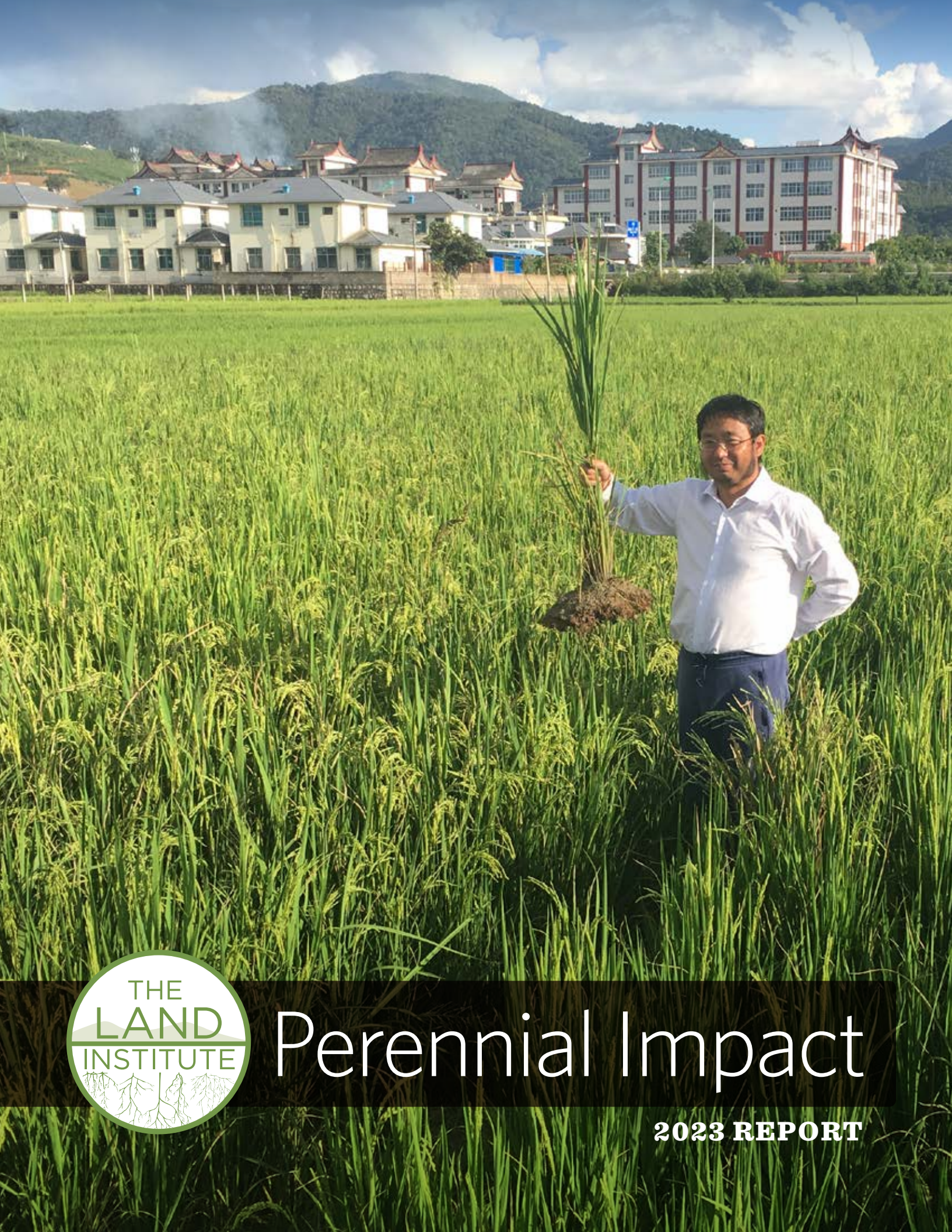
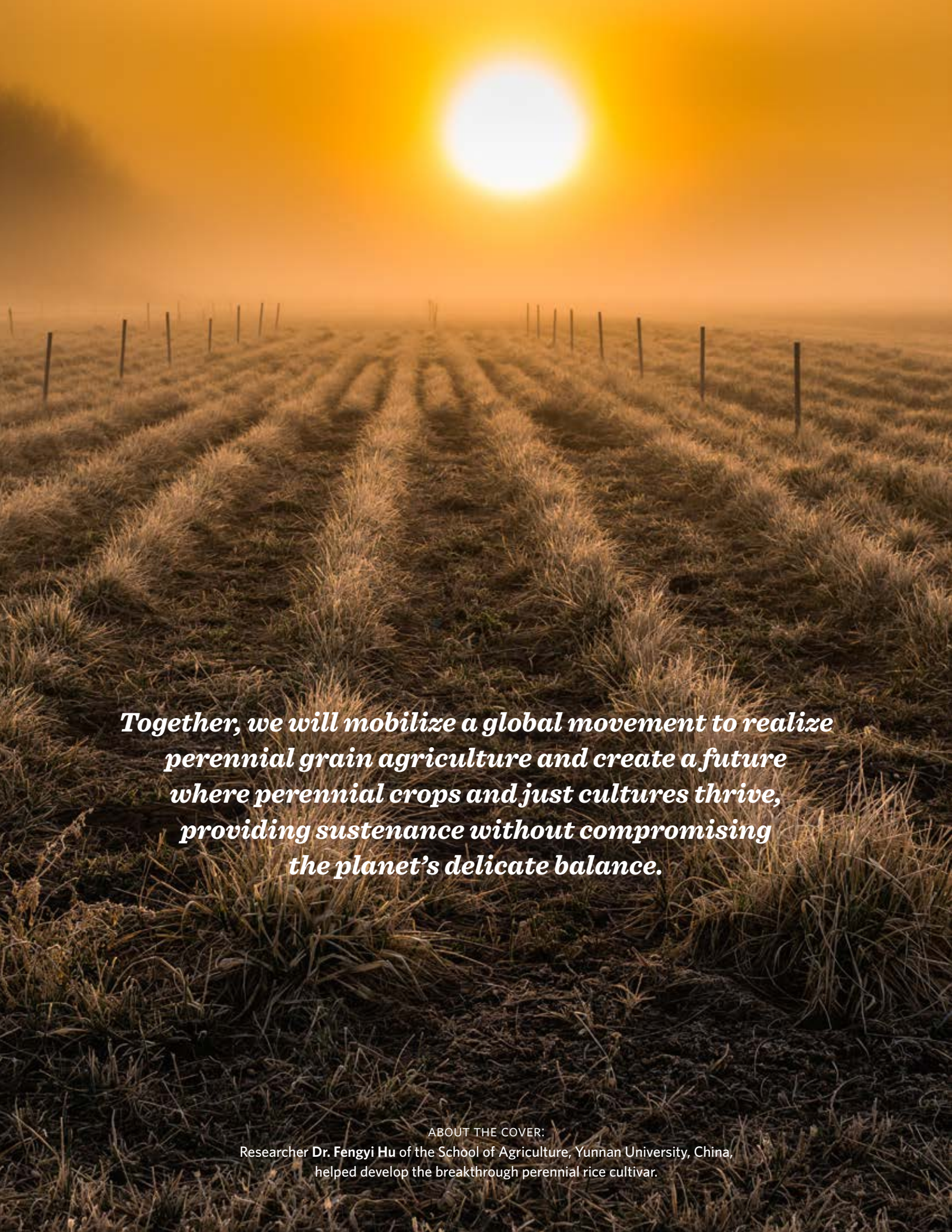


THE LAND INSTITUTE

Perennial Impact

2023 REPORT



Together, we will mobilize a global movement to realize perennial grain agriculture and create a future where perennial crops and just cultures thrive, providing sustenance without compromising the planet's delicate balance.

ABOUT THE COVER:
Researcher **Dr. Fengyi Hu** of the School of Agriculture, Yunnan University, China, helped develop the breakthrough perennial rice cultivar.

Building the Bridge Toward a Perennial Future

MESSAGE FROM THE PRESIDENT:

We stand at a pivotal moment in the history of agriculture and humanity. The Land Institute has been constructing a bridge to carry us into a future where sustainable, perennial grain crops flourish, and just communities live in deep relationship to the ecosphere from which they support perennial agriculture.

In the past fiscal year, we witnessed remarkable progress on our journey to transform agriculture. Our researcher collaborators in Yunnan, China, with support from The Land Institute, achieved a momentous milestone in developing perennial rice. High-yielding varieties of this new perennial grain are planted on 37,888 acres and stewarded by nearly 50,000 smallholder farmers throughout China. This achievement marks a turning point in the transition from annual grain agriculture to perennials, which ultimately could encompass a staggering 2.7 billion acres globally. In agriculture, viable perennial rice development rivals the importance of landing on the moon. And while it may not garner national headlines, this breakthrough merits such acclaim.

While our bridge to the future is still under construction, we are ready to test the strength of its foundation. This decade is the most critical to confront the climate crisis. The time to act is now. The Land Institute has and will continue to play an adaptive and significant role in ensuring a transition to a perennial grain agriculture system that can nourish people without depleting the precious natural resources we depend on. It is time to test our bridge, adapt to new ways of planning for the future, take calculated risks, and embrace new possibilities.

The Land Institute continues to deepen its work with sorghum in Africa, sainfoin in Palestine, silflower in Argentina, Kernza® in the European Union and Ukraine, and vital perennial grain polycultures within the United States. Together, we will test our resilience and determination. The possibilities are nothing short of exhilarating. Together, we will mobilize a global movement to realize perennial grain agriculture and create a future where perennial crops and just cultures thrive, providing sustenance without compromising the planet's delicate balance.

