in a typical greenhouse. Its abundant seed has an objectionable flavor. The seed's safety for food has been difficult to demonstrate clearly. And the plant's roots have a regulated hallucinogenic chemical.

With enough time and money, all of these hurdles might be cleared, and to great reward. But they are high hurdles. Domestication comes faster and more economically when a plant has fewer, lower limitations.

For example, consider intermediate wheatgrass. The Land Institute initially used this wild plant to cross with and bring perenniality to wheat. But researcher Lee DeHaan soon recognized that it could become a grain crop itself. It had no major weaknesses or strengths – beyond being an excellent perennial. But it responded quickly to selection for larger seed. DeHaan hopes for it to yield profitably by 2020, achieving in less than two decades a success that the institute generally estimates will take 25 to 30 years. Silphium, a genus of the sunflower family, offers a crop candidate with an initial weakness – few seeds per head – that researcher David Van Tassel quickly proved surmountable. It has the strengths of deep perennial roots that weather drought, and rich production of pollen for beneficial insects. Perennial flax might be made a new crop by playing to the strength of high demand for the kind of fatty acids in its seeds. The Land Institute also progresses toward perennial sorghum. Colleague Fengyi Hu in China has rice that maintains competitive yields after four years without replanting.

Those are some of the perennials that could turn farming away from its millennia of yearly soil disturbance and loss. But for each of those improving plants there are one or more problems like bundleflower. The lesson here is twofold. First, don't see the low success rate with new-crop candidates as failure. Instead, compare the effort with how new drugs are developed: the odds of one candidate having all of the qualities for commercial success are low. To achieve one good drug requires examining many, screening them, and re-screening them, and at each stage winnowing. The other part of the lesson is that breeders should first address a crop candidate's clear limits. If those limits can't be cleared quickly, it's better to move on and work with another species.

The lesson is crucial because the world needs new crops, especially new grain crops, and especially grain crops that, compared with most of the others throughout history, would be new to farming in the way they live. Grain crops have cost the earth's land and water so much, and no amount of technical tweaking of these old crops and how they are grown will solve their innate problem of being annuals. They require annual replanting, and for a majority of each annual cycle they often leave soil exposed to erosion.

The novel crops could include more annual winter crops, such as fast-maturing pennycress, that can be grown between standard summer crop rotations. More novel and much better would be perennial grains. Alive throughout the year, and for years with no need for replanting on bare ground, they would greatly cut the expenses, losses, and pollution under annual grain crops.

Scientists have written much about the need for new crop plants and proposed quite a few. Recent focus has been on theory and policy, on food trees, and on plants that would be made into fuel. Trees of course are perennials, and so now are proposed energy plants. But these don't make grain, and it is grain crops that cover most cultivated land, and make more than two-thirds of our food.

Wild trees and biofuel crops require few changes to serve as crops. Perennial grains require plenty. They must be coaxed to put more energy into seeds, and not into leaves, stems, and roots so much that their growth is wastefully competitive. They also must not drop those seeds like a typical wild plant, but bear them for harvest. The challenge has been daunting, and though attempted since mid-20th century, it has not been met.

This kind of domestication is a new field of applied research. There isn't much to go on from the largely prehistoric domestication of annual grains. Annuals and perennials grow quite differently, and the people who tamed corn and barley thousands of years ago did so by a method far less intentional and allowing far more time than what's needed now. But in the past 30 years or so knowledge and knowhow with plants and genetics have put the goal in reach. And even people apart from those working toward perennial grains saw the need for new crops to conserve soil and address climate change. Some new crops were even developed.

Few of these newcomers spread widely into farmers' fields. Examples are jojoba, which enjoyed a boom of speculative farm building followed by a bust, and meadowfoam, which must compete with the large, established canola oil industry.

Often there was no scientific record of what had been learned. And no one appeared to publish any kind of general guideline for domestication. New crops are at least as complex and important to the world as new drugs. Rather than groping toward those crops solely by independent hits and misses, shouldn't work be informed by learning and with a comprehensive strategy?

By fall 2014 The Land Institute had drawn enough interest in perennial grains to attract more than four dozen researchers from every continent where grains are grown, to meet at Estes Park, Colorado. For most of a week they discussed how to develop perennials. Over the following year, led by DeHaan and Van Tassel, they devised a guide, put it through cycles of review by critical peers outside their group, and finally saw it published in the journal Crop Science.