Rachel A. Stroer
PRESIDENT
The Land Institute

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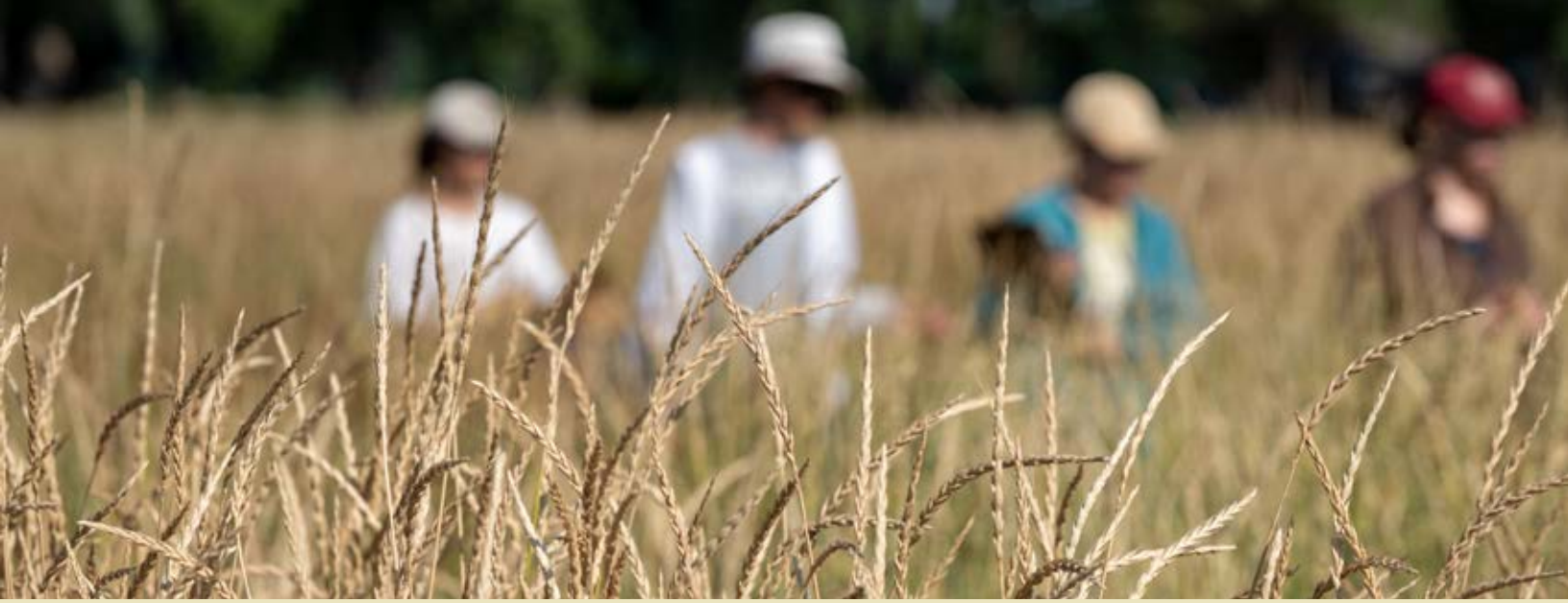


Key Milestones to Perennial Grain Success

- Perennial grains **must be robustly perennial,** surviving and producing a harvest for a minimum of three years.
- Perennial grains **must be high yielding,** producing similar abundance to annual grain counterparts.
- Perennial grains **must be safe to eat,** obtaining proper government approval for these new foods.
- Perennial grains crops should be **researched and regionally adapted** to grow in different geographies.
- Perennial grain **uses as food ingredients and whole foods** must be identified, including the potential for oil, starch, fiber, and nutrients.
- Perennial grain **economic and ecological uses beyond food** must be identified, including fodder, forage, conservation plantings, habitat, buffer zone water protection, cover cropping and more.
- Perennial grain agriculture must be **widely recognized as a scientifically credible and viable climate solution**.
- Researchers, farmers, processors, and producers must **understand how to grow, harvest, and process** perennial grain crops.
- People must **know how to prepare and eat** perennial grain products at their tables.
- Researchers and producers must **understand how to grow perennial grain crops in diverse polyculture mixtures** for maximum ecological benefits.
- **A global perennial grain research consortium** is formalized and builds collaborative research communities in the US and abroad.

Perennial Rice Achieved "Moon Landing" Breakthrough

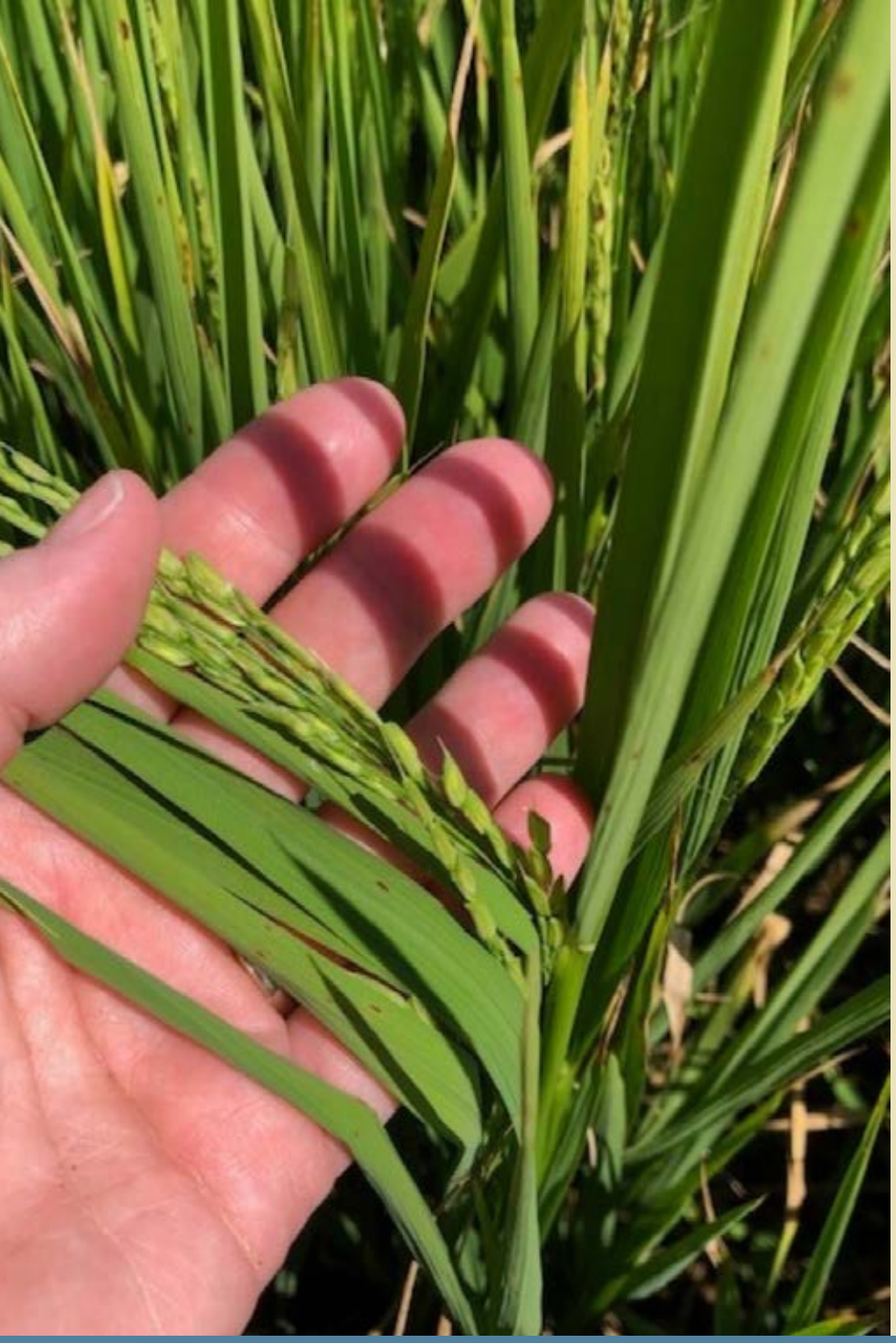
A breakthrough study in the journal *Nature Sustainability* documenting a high-yielding, long-lived perennial rice with significant environmental, economic, and social sustainability impacts proved the viability of perennial grains. Researchers in China's Yunnan Province developed high-yielding perennial rice in a relatively short two-decade timeframe, with yields comparable to annual rice varieties. The team had support with seed funding and scientific expertise from The Land Institute and a global network of perennial grain researchers.

"One of the most important reports in modern agriculture. I believe this will catalyze a generation of new discoveries by scientists who have not yet been involved in pursuing perennial traits in staple grain crops. This research marks a distinct new line of possibilities for global food production from the nearly 10,000-year single-track reliance on annual grain crops."

JERRY GLOVER
National Geographic Society Explorer

Rice feeds four billion people, is the grain most consumed by humans, and is the third most-produced cereal crop worldwide after corn and wheat. But annual grain agriculture comes at an ecological and economic cost, compromising ecosystems and forcing ever-higher inputs of chemical fertilizers, pesticides, fossil fuel energy, and labor to maintain yields. The growing perennial grain agriculture movement is shifting this paradigm to address some of the food system's most pressing challenges.

Perennial Rice Development Timeline



Perennial rice holds advantages over annual rice

LONG-LIVED PRODUCTION

Perennial rice produced grain for **eight consecutive harvests** over four years from a single planting

COMPARABLE HIGH YIELDS

Average **perennial rice yields were equivalent to annual rice** for each perennial rice regrowth cycle

SIGNIFICANT CARBON SEQUESTRATION

By switching from annual to perennial rice, soils accumulated **almost a ton of organic carbon per hectare per year**

LABOR AND INPUTS SAVINGS

Farmers used **nearly 60% less labor and spent almost 50% less on seed, fertilizer, and other inputs** for perennial rice than annual rice

IMPROVED FARMER LIVELIHOODS

Farmer profits from perennial rice ranged from **17% to 161% above annual rice**

1996
Development Began

Researchers achieved a successful cross between an annual domesticated Asian rice cultivar from Thailand and an undomesticated African perennial from Nigeria via embryo rescue.