They call their process a domestication pipeline, after the pharmaceutical researchers' drug discovery pipeline. There, many candidate chemicals are poured in one end, but only a few make it through the series

Marty Christians tends to seedlings of intermediate wheatgrass, a wild plant judged as a good candidate for domestication because it was strongly perennial, responded quickly to selection and breeding, and had no great weaknesses for researchers to overcome. Scott Bontz photo.

of rigorous tests to emerge from the end of the pipe as viable medicines. The plant researchers recommend collecting candidate species by looking broadly. They propose then applying a comprehensive set of logical steps to gauge and groom candidates. This means expecting many to be left behind. But such a wide-eyed method should bring for perennial grains more success. Over the past decade researchers have tried fragments of this process. But they haven't brought the parts together strategically like the Estes Park team did.

The pipeline's first step is to find an agricultural target. This is different than starting with a plant simply because it's interesting, perhaps because it makes large seeds, and then seeking ways to make it profitable. That route might lead to a niche that's already filled. For example, look at crops new in the sense that farmers in many regions don't grow them, such as annual buckwheat and spelt. These are very similar to established, high-yielding cereals. They probably will struggle to gain ground without having a novel flavor, nutrient, or growth habit like perenniality.

Pharmaceutical companies first find a pathogen, symptom, or disease for which current treatments fall short. Only after they have a target such as killing germs or halting the division of tumor cells can large numbers of chemicals be tested. Similarly, plant researchers could first pick a target, such as stopping erosion in temperate, semiarid climate by increasing the soil cover in drought years. For a single effective crop to emerge from the end of the pipeline, many wild species might need to be screened at its beginning. Much of this might be done quickly with herbarium specimens and literature, or through specialists experienced at collecting and growing wild plants, and able to suggest candidates with traits desirable for the farm. Then if necessary can come testing for things like seed nutrients and edibility.

A species' particular strengths or weaknesses are less critical than whether an overall domestication strategy can bring it along. The pipeline strategy includes time for proofing. It also recommends considering the economics and politics involved.

Other targets for new crops could include food with better nutrition, food security in places prone to drought, nitrogen fixation in difficult soil, and soil conservation and restoration. Each of these problems could be met with perennial grains or legumes.

Beyond where the plant would grow, things to consider in vetting candidates include whether production will be by subsistence farmers or commodity growers; the technology involved, such as mechanization and irrigation; and whether the crop is to be for cereal, oil, animal feed, or forage. This narrowing speeds progress.

So the pipeline has three phases: First screen lots of promising candidates. Second, plan how to understand, breed, and even market the species. Third, combine this all to improve the plant as a crop.

Screening candidates requires criteria. The Estes Park team proposed a ranking set. None of the candidates will meet all of the criteria, but some plants will need less work than others. Knowing their relative strengths and weaknesses also will guide the particular path of domestication. Key is that before plunging into domestication, all of the points should be thoroughly examined and balanced against others.

A good candidate will germinate and grow fast, compete with weeds, and be ready for timely harvest. For that harvest to be made mechanically, seeds should ripen together, rather than strung out over time, and without falling to the ground. For a subsistence grower who works by hand, harvest is easier with seed borne in large clusters. That doesn't hurt for a combine, and either way is better if the seed is large, smooth, dense, and, in threshing and winnowing, easily sheds its hull.

On the road to harvest, the plant shouldn't spend energy on long, spindly stalks to compete for sunlight and also risking topple by wind, rather than investing in plump seed. Appeal and adoption of the crop will be much higher if it can be grown and harvested without need to invent or buy new farm equipment.

Also important is how the plant reproduces. This is unique to each species. To know whether a wild plant will take well to domestication, it's good to know the candidate's sex life. Does it need to be pollinated by another plant, or can it pollinate itself? How long does its pollen survive, while researchers are trying to catch and move the pollen between particular, attractive plants? What flowering cues does it give researchers so they can be ready for the pollen?

Perennials may mature slowly and take several years to fully show their traits. DNA testing has become much more affordable and could identify promising individuals at the seedling stage. DNA markers aren't necessary for domestication, but they might make the job much quicker. Finding them is more difficult and expensive when the new species has a large complex genome. Wheat has such as genome, as does intermediate wheatgrass. Wheatgrass makes up for this with other traits. But ideally a candidate would have a relatively simple genome.