1999
Collaboration Began

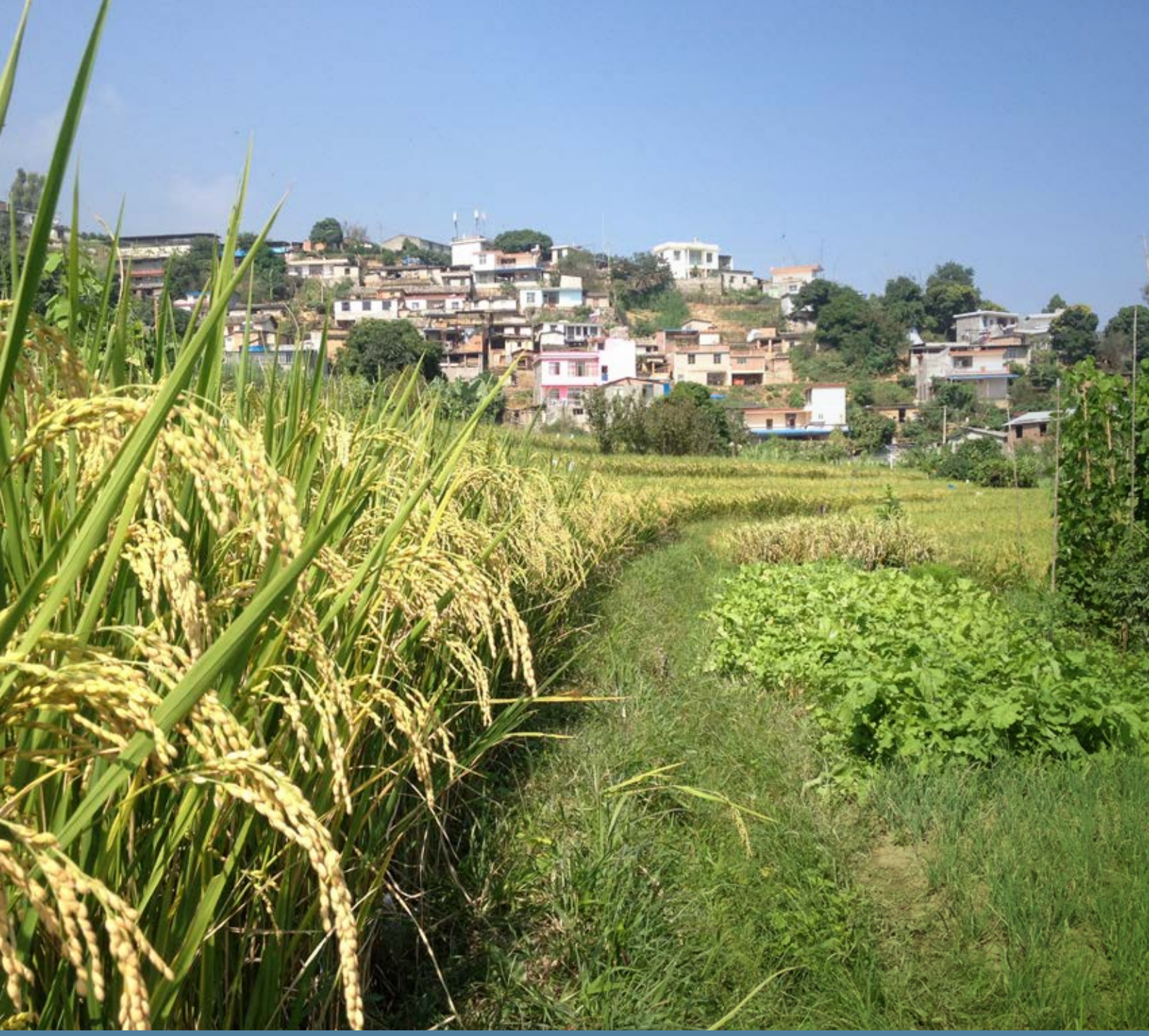
Researchers Fengyi Hu and Dayun Tao began working with Erik Sacks to develop perennial rice in a collaboration between the Yunnan Academy of Agricultural Sciences (YAAS) and the International Rice Research Institute (IRRI).

2003
Development Stalled

Due to a lack of funding, IRRI shuttered the program.

2005
Interest Rekindled

Hearing of the IRRI project, The Land Institute invited Sacks to present his research.



2007
New Partnerships Formed

Hu and the YAAS team partnered with the perennial grain breeding experts at The Land Institute to jumpstart development of a wide hybrid cross between annual, cultivated rice and a perennial rice cousin from Africa.

2008
Efforts Reignited

The Land Institute provided critical funding, technical support, and mentoring to help expand a network of global peer researchers.

2012
Global Collaboration

The University of Illinois, Yunnan University, and the University of Queensland joined the effort.

Perennial rice is direct evidence that developing perennial versions of grain crops is feasible and provides a clear reason to vastly increase research and investment in ongoing work to create perennial versions of crops like wheat and sorghum. Nearly 45,000 farmers in southern China adopted the crop. They grew it on over 15,000 hectares (37,000 acres), showing that farmers respond positively to perennial grains.

Senior author Fengyi Hu and Dayun Tao began working with co-author Erik Sacks to develop perennial rice in 1999 in a collaboration between the Yunnan Academy of Agricultural Sciences (YAAS) and the International Rice Research Institute (IRRI). Hearing of the IRRI project, The Land Institute invited Sacks to present his research in 2005. This connection eventually led to Hu and the YAAS team partnering with the perennial grain breeding experts at The Land Institute in 2007 to help jumpstart the development of a promising wide hybrid cross between annual, cultivated rice and a perennial rice cousin from Africa. Inspired by the potential for Hu's research to develop upland perennial rice, given the catastrophic soil erosion in the hilly regions of Southeast Asia, The Land Institute provided critical funding, technical support, and mentoring from a global network of peer researchers. The University of Illinois, Yunnan University, and the University of Queensland soon joined the effort.

The breakthrough earned global attention from the press and science, agriculture, finance, government, and international development groups. The journal *Science* named Perennial Rice a 2022 Top 10 Scientific Breakthrough alongside the new James Webb Space Telescope. ▪

The journal *Science* named Perennial Rice a 2022 Top 10 Scientific Breakthrough alongside the new James Webb Space Telescope.

2018
Key Milestone Achieved

PR23, an especially promising line that exhibited high and stable grain yields over multiple years and good performance at most locations, was released to farmers in China.

2020
Variety Released

PR25 was released as Yunda25 in China.

2022
Research Breakthrough

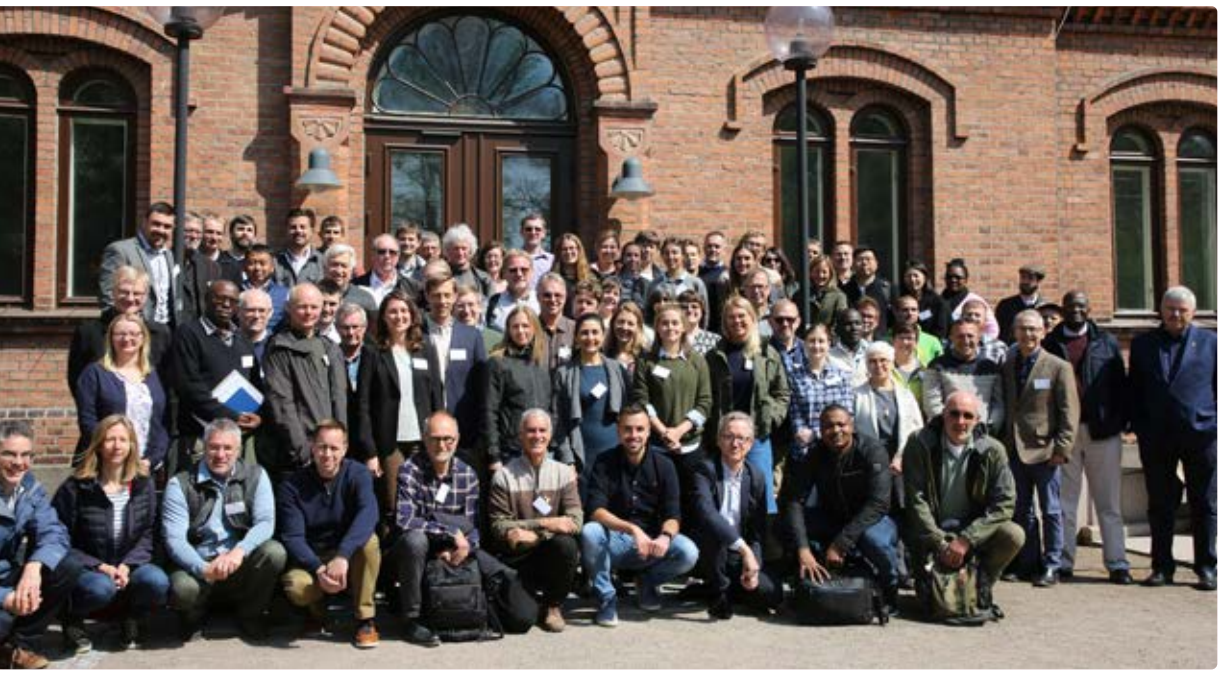
Published in *Nature Sustainability*. Named 2022 Top 10 Scientific Breakthrough by ***Science***.

Global Research Community Resoundingly Affirmed Perennial Grain Promise

A consortium of key global researchers and staff at The Land Institute published a paper spotlighting the international consensus around the promise of perennial grains. Authored by lead scientist Lee DeHaan and co-authored by The Land Institute's Pheonah Nabukalu, Shuwen Wang, and Tim Crews, plus 25 collaborators from 21 institutions in 8 countries, the group released the paper "Prioritize Perennial Grain Development for Sustainable Food Production and Environmental Benefits" in the journal *Science of the Total Environment*.

Farmers and scientists have long agreed that perennial grains yielding similarly to their annual counterparts would revolutionize farming, benefiting the environment and society. Yet, along with this broad consensus, a looming question remained: "Is it feasible?" Skeptics reasoned that if the effort to develop perennial grain crops is expensive, long-term, and only theoretically possible, it may not be worth attempting.

The recent perennial rice breakthrough reported in *Nature Sustainability* of yields equivalent to its annual counterpart across eight harvests is not limited to rice and could pave the way for developing other perennial grain crops. The journal *Science* underscored perennial rice's potential to transform the agricultural sector. By dismantling perceived barriers and myths, perennial rice has opened up vast possibilities for new perennial crops, like sorghum and wheat—and the article urged immediate and robust investment in perennial grain research.



"For a new crop to succeed, a substantial societal investment in breeding, agronomic research, and early supply chain coordination is essential."