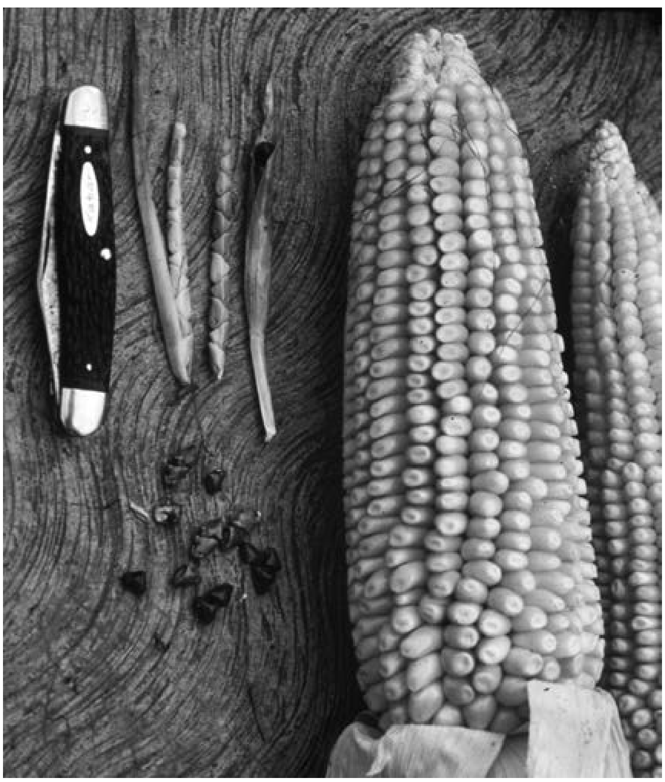
The final goal, high yield, mainly depends on two things: total biomass and harvest index. Harvest index is how much of the plant's total growth aboveground goes to the grain harvested. In most wild plants seed makes a small fraction of the whole. In a modern grain variety seed can constitute half of the weight. This shift is crucial for high grain yield and comes from genetic changes brought by breeders. Things such as soil fertility and moisture affect crop biomass, but breeding can improve the ability of a plant to take advantage of plentiful resources or to tolerate stresses like drought and wind.

The commodity market and food consumers are set in their ways. A new crop will more easily win them over if it works and tastes like an existing grain but costs no more. Acceptance has come slowly even for whole-grain varieties of established crops. Conversely, grain with a new flavor or use could work for a premium product with a selling point such as being gluten-free, rich in antioxidants, or benefiting farm sustainability or wildlife conservation.

Whatever the market entry, success depends on confidence that eating the new food is safe. Chances for that are better if the plant has no near relative species identified as poisonous. Chances are dramatically better if such a relative is already widely eaten, or if the newcomer is already used in hybridization of a current crop, as is intermediate wheatgrass, for disease resistance, with wheat.

Many current food crops take processing before we should or will eat them. Kidney beans are toxic unless cooked. Rapeseed oil was unpalatable for both human and beast until breeders selected for what is now called canola oil. This cost about $95 million. It's better for a new, perennial grain to be tasty without going to such time and expense. But a crop not quite there yet might first be used for industry or animal feed, while culinary improvement continues.

Breeders of crop plant varieties strive toward a population of high, dependable homogeneity. But the traits of the purebred derive from a whole-species gene pool, and that boasts a mess of possibilities. That range might not be expressed in the wild, but breeders who patiently make hundreds and thousands of selections and crosses can draw it out. For example, see how wild teosinte became domestic maize:



Hugh Iltis photo.

The larger the gene pool, the better the numbers for success with improving a crop or making a new one. So evaluating a candidate goes beyond the plant, to include things like whether political strife blocks access to valuable wild populations. Another thing to consider might be the gene pool size and availability of closely related species to use for cross-breeding.

Other concerns: whether the plant reproduces asexually, which could stymie breeding and improvement, and whether the species genome is stable or is shifting. If the candidate species has a close relative among the major grain crops, they will share well-known DNA, which would greatly help breeders.

Another thing that breeders strive for in a commodity grain crop is adaptability: the plants must be able to grow over a broad area, not just in a geographic niche. Testing that ability might prove hard if governments fear that a non-native species will be invasive. Domestication likely will reduce invasiveness, with shorter plants, and seeds shorter-lived and less dispersed. But if it is predicted that a foreign plant will be invasive, it might be wise to avoid domestication. If people already use a species for another purpose, regulators will know and likely welcome it.

When a native species is domesticated, the Estes Park researchers say, put test plots far from enough from critical wild populations to avoid cross-pollination.

Farmers will like new crops that need less irrigation, tillage, and pesticides. They may increasingly need plants that tolerate water shortages, work with other species to secure nitrogen from the air, and resist pests and disease. Crops with these lower ecological costs might command premium prices, as do certified organic crops that compensate for lower initial yields.

In crop candidates it could pay to seek not just lower ecological negatives, but also ecosystem-serving positives. Support grows for plants that do more than only make grain. Such strengths include pulling carbon out of the atmosphere to enrich soil, making habitat for wildlife including crop pollinators, and preventing the contamination of drinking water by runoff and nutrient leaching. At all of this, perennials trump annuals.

Looking beyond how a candidate plant might feed us and improve farmland, there is the plant's source to consider. Some 80 percent of biodiversity is on land occupied by indigenous people. Wild species important to them shouldn't be domesticated without those peoples' consent and collaboration, the Estes Park team concludes.

Those are guidelines for screening candidates. Here's how the researchers say to take the plant from wild species to crop. Each candidate will uniquely blend strengths and weaknesses. Each should get a custom set of domestication milestones. If a plant fails to meet one of these goals, thoroughly re-evaluate it or look to other candidates.

The milestones come from one or more of three strategies. One is to look for traits that limit the plant's prospects, such as falling in wind or dropping seed before harvest, and see if they can be quickly overcome. Comb the gene pool for the rare individual that behaves differently. Or see if the plant does better in different soil and climate.

Another approach is to build on strengths noticed in the screening, whether they are how the plant grows, what kind of food it can make, or how it serves an ecosystem. Exploit the strengths to attract funding and research support.

Lastly, if the plant has no great weakness or strength, focus on breeding it for improvements, such as grain yield, that come over years.

If a candidate passes one of these tests and proceeds to full-on domestication, eventually apply all three strategies. And if a weakness is overcome to reach the first milestone, find and address the next most significant limit to the plant's success as a grain crop.

"Modern domestication is an economic and political activity as much as a biological one," the Estes Park collaborators write. Public investment in plant genetics is flat or falling. Time and space devoted to one crop candidate takes from another. But with soils continuing to degrade, the need for new crops is high. The team answers this problem with four economic rationales: Reduce research and development cost by ranking wild plants according to domestication strengths, such as large seeds. Quickly screen out candidates whose weaknesses appear insurmountable. Invest in boosting a plant's appeal to additional supporters. Work simultaneously for both yield gains and marketability.

And don't just tell other researchers about successes, but also publish records of the candidates that are cut, and how those decisions are made. Given the time and expense involved, as well as the potential for the same or similar species to be independently reconsidered later, even negative results should be viewed as important findings.

Domesticating a wild plant takes an investment of money and many years. So the candidate should enjoy a reasonable chance of growing successfully over a large area for many more years. For that to happen, it must replace other crops. And to do that it must be more profitable. That means it must both yield well and provide some advantage in grain quality, reduced cost, dual purpose, or ecosystem improvement. The Estes Park team proposes criteria and strategy, so they and other researchers can advance only the best candidates, and to speed the world's development and adoption of perennial grains.

Laura Kemp cuts alfalfa amid intermediate wheatgrass. Both plants are perennials. The first is a legume that fixes nitrogen in the soil, the second is a grain crop in the making. In ground once regularly disturbed to grow annual grains, the perennials will make a soil community richer and more complex. Kemp is helping study this years-long change that ecologists call succession. Scott Bontz photo.

The sweet smell of succession

How grain fields left undisturbed will naturally become more complex

A prairie or forest is an arrangement developed over time that humans find hard to fathom, become too complex for them to fully explain, and refined to efficiency their derivations cannot match. Unless their field of artifice enjoys a subsidy – and often not even then – the natural system is more productive – it makes more stuff. This is a system of myriad specialists, of niche fillers, all working with and off the others, putting sun, water, and nutrients to high use with low loss, like money changing hands repeatedly in a town and staying in town, so the town feels rich. Here the exchange is not paper, it is real material and energy.

Agricultural ecosystems – farms – tend toward far fewer species of plants and animals. Those who study farm science, agroecologists, have long recognized this and explored how to make farms more diverse, intense, and tight, like nature. What they haven't looked at so much is nature's way of getting there, a path called succession.

A flood or fire disturbs a natural system's arrangement of species and their interplay. This can initially unleash from the soil nutrients for regrowth. But disturbance repeated too often breaks down and drains the system.

If in the chaos not too much soil is lost, successive changes and feedback among species return the system to a sweet spot of niche arrangements and productivity. It might not be exactly the same as before, but just as nature abhors a vacuum, it takes every opportunity to use carbon and life's other building blocks. And the ensuing succession almost always leads to the sun-powered prime mover, plant life, becoming a mix of species dominated by perennials.

By plow, disc, or weed killer, a crop field of annuals is designed to be greatly disturbed at least once every year. This system aims to get the most it can from short-lived species, and in most industrial agriculture from vast fields of just one such species. It intentionally and continually blocks anything like natural succession and its success with perennials. To feed their families or to serve the world commodities market, farmers accept the degradations of soil erosion, leached water and nutrients, weed invasions, and loss of the primary component to healthy and productive plants: soil organic matter. Not only does the agroecosystem suffer, but so also do ecosystems down wind, hill, and stream.