L.R. DEHAAN et al.
Science of the Total Environment

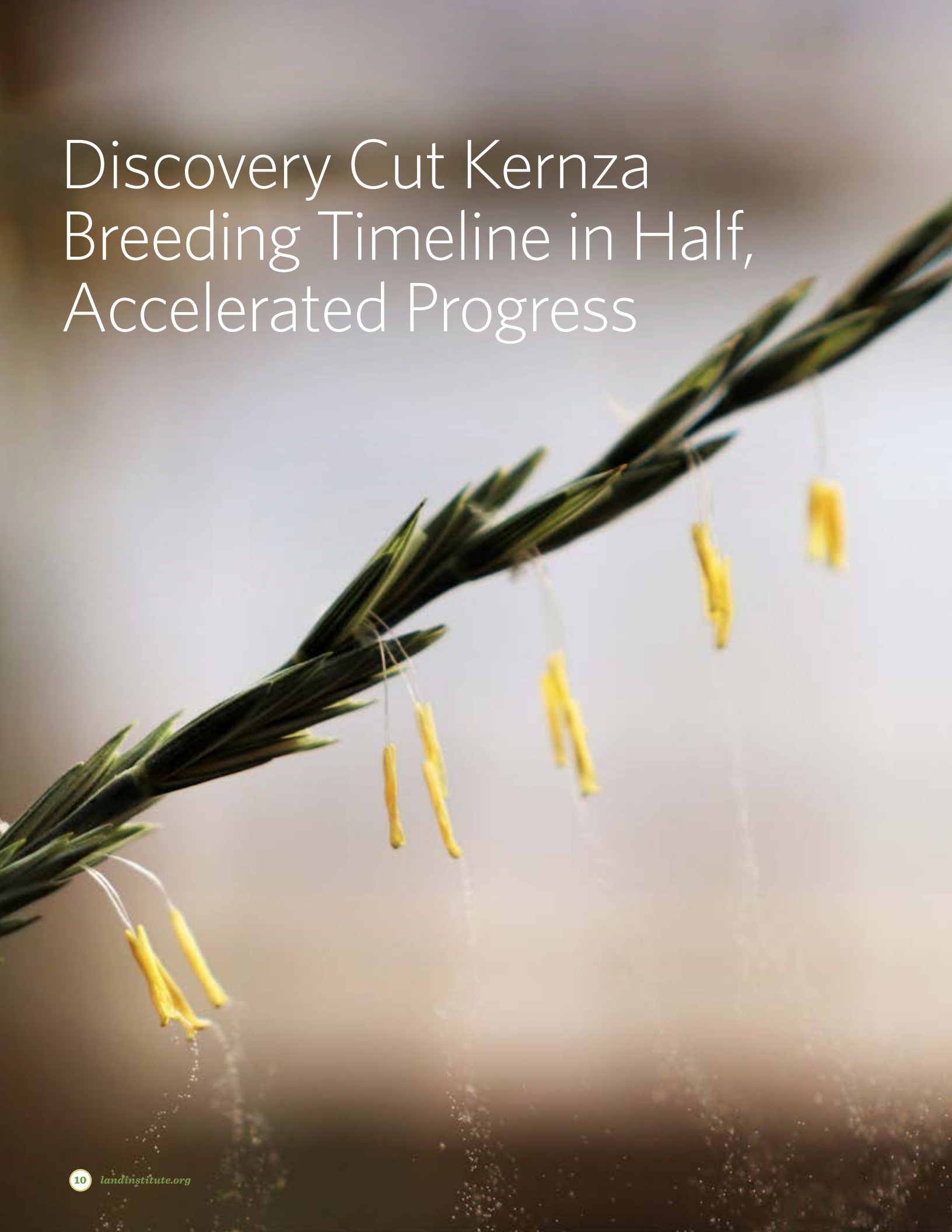
The authors also argued that the promise of perennial grains is not a recent discovery. The potential ecological and economic benefits of perennial rice and Kernza perennial grain, like soil conservation and increased farmer profits, drove their development. Over the past two decades, as research has evolved, the scientific community has increasingly recognized the potential of these grains to combat climate change. However, perennial grain research and development must catch up to their annual counterparts, and the authors urged immediate and substantial investment in the study of these crops.

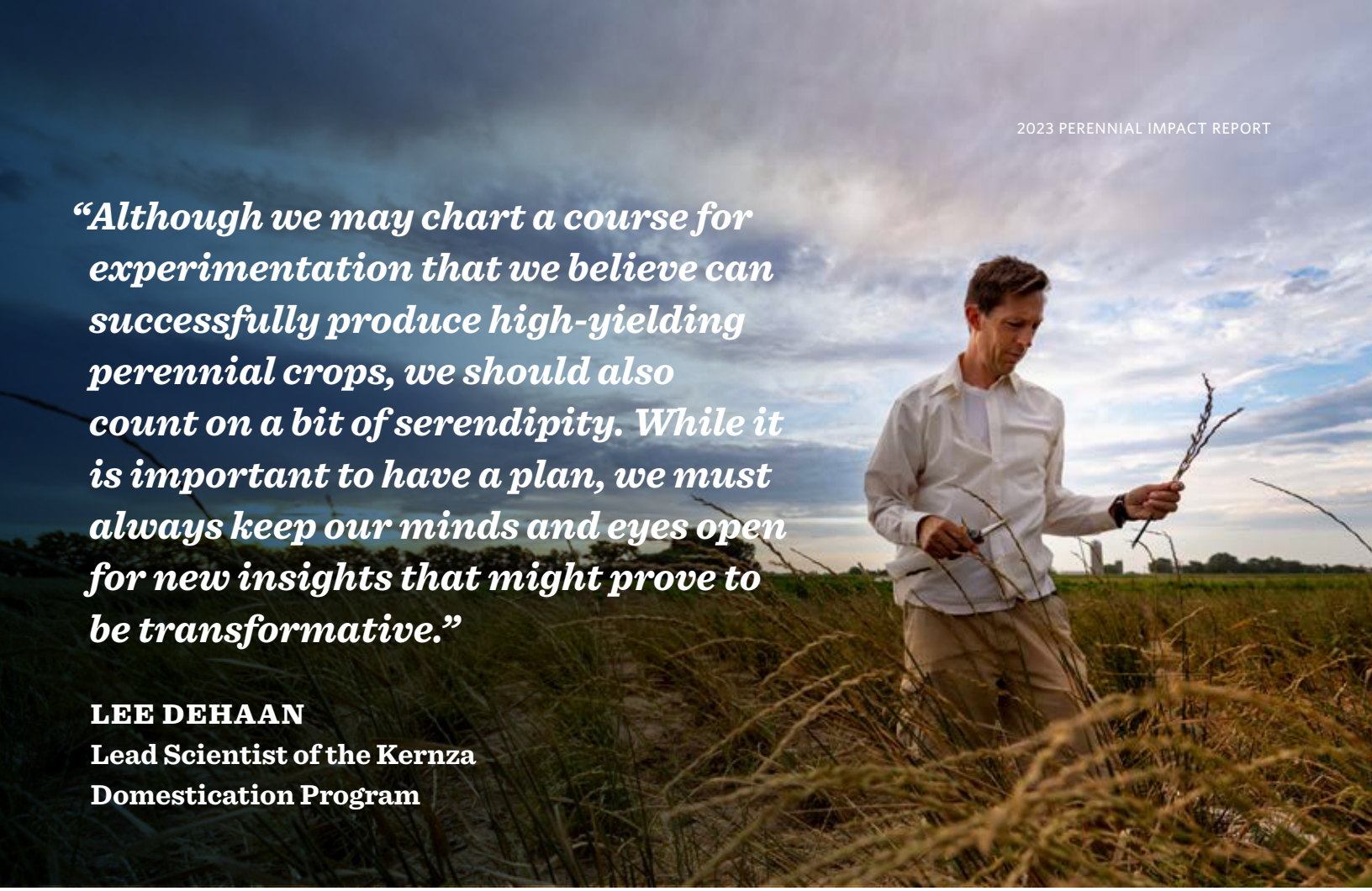
The release of this paper marked a critical transdisciplinary consensus around the development of high-yielding perennial grain crops as both possible and imminent. Now, more than ever, empowered by technological advancements, making perennial grain agriculture a reality must be a priority. ▪

For a Deeper Dive

Read the paper at qrco.de/beSkBo or use the QR code:

Discovery Cut Kernza Breeding Timeline in Half, Accelerated Progress





"Although we may chart a course for experimentation that we believe can successfully produce high-yielding perennial crops, we should also count on a bit of serendipity. While it is important to have a plan, we must always keep our minds and eyes open for new insights that might prove to be transformative."

LEE DEHAAN
Lead Scientist of the Kernza Domestication Program

Kernza perennial grain has sparked the imaginations of many, from farmers to food enthusiasts, bakers to brewers, and conservationists to climate activists. With its 10-foot-long roots that help foster healthy soil, clean water, and biodiversity while removing carbon from the air, there's much excitement around the potential of this novel experimental grain. But with its small seed size and relatively low yields compared to modern commodity grain crops, Kernza still needs more breeding improvements before it's an easy economic switch for farmers.

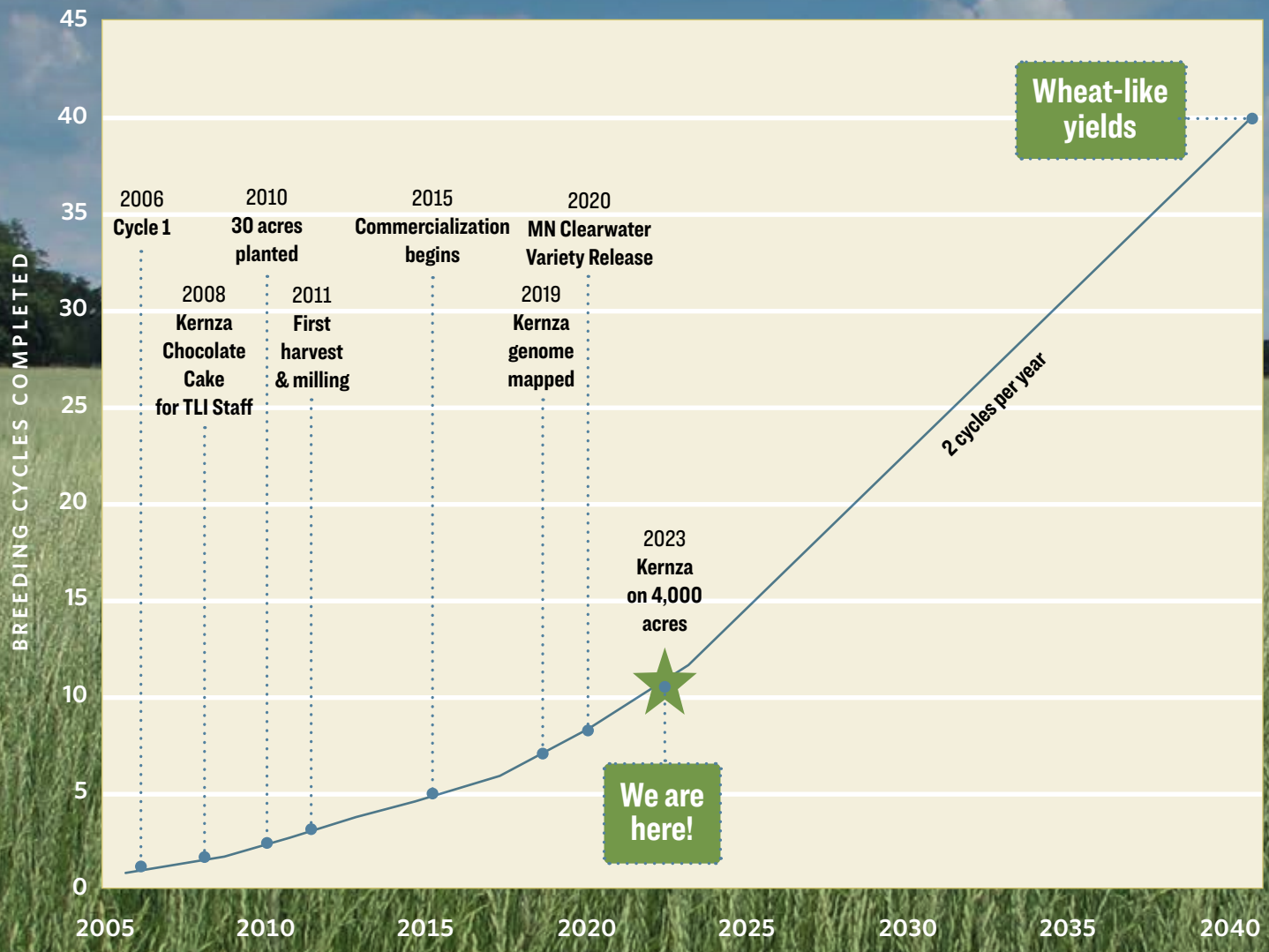
In 2023, the far-off goal of high-yielding Kernza became more attainable when an unexpected new discovery changed the course of Kernza breeding progress.