For relief agronomists and ecologists have tried to keep soil more continually protected by plants, with cover crops to hold ground between the production grain crops, and by putting between those crops buffering strips of perennials. These do help keep nutrients in soil, curb weeds, and take carbon from air and add it to soil better than do simpler annual systems. But they don't address the root of agriculture's successional stagnation. Succession leads to perennials, and succession in farming would require that annuals, which thrive on disturbance, give way to perennial grains.

It is perennials that build soil, and it is grains that occupy most tilled land and make most of our food. So The Land Institute is developing perennial grains in the form of wheat, intermediate wheatgrass, sorghum, and oilseed crops. Researchers in other countries are working on perennial rice, rye, and barley, and with the perennial legume called pigeon pea.

As these perennial crops age, in a way that annuals cannot, they will change, and the soil community around their roots will see succession. If the plants are grown in mixtures of species, more like in nature, and as The Land Institute proposes for agriculture, there might be succession aboveground too. Researchers predict that succession might dramatically affect how soil is built and works, including how nutrients are conserved and used, how carbon is pulled from the atmosphere, how water soaks in and is held, and how weeds are suppressed. With perennials, all of these should change for the better, sometimes much better. Succession also might change how soil makes available to plants the major nutrients phosphorus and nitrogen. Here what will happen is less certain, and agroecologists are exploring.

Nitrogen is most often what limits a crop plant's growth. A farmer might add some other nutrient but see no improvement until the plant gets more nitrogen. Nothing in industrial farming takes more fossil fuel energy than pulling nitrogen from the atmosphere and changing its molecular form to one which plants can use. This fertilizer's cost has not kept it from becoming something upon which billions depend for their very existence.

Nitrogen is vital, but the annual grains that depend on synthesized infusions often waste half or more of it. The fertilizer must go on the field before plants mature, or they'd use none of it at all. Even a mature annual's roots haven't had time to build the water and nutrient net that a perennial can, and in a young plant, roots are small and poor. Lost fertilizer pollutes water or returns to the atmosphere, some in the original harmless form, some as nitrous oxide, a potent greenhouse gas.

A cap traps nitrous oxide, a greenhouse gas, coming from soil where alfalfa and wheatgrass grow. The syringe is used to withdraw samples for analysis. This helps in study how soil changes while organisms and their relationships shift over the long haul of perennial plant growth. Scott Bontz photo.

Perennial grains would dramatically cut the nitrogen loss to leaching. But a perennial grown in a single-species stand like an annual crop will still need imported nitrogen for the element's export in grain protein. Better would be to grow legumes among the grass plants that make grain. Together with root bacteria, legumes fix atmospheric nitrogen in the soil. This would especially help farmers in poor countries who can't afford synthesized nitrogen.

But the amount of reactive nitrogen – the form that plants can use, not the inert nitrogen that makes up 78 percent of the atmosphere – has over a century of fossil-fueled synthesis dramatically altered the balance of nitrogen in water and land life. (See Land Report Number 107, fall 2013.) A recent study estimated that to keep the ecosphere stable we should cut reactive nitrogen production, whether from factory or legume, by 60 percent. So it's most important to strengthen the soil net with perennial grains. Make less, use more.

In fall 2014 The Land Institute and researchers from around the world met for several days in Estes Park, Colorado, to discuss strategy for making perennial grains and how to grow them. Most talked about finding the right plants and breeding them to be grain crops. They recently published a strategy paper. (See page 8.) One group, including Tim Crews, the institute's research director, talked about how to get the grains nitrogen and limit the element's loss.

The problem is one of making and managing an arrangement more complex than any seen by grain agriculture in its 10,000 years. (Many people in the New World grew maize and squash with leguminous beans, but these were all annuals, with high disturbance and arrested succession.) Solutions will be proved only through long trial. But Crews and other researchers at Estes Park have years of study in the hopper, and to help other researchers interested in developing the new agriculture, they will publish their thoughts this spring in a professional journal called Agriculture, Ecosystems and Environment.

As one example of the challenge: will fertilized monocultures of perennial grains emit less nitrous oxide? How this greenhouse gas moves depends on three connected things in the soil: how rich it is in nitrate, a useable nitrogen form and also a potential polluter; how much water fills its pores; and how rich it is in carbon for feeding soil microbes.

The researchers expect perennial crops to use more nitrogen and reduce soil nitrate, and increase reactive carbon. That last change could be good and/or bad. More soil organic matter, especially in a field degraded by cropping annuals, depends on more carbon. But too much carbon in proportion to other nutrients, such as phosphorus, can tie them up. Such will be among the new agriculture's delicately balanced suit, one to be tailored differently from field to field.

Other possible challenges for the new agronomy: controlling competition between grain crops and companion legumes, and little control over which nitrogen-fixing bacteria colonize the legume – some work better than others.

Known is that nitrogen from legumes flows more gradually than from synthetic fertilizer, and should reduce nitrous oxide emissions. Legume nitrogen also takes less energy and money. And tucking in legumes makes the farm field ecology more diverse, which can check pests and diseases.

To think about succession – or lack thereof – and nitrogen in agriculture, consider the grasslands that dominated an area from the Missouri to the Rockies. These prairies had built soil organic matter as high as possible given climate, soil makeup, plant growth, and carbon-releasing disturbances such as fire, grazing, and drought. Come the disturbance of plow and annual grain cropping, soil organic matter began to fall. The researchers call this retro-successional, a throwback. Tillage breaks soil structure, and once-stable organic matter is exposed to microbes, oxygen, and warmth. The microbes go after the organic carbon and exhale it as carbon dioxide. (This, not just burning fossil carbon, makes for global climate change.)

Meanwhile, unless enjoying the subsidy of irrigation annual crops cannot do more than equal the total growth of the perennials that they replaced, and they often produce less. Annuals, with only one growing season to live, aim for seed, and put only 15 to 20 percent of their growth belowground. With perennial grasses that investment nears half. Within five years the perennial roots might reach three times as deep as those of annual wheat and barley. Roots are key to putting carbon in the ground to make soil organic matter. Soil organic matter feeds plants. A stockpile of it richly feeds plants come opening by the plow. But Crews thinks annuals can only be net spenders of soil carbon: a net saving and building of soil requires perennials.

So under annual grain cropping soil organic matter falls. By the time the soil community bottoms out back at a state of early succession, soil organic matter has dropped an average of 30 percent, and sometimes more than 60 percent. With this falls crop production. Farmers compensate with fertilizers.

If they stop tillage, the next succession might be by annual weeds. But grassland perennials, with their persistence, gradually reclaim acreage and soil depths, and with that soil organic matter comes back. The climb can go on for decades, sequestering up to about 1,000 pounds of carbon per acre. In restored grassland the organic matter should plateau near its level before the plow.

(This plateau is why controlling climate change cannot be solely by carbon sequestration, but also depends on cutting emissions. Some calculate, however, that a rapid, widespread conversion of land to perennial vegetation could sequester carbon faster than nations will soon reduce their burning of fossil fuels.)

If annual cropping is replaced not by native grassland, but by a mixture of perennial grain and legume, belowground growth and soil organic matter will rise. The team from Estes Park predicts that perennial grain agriculture's organic matter still won't equal that of native grassland. Legumes will more easily decompose, giving to the atmosphere more carbon than does grass, and less to the soil. Also, some of what the plants make will be taken away from the field to feed people. Perennial grain crops will be bred to make more grain, and this may mean less root mass, especially if the plants are bred to not compete with neighbors. And if a perennial grain field still needs some kind of occasional tillage, to check competition or replace plants, soil microbes will eat exposed carbon and send some of it back to the air.

But the soil should be much more diverse, rich, healthy, and self-reliantly productive than it is under annuals. The amount of nitrogen leached from an established field of intermediate wheatgrass, one of the plants that The Land Institute is making a perennial grain, was less than 2 percent of what escaped annual wheat. Even if not full succession, this is great success. And though the numbers to confirm it are, like a polished agroecology for perennial grains, years away, with those kind of grains farming might finally build the soil it uses.

Land Institute shorts

Silphium in South America

Many silphium plants from Kansas did not pass the test for adaptability in a Uruguayan field. A smattering struggled through South America's summer, however, and Land Institute researcher David Van Tassel learned that the plot provided by the University of Montevideo was highly acidic. Test results may soon confirm that this explains the losses. After being moved to potting soil with a balanced pH, survivors perked up. Some crops or fertilizers can acidify soils that are not well "buffered."

This was the last of Van Tassel's two summers in Uruguay on a Fulbright scholarship to gauge silphium's adaptability. He taught classes about perennial grains at the university and hopes to nurture continued silphium work in Uruguay. It is one of South America's most politically stable, literate, and democratic nations, and so might serve as a base for expansion of research and development of perennial grains in the southern hemisphere.

Van Tassel also traveled to see how Alejandra Vilela and her husband, Damian Ravetta, plant biologists with the National Scientific and Technical Research Council of Argentina, are studying whether domestication changes silphium's basic physiology and anatomy. For example, does it make plants less efficient with water and nutrients? Are there ways to raise seed yields but keep the best features of wild silphium, such as drought tolerance? The Argentinians' measurements so far find that Van Tassel's improved — and healthy — plants differ from wild ones mainly in having bigger seeds. The researchers were happy to catch the process early enough that there has been only the one, desirable change.