While searching for new ways to accelerate the speed of Kernza breeding, a surprise breakthrough effectively doubled the rate of Kernza breeding efforts. Researchers were treating intermediate wheatgrass (the plant that produces Kernza grain) with special LED lights that produce a wavelength known as far-red light to study how the plants grow in a crowded environment. Initially, they didn't observe any changes in plant growth. But after leaving a group of plants under this light for a long period of time, they noticed that the plants developed seed heads without the usual seven-week period of cold temperatures (called vernalization), which stimulates seed head production.

Lee DeHaan, Lead Scientist of the Kernza Domestication Program, took an interest in this observation and pursued the same experiment the following season to learn more using different timings and intensities of far-red light. After a series of experiments, he was able to find an intensity of light that would induce Kernza plants to flower in less than half the time of the previous method.

By using this newly discovered far-red light technique, researchers can now complete two cycles of breeding in a single year, effectively doubling the rate of Kernza perennial grain development. This advancement will significantly contribute to the program's goal of quickly improving Kernza yields. ▪

Kernza® Perennnial Grain Breeding Cycles Progress



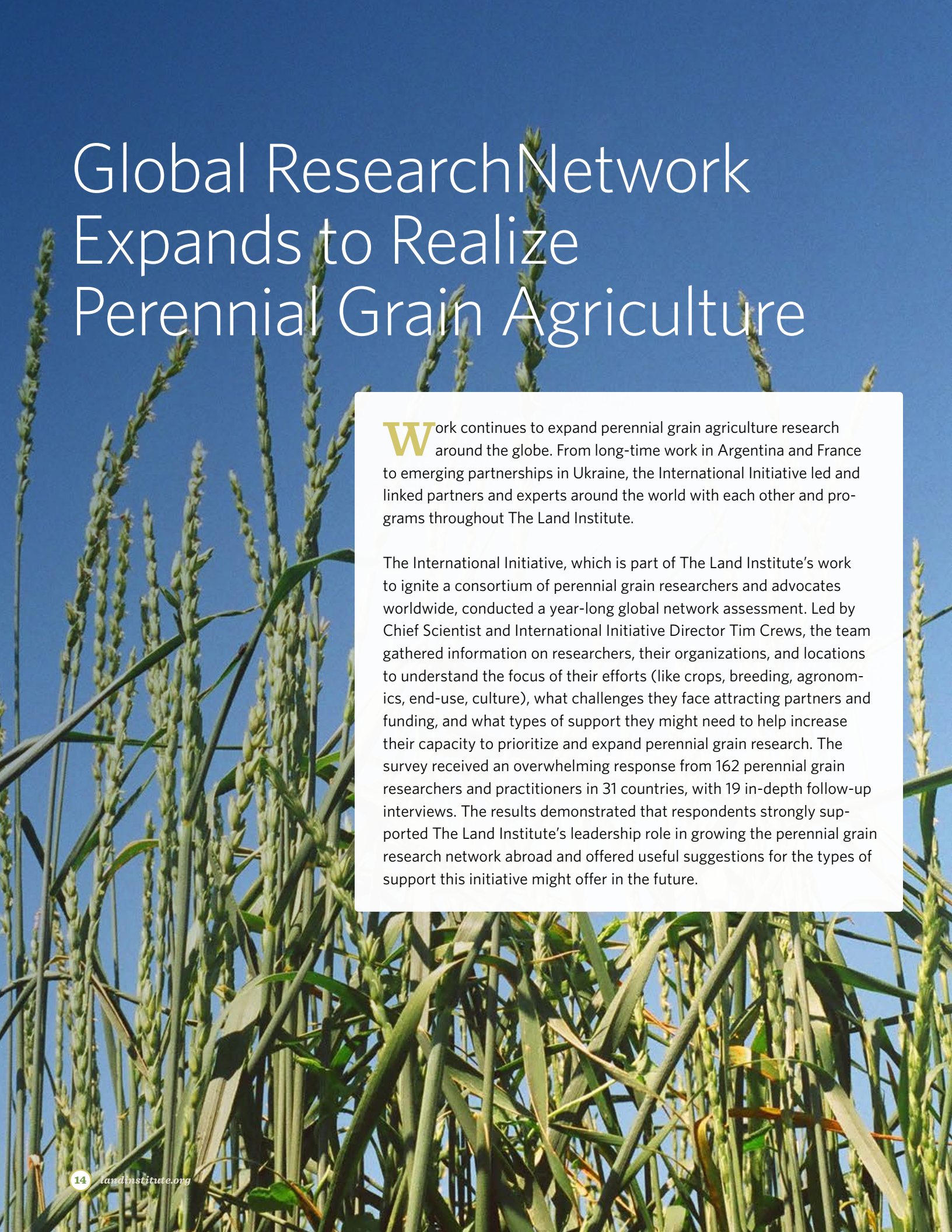
Innovative food companies, home cooks, and bakers led the way in demonstrating the capabilities of Kernza in a wide range of dishes and packaged foods.

Minnesota-based food company Perennial Pantry released their report titled "Baking with Kernza: An In Depth Analysis & Introduction," after conducting rigorous tests in baking, malting, blending, and more to analyze how Kernza compares to conventional grains in various foods.

Additionally, partners at Michael Fields Agricultural Institute partnered with bakers around the country to showcase the possibilities of cooking with Kernza at home. Participants developed recipes ranging from coffee cake to biscotti, calzones, Kernza pilaf, and more.

The prominent pancake company Kodiak Cakes also released their Kodiak Kernza® Cakes pancake and waffle mix in select Sprouts Farmers Market stores and online, and even received the 2023 On Trend Award from the KeHE Distributors Holiday Show for their work with the perennial grain. ▪

Global ResearchNetwork Expands to Realize Perennial Grain Agriculture



Work continues to expand perennial grain agriculture research around the globe. From long-time work in Argentina and France to emerging partnerships in Ukraine, the International Initiative led and linked partners and experts around the world with each other and programs throughout The Land Institute.

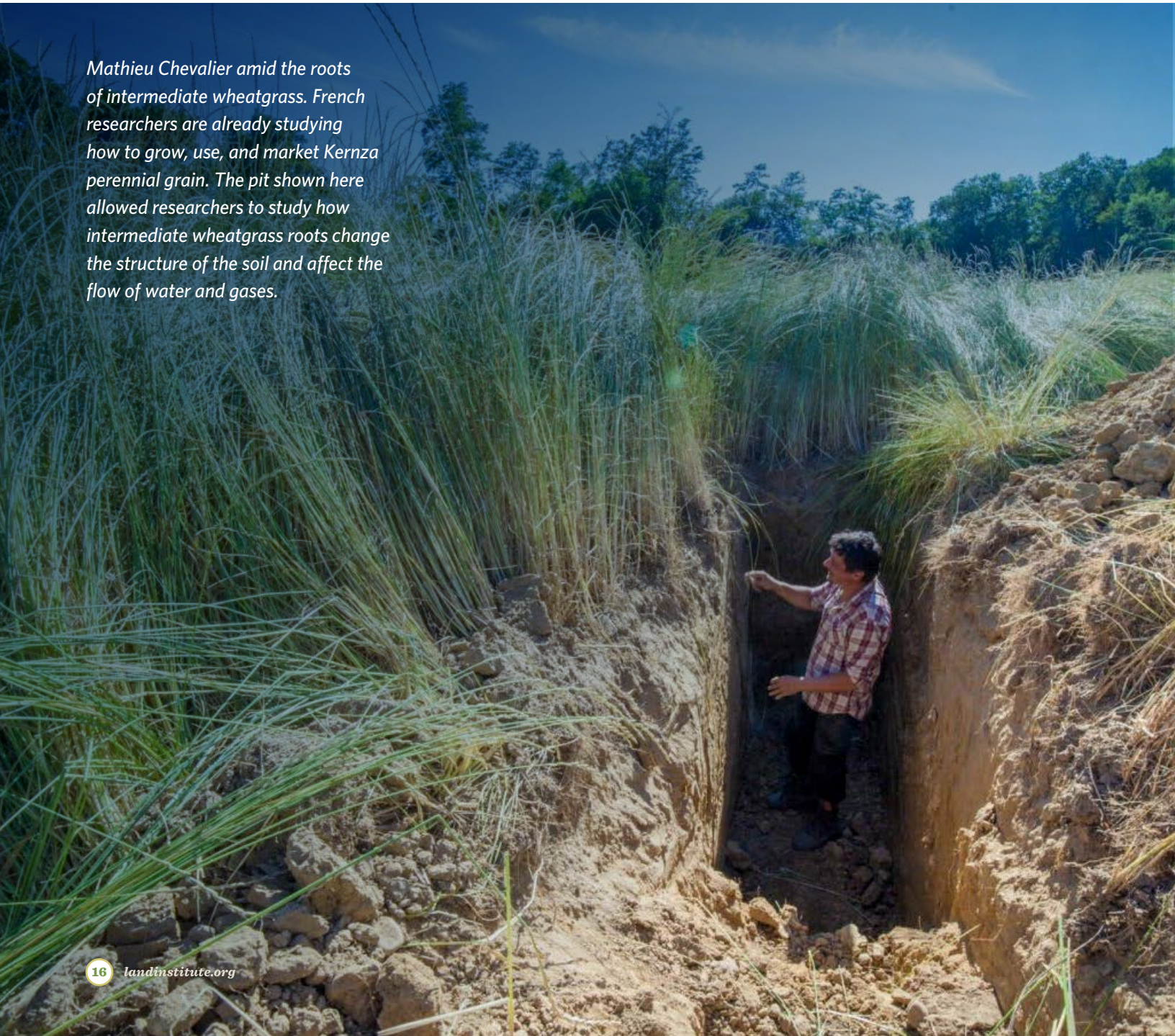
The International Initiative, which is part of The Land Institute's work to ignite a consortium of perennial grain researchers and advocates worldwide, conducted a year-long global network assessment. Led by Chief Scientist and International Initiative Director Tim Crews, the team gathered information on researchers, their organizations, and locations to understand the focus of their efforts (like crops, breeding, agronomics, end-use, culture), what challenges they face attracting partners and funding, and what types of support they might need to help increase their capacity to prioritize and expand perennial grain research. The survey received an overwhelming response from 162 perennial grain researchers and practitioners in 31 countries, with 19 in-depth follow-up interviews. The results demonstrated that respondents strongly supported The Land Institute's leadership role in growing the perennial grain research network abroad and offered useful suggestions for the types of support this initiative might offer in the future.

Teams engaged with agricultural research scientists in Ukraine in experimenting with perennial grains, even as the war with Russia was raging. Working closely with consultants Richard Warner in Minnesota and Roman Rusev in Ukraine, Ukrainian researchers from six universities and institutes responded with enthusiasm when presented the opportunity to work with perennial grains. In the late summer and early fall of 2022, researchers at five locations sowed experimental plots that will comparatively evaluate the productivity of Kernza when grown in companion with the perennial legume bird's foot trefoil clover and in fertilized and unfertilized monocultures, the cultivation of a single crop on a given field. Despite challenges, like tight restrictions on energy for heating and electricity and often being bundled in heavy winter coats on virtual calls, the agronomists, ecologists, and perennial plant breeders were undeterred from designing a multi-site perennial grain research project.

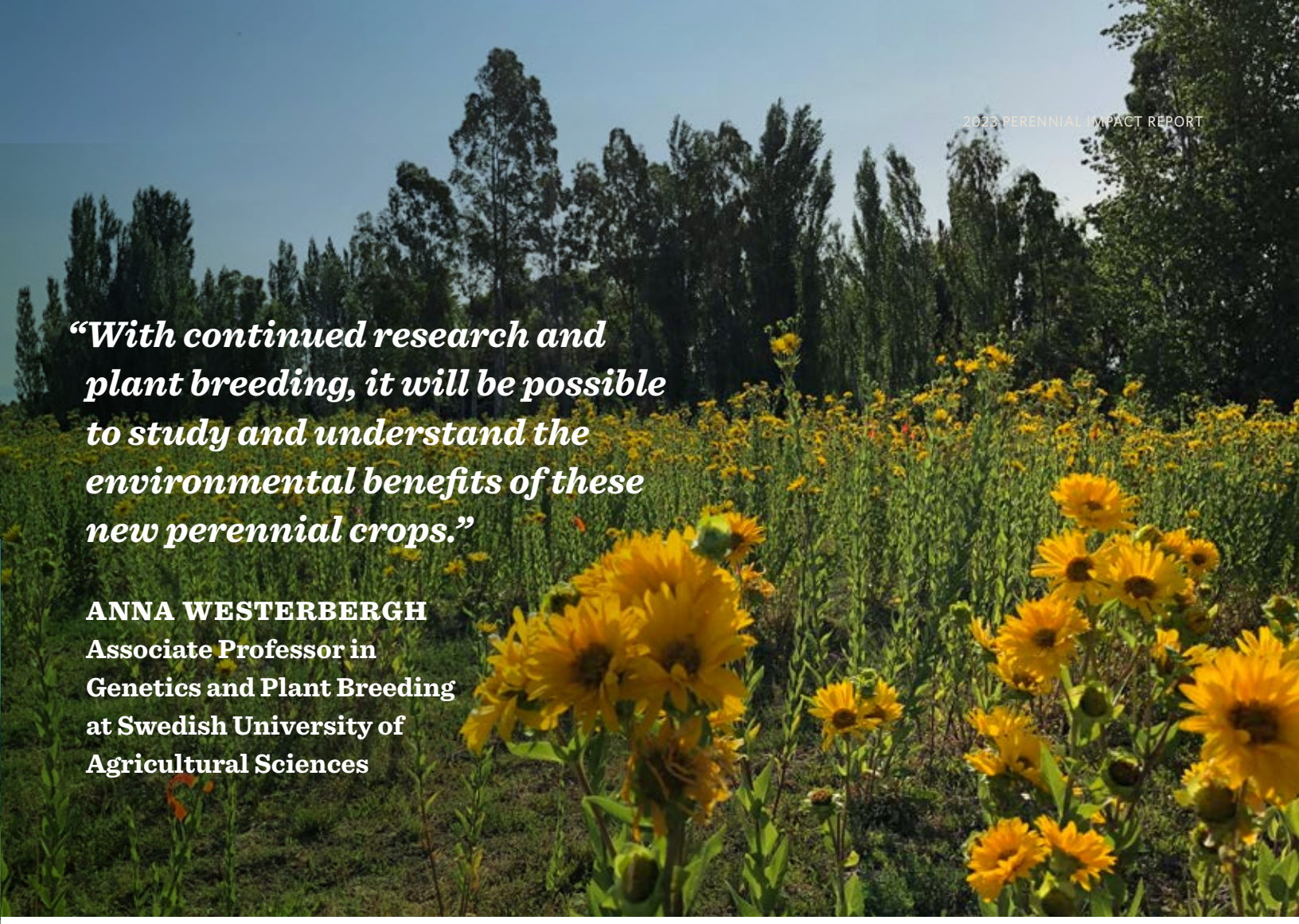
Meanwhile, in the Chubut Province of Argentina, The Land Institute's long-time collaborators Alejandra Vilela, Damina Ravetta, and Luciana Gonzalez-Paleo converted a semi-abandoned farm into a valuable field station for silflower breeding and agroecology research. This 50-acre parcel is in a fertile, irrigated valley within the dry ranching lands of Patagonia. By clearing abandoned fields of brush, laser-leveling the land, and renovating the irrigation ditches, researchers could then successfully establish plots of both silflower and Kernza perennial grain in December of 2022. With financial support from The Land Institute, Alejandra's team purchased a new tractor and a small seed planter, custom-built in Argentina for planting silflower, *Silphium integrifolium*. In February and March of 2023, five researchers from The Land Institute's Perennial Oilseed Program visited the farm, assisted with plot management, transformed the old farmhouse into a productive space for on-site and visiting researchers, helped with weed control, and harvested older test plots. This newly established research site will screen large breeding populations for plants showing key domestication traits such as larger, plumper seeds and high seed oil content, and serve as a hub for an expanding array of breeding, physiology, agronomy and agroecology studies in collaboration with farmers and other research organizations in several bioregions of Argentina.

Three varieties of silflower growing in the town of Trevelín in the Chubut Province of Argentina.
PHOTO: @PERENNE.PATAGONIA ON INSTAGRAM

The Land Institute's global network also made strides to advance Kernza perennial grain in the European Union, led by the Crop Stewardship Program. ISARA-Lyon, a French university emphasizing sustainable food systems and agroecology, currently works with 23 Kernza growers. ISARA researcher Christophe David created a French startup to process Kernza and further investigate food applications. The Land Institute, along with partners from Carlsberg Brewing Company and Manto Foods, has been pursuing Novel Food Status (similar to FDA Generally Regarded as Safe or GRAS food status in the US) for Kernza. The team also established the EU's first licensed Kernza seed producer, the University of Bern in Switzerland.



Mathieu Chevalier amid the roots of intermediate wheatgrass. French researchers are already studying how to grow, use, and market Kernza perennial grain. The pit shown here allowed researchers to study how intermediate wheatgrass roots change the structure of the soil and affect the flow of water and gases.



"With continued research and plant breeding, it will be possible to study and understand the environmental benefits of these new perennial crops."

ANNA WESTERBERGH
Associate Professor in Genetics and Plant Breeding at Swedish University of Agricultural Sciences

On top of this progress in western Europe, scientists to the north received a kickstart for new perennial cereal development. In May of 2023, research partners at the Swedish University of Agricultural Sciences (SLU) secured a grant of 23.1 million Danish Krone ($3.37 million USD) from the Innovation Fund of Denmark to accelerate perennial grain development in collaboration with the University of Copenhagen and Carlsberg Research Laboratory. This funding is specific to a type of perennial barley named *Hordeum bulbosum*, a perennial relative of the annual barley grown today, but accompanies the foundation laid by Kernza research in Sweden by collaborator Anna Westerbergh. This project will work to produce a high-yielding perennial barley that considers both economic and ecological sustainability through reduced fertilizer use and carbon capture.

Additionally, Lennart Olsson of Lund University in Sweden (and board member at The Land Institute) received a 6-year, 2.6 million € ($2.83 million USD) grant from the European Research Council for the project "Is there a perennial future of agriculture?," one of the most prestigious grants made by the council.

With international momentum, The Land Institute's work with perennial grains spread its roots from North America's Central Great Plains onto multiple continents across the globe. Through this work, The Land Institute continues to bring together a global network to build a movement that scales the research needed to develop perennial grain crops ecologically adapted, culturally valued, and economically viable at local and regional scales. •

Baki™ Bean on Track to Become the First Temperate Perennial Pulse Crop

Big strides were made to domesticate the perennial forage legume sainfoin as a new food crop, named perennial Baki™ bean. The multilateral effort by The Land Institute's Perennial Legume, Crop Stewardship, and Communications Programs, along with research and farmer partners in Montana, Washington, and the Colorado River Basin in the US and internationally in Turkey and Palestine, is helping this small-but-mighty bean ultimately become the world's first scalable perennial pulse for temperate regions, with benefits to both the food systems and the environment.