Cafe uses perennial's flour

The Birchwood Cafe in Minneapolis, Minnesota, serves tortillas made with flour from intermediate wheatgrass, a perennial that The Land Institute is developing as a grain crop. The University of Minnesota is helping in this work (see page 4.), and allowed the cafe to experiment with recipes using flour milled from the school's wheatgrass.

New work by former fellow

Picasso

A former Land Institute graduate school fellow has joined the University of Wisconsin as an assistant professor to develop perennial cropping that simultaneously produces grain for people and forage for livestock. Valentin Picasso comes to the Madison campus from Uruguay. Picasso earned his doctorate from Iowa State University while The Land Institute helped support his research that tested how growing multiple crop species together affects overall production. His perennial grain plants, including intermediate wheatgrass from The Land Institute, likely will be grown with legumes to fix nitrogen in the soil and increase protein in the forage. (See page 4.)

Picasso's wife, Lucia Gutierrez, was another Land Institute graduate school fellow. Her work included exploring the genetics of a wild perennial barley. She also is an assistant professor at Wisconsin, breeding annual cereal crops.

Press and presentations

Land institute staff members spoke in Minnesota, Saskatchewan, New Hampshire, and Iowa. Scheduled presentations include April 5 in Kansas City, Missouri, and April 20 in Raleigh, North Carolina. The Kansas City event, a panel discussion, will be broadcast live on National Public Radio; see https://www.nprpresents.org/event/going-there-in-kansas-city-how-we-eat/.

Jamie Ramsey, left, and Emma Hauser thresh the grain from individual heads and plants of perennial wheat. Air blows chaff up the clear tubes and into the bags at left. Seed is heavier and drops for collection. It then is measured to gauge the worth of the parent plant. For news on wheat progress, see the page 2 caption. Scott Bontz photo.

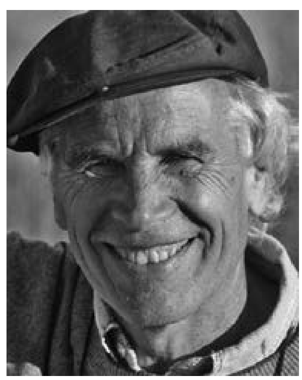
Image director, wilds man, farmer

Doug Tompkins painted agriculture into his vision for preserving Patagonia

SCOTT BONTZ

Doug Tompkins had recently cashed out of Esprit. This was the global clothing company that he and his wife at the time started by selling girls dresses from a VW bus – after they launched and sold off the mountaineering outfitter North Face and Tompkins tried his hand at adventure filmmaking. Tompkins had grown concerned about ecological damage wrought by the fashion industry and consumerism in general. Now he could afford to do something about it.

Wes Jackson had quit his tenured university position. He soon became concerned about ecological damage that comes with farming annual grains, and about an economic system based above all else on growth. For more than a decade he'd been working on solutions through the nonprofit Land Institute begun with his wife at the time on their homestead.



Tompkins

The two men didn't know each other. But at the start of the nineties, they both were at an ecology meeting in Washington, DC, and at the mixer they met and talked.

Tompkins flew to Kansas to see The Land Institute. On they talked. Tompkins was passionate about wilderness, and he thought agriculture wrecked everything. Jackson blurted something like "If we don't fix agriculture first, wilderness is doomed."

He doesn't remember Tompkins responding. But the idea stuck. On June 30, 1991, Tompkins's Foundation for Deep Ecology gave the institute $30,000. Tompkins and his second wife, Kris, kept visiting Jackson and his second wife, Joan, and making donations. Until last year they were the biggest benefactors in the institute's history, giving more than $1.5 million.

Meanwhile, they spent far greater amounts buying more than 3,000 square miles in Chile and Argentina. They became the largest private landowners in the world and, as Outside magazine put it, protected more land than any other individuals in history. Writer Edward Humes called Tompkins an "eco baron." Sarah Kaplan wrote in The Washington Post, "Tompkins will be better remembered in the US as the guy who brought domed tents to hippie hikers and brightly patterned 'casual wear' to the Reagan-era teenage masses." But in Patagonia, "he is the man who tried to buy paradise, not to exploit it, as so many millionaires like him had done throughout history, but to preserve it."

South Americans had indeed seen

nothing like this, and many were mistrustful. Tompkins was rumored to be building a nuclear dumping ground. Planning to bottle and ship away Patagonia's water. Trying to establish a Jewish state – though Kaplan called him decidedly WASP. What Tompkins did included opposing developments, such as billion-dollar salmon farms, that many South Americans wanted. Rodrigo Pizarro, director of a leading environmental group in Chile, told The New York Times that Tompkins's project was very good, a model, but that his "entrepreneurial mentality," wanting to do things his way, disdainful of others, led to communication errors.