The name "Baki," which means "eternal" in Turkish, honors the grain crop's perennial nature, regrowing year after year without replanting. It also ties back to its Central Asian home range and the ongoing research collaboration with scientists in Turkey and Palestine. Similar to Kernza® perennial grain, The Land Institute trademarked the name for the grain harvested from improved sainfoin, *Onobrychis viciifolia*, which has been grown around the world including places like Wyoming and Montana as a perennial forage crop.

Supporting the food potential of Baki bean, researchers published a new scientific paper, "Nutritional quality of *Onobrychis viciifolia* (Scop.) seeds: A potentially novel perennial pulse crop for human use," in the journal *Legume Science*. The results showed that the pulse contains protein levels similar to soybean with fat content close to chickpeas. The paper was authored by The Land Institute's Evan Craine, with co-authors Brandon Schlautman, Spencer Barriball, Tessa Peters, and Turkish researcher Muhammet Şakiroğlu. The high protein content results prompted the Legume and Crop Stewardship Programs to consult with the University of Minnesota's Plant Protein Innovation Center, which is investigating Baki bean's potential use as an ingredient in plant-based protein applications, like plant milks and meat alternatives. Evan Craine developed a working strategy, communication rhythm, and worked with The Land Institute's Impact Team to allocate funding to the university to make this cutting-edge work possible.

The research team is also working to fully understand the food safety of Baki bean. After identifying the need to test for a specific toxic compound named l-canavanine, the Legume Program hired the University of Missouri to conduct chemical analyses to ensure that seeds contained no detectable levels of the compound. The Crop Stewardship Program is now working to register Baki™ as a Generally Recognized as Safe (GRAS) food with the US Food and Drug Administration (FDA).

Researchers are encouraged by the potential that Baki holds for sequestering carbon, limiting fertilizer use, reducing the amount of water used for grain and forage production, and providing the market with a competitive perennial plant-based protein source.

Baki bean has also shown potential for significant ecological co-benefits to healthy soil and water, efficient nutrient use, drought tolerance, and greenhouse gas capture. With its deep taproot, sainfoin, from which Baki bean is harvested, thrives in low-fertility, semi-arid landscapes where frequent irrigation may be needed. The drought-tolerant nature of sainfoin could be an important consideration in the arid western region of the US, where farmers will need to significantly reduce agricultural water use in the face of a historic prolonged drought.

Combined with the deep roots of sainfoin, the legume also captures nitrogen, a key plant nutrient, and potent greenhouse gas, from the air and returns it to the soil, potentially reducing the need for farmers to apply synthetic nitrogen fertilizers. Research in the Intermountain West region of the US is ongoing to determine the applicability of sainfoin, as well as Kernza and silflower, to reduce water and fertilizer use for farmers and ranchers along the Colorado River basin. ▪

Ecosphere Studies Program Transformed into the Perennial Cultures Lab

The Land Institute's Ecosphere Studies Program became the Perennial Cultures Lab, a program focused on researching how to develop more just and enduring human cultures integrated with and sustained by diverse, perennial grain agricultural systems. This translational research lab investigates how people relate, learn, and change with perennial grains and each other.

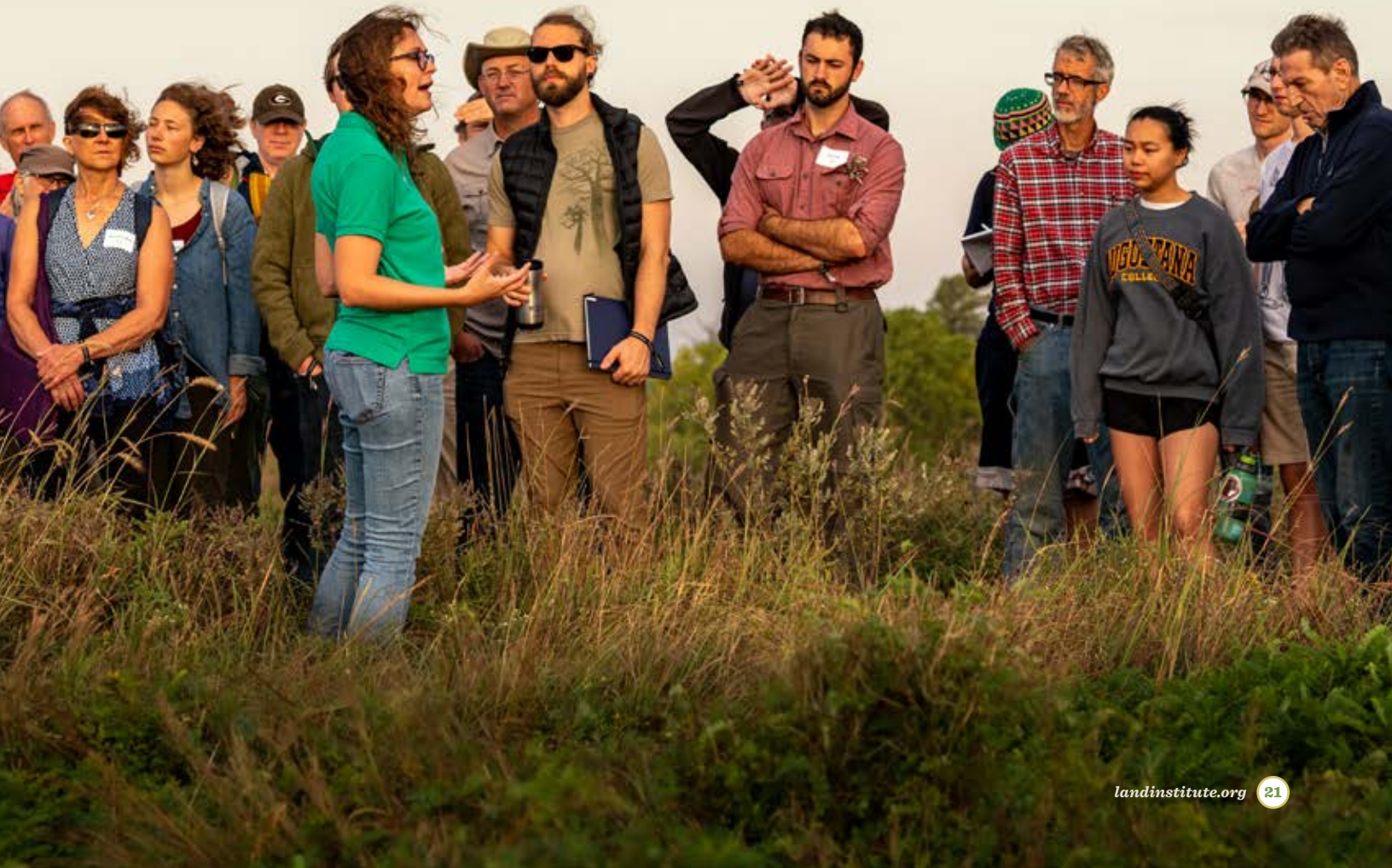
As an organization and research network, The Land Institute and our partners co-develop cultures and relationships in tandem with developing perennial grain agroecosystems. Culture isn't built "on top of" agriculture. Society continually makes culture as it creates systems. The Perennial Cultures Lab pursues cultural research to expand our awareness, inform The Land Institute's priorities, and help it increase the likelihood of realizing more just cultures of perennial grain agriculture.

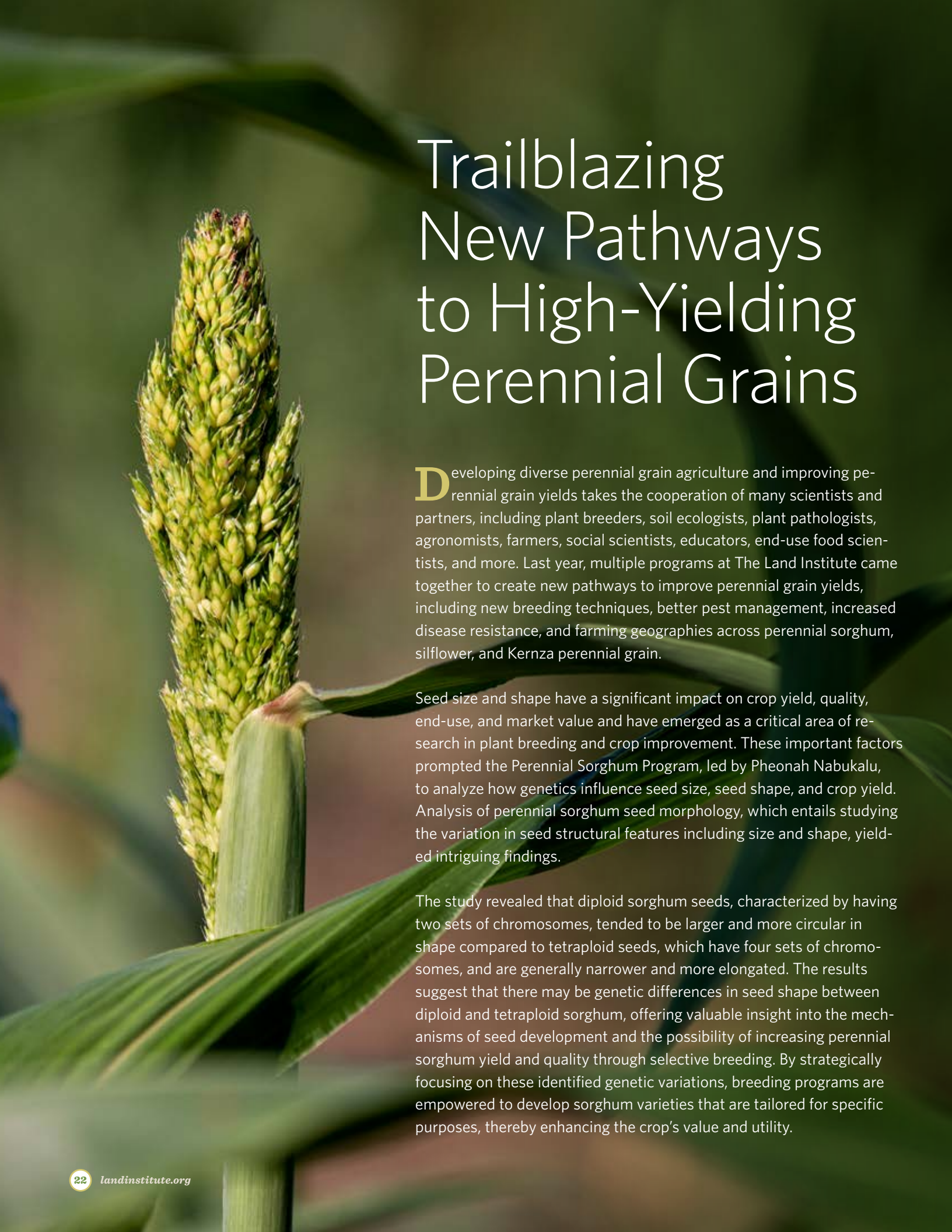
The Perennial Cultures Lab includes civic science, ethnobotany and ethics research, educational design and storytelling activities, and land relations. The new lab includes Aubrey Streit Krug, Reece Knapic, Lydia Nicholson, Anna Andersson, and new team member, Amy June Breesman. As the Land Relations Specialist, Amy June will put The Land Institute's commitment to openness and reciprocity across lines of cultural differences in the organization's home hub into action, and inform culturally-responsible approaches to partnerships across the broader research community.

A new Ecosphere Fellows Program will form to explore the more-than-agricultural context in which The Land Institute operates. Topics may include climate change, human migration, and planetary boundaries. Ecosphere Fellow Stan Cox and an internal cross-programmatic team are designing the program. ▪

"Human cultures are critical to consider because they can drive and mediate change across scales through social-ecological processes—including agriculture. Perennial cultures could be ways of life that adapt, evolve, and persist within the context of particular places and the ecosphere. Perennial cultures could be the patterns of meaning, norms, and behaviors that are shaped by sun-powered diverse, perennial ecosystems. Perennial cultures could catalyze and care for perennial grains."

AUBREY STREIT KRUG
Director of the Perennial Cultures Lab





Trailblazing New Pathways to High-Yielding Perennial Grains

Developing diverse perennial grain agriculture and improving perennial grain yields takes the cooperation of many scientists and partners, including plant breeders, soil ecologists, plant pathologists, agronomists, farmers, social scientists, educators, end-use food scientists, and more. Last year, multiple programs at The Land Institute came together to create new pathways to improve perennial grain yields, including new breeding techniques, better pest management, increased disease resistance, and farming geographies across perennial sorghum, silflower, and Kernza perennial grain.

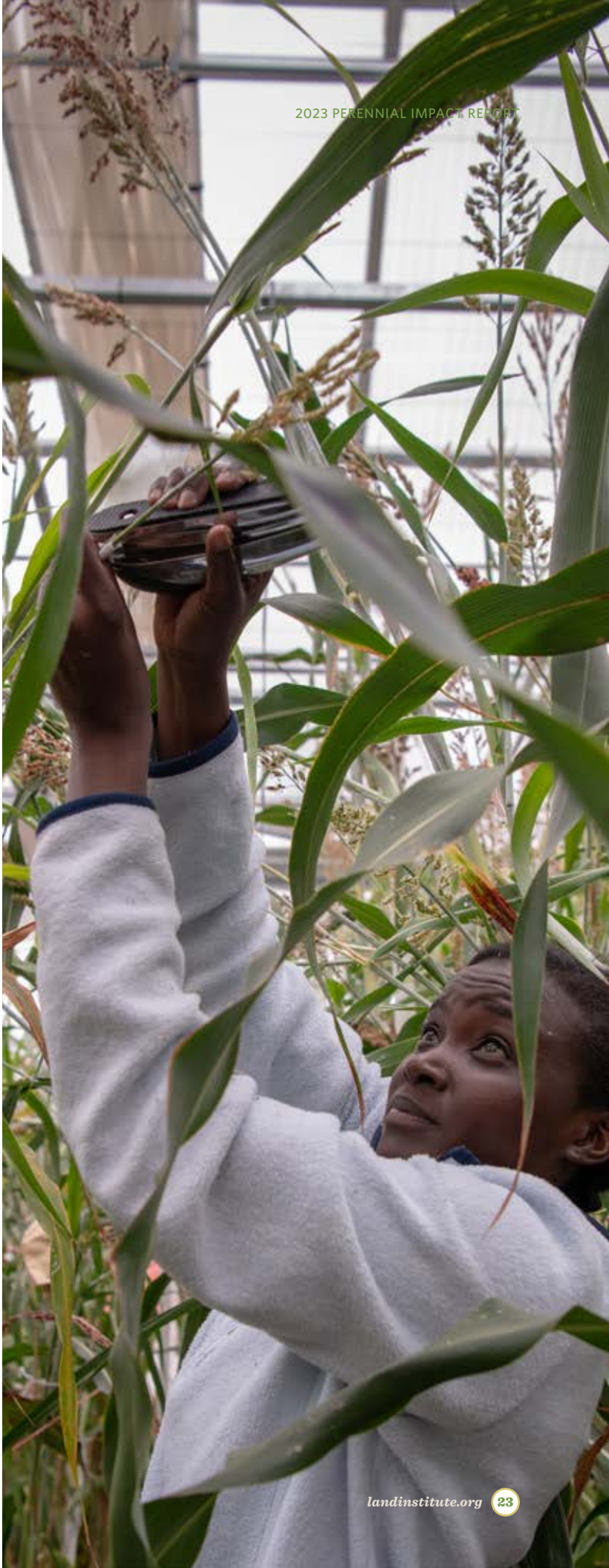
Seed size and shape have a significant impact on crop yield, quality, end-use, and market value and have emerged as a critical area of research in plant breeding and crop improvement. These important factors prompted the Perennial Sorghum Program, led by Pheonah Nabukalu, to analyze how genetics influence seed size, seed shape, and crop yield. Analysis of perennial sorghum seed morphology, which entails studying the variation in seed structural features including size and shape, yielded intriguing findings.

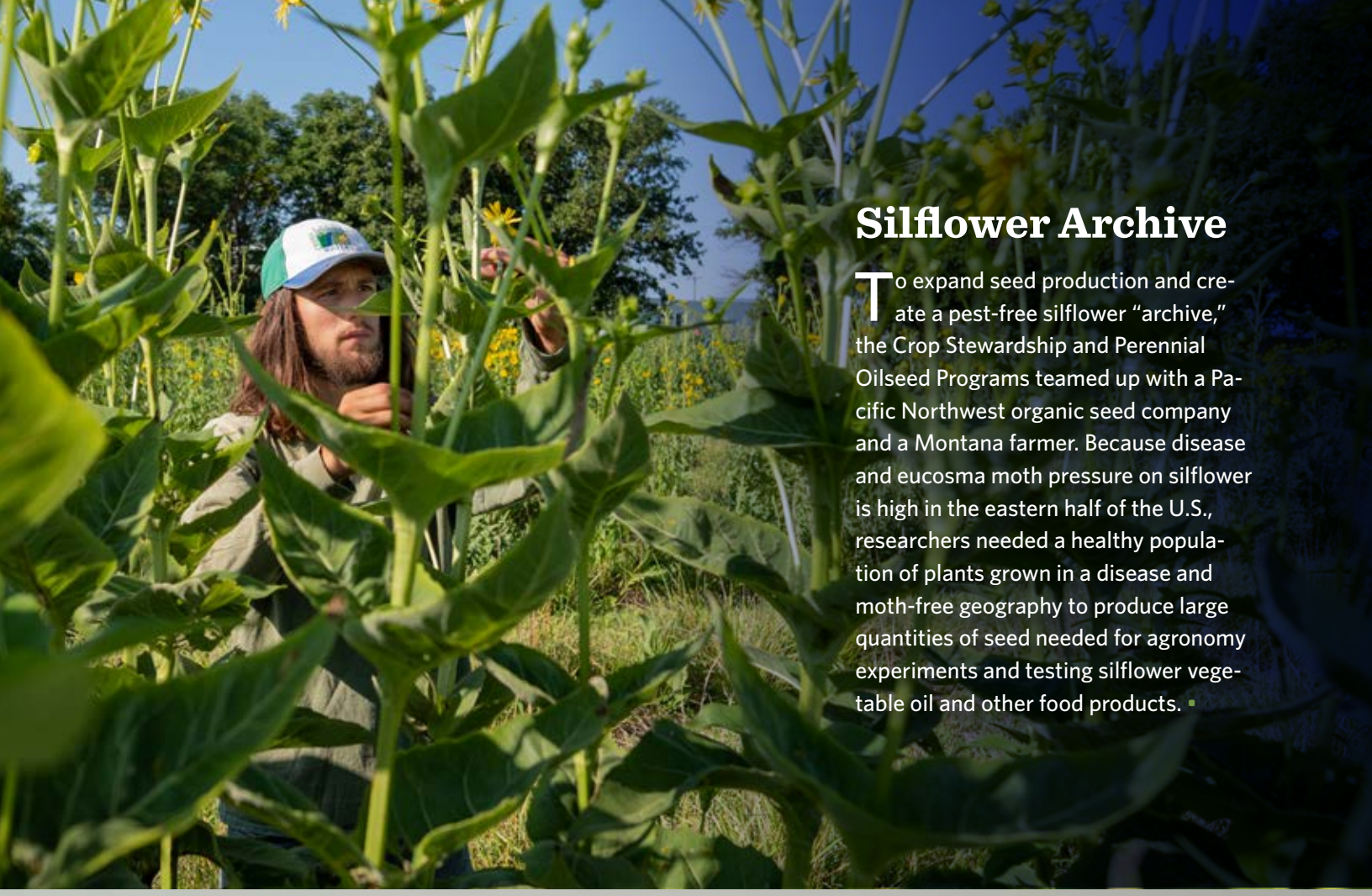
The study revealed that diploid sorghum seeds, characterized by having two sets of chromosomes, tended to be larger and more circular in shape compared to tetraploid seeds, which have four sets of chromosomes, and are generally narrower and more elongated. The results suggest that there may be genetic differences in seed shape between diploid and tetraploid sorghum, offering valuable insight into the mechanisms of seed development and the possibility of increasing perennial sorghum yield and quality through selective breeding. By strategically focusing on these identified genetic variations, breeding programs are empowered to develop sorghum varieties that are tailored for specific purposes, thereby enhancing the crop's value and utility.

Reducing pressure from pests that impact perennial grain crop growth is also fundamental