Tompkins said time would bring his opponents to appreciate preservation of their wilderness. He encapsulated this in a quote attributed to Lincoln: "Laws change; people die; the land remains." And as Tompkins and his wife made vast acreages into national parks and donated them to Chile and Argentina, Jackson said, opinion turned.

Over the years Jackson occasionally visited the Americans at their adopted home in Chile. Tompkins ran the cattle off of his new land, but he started small gardens and eventually expanded to farming thousands of acres. He sent a farm manager and the manager's wife to spend a summer working and learning at The Land Institute. He assimilated Jackson's message about patterning farming after natural ecosystems. It fit as well as agriculture could with Tompkins's demand for wild diversity. The institute couldn't yet give him perennial grains grown in polycultures, but Jackson said Tompkins did the best possible with what he had. The crops were organic. He rotated them, and he planted them in adjoined strips of varying color. From the air, Jackson said, the farms were "a tremendous scene. A painting."

"What he wanted ahead of everything else was it had to be beautiful," Jackson said. And to achieve that, Tompkins carried from serving as Esprit's "image director" to acting as South America's equivalent of John Muir, champion of conserving his adopted home's wilderness, this philosophy: "No detail is too small." Tompkins paid attention to the farm layout, the crops and the pastures, and between them the fences and any litter that the fences caught. Recently at The Land Institute's Prairie Festival, without invitation he rearranged the presentation of books for sale and said, "Doesn't that look better?"

Tompkins grew up in affluent Millbrook, New York, son of an antiques dealer and decorator. He attended boarding schools in Connecticut, but before earning a diploma was expelled for an accumulation of minor infractions. He never returned to organized schooling.

Instead he went west to California, and then beyond, to ski and climb and kayak. He pioneered mountaineering routes and claimed first descents of whitewater around the world. From this passion for adventure in the wild came expertise for establishment of The North Face, purveyor of climbing and camping equipment. It also brought him friendship with Yvon Choinard, founder of a like company, Patagonia. Kristine McDivitt was Patagonia's CEO before marrying Tompkins and moving to Chile.

Choinard told Men's Journal about his decades of adventure with Tompkins: "Doug and I were both overly cavalier about jumping into dangerous things. It's almost as if we've had a subconscious wish to invite catastrophe so we can try to get out of it." He said Tomkins was wearing pressed chinos, a Brooks Brothers shirt, a light sweater, and a rain jacket when they and four other friends went kayak camping last December. They paddled on a lake, not in whitewater. But it was General Carrera Lake, Chile's largest, fed by Andean glaciers in the latitude of the Roaring Forties. Tompkins's paddling partner, Rick Ridgeway, said their kayak had a faulty rudder, and when winds struck with gusts up to 50 miles per hour, 6-foot waves capsized them. The water was 38-40 degrees. Several attempts to right the boat in the windstorm failed. They swam for shore, but the current beat them back. Another tandem kayak reached Ridgeway, who struggled against hypothermia while he was towed to land. Another single kayaker, Weston Boyles, tried to tow Tompkins. Tompkins lost consciousness, and then Boyles risked capsize and his own life while he grasped Tompkins with one arm and paddled with the other. A helicopter finally arrived and pulled the two in. Tompkins's body temperature had dropped to 66 degrees. In a nearby hospital he died.

Jackson spoke at a January 31 memorial in San Francisco. The short presentation's title praised Tomkins for his "dedication to the good, the beautiful, and the wild."

At home in Kansas, Jackson said, "Doug was a friend, and we were a mutual admiration society. He was fun to be with. We had spirited conversation. He was always sending something that he had read and thought was good."

Jackson also said, "He was a deep intellect. He wanted to know things. He'd drill down to find things." The scientist spent two hours explaining how nitrogen cycles through air, soil, organisms, and water, until Tompkins was satisfied with his understanding of the process.

"He also could be overly serious," Jackson said, then corrected himself: "He could be pretty intense."

Tompkins would have turned 73 on March 20. He leaves his wife, mother, a brother, and two daughters. He was buried in Chile. Kris Tompkins continues conservation work in South America.

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Australian Mark Peoples talks at The Land Institute about his study of nitrogen in agriculture. This was shortly after he and other researchers from around the world met those from The Land Institute in late 2014 to discuss domestication of perennial grains, and how those grains might be grown with legumes to supply nitrogen. Now the scientists have published papers. For the story about finding new crops, see page 8. For the story about intercropping, see page 16. Behind Peoples are pictures by Terry Evans of herbarium specimens. Researchers seeking candidates to make new crops could use information gathered in herbariums. Scott Bontz photo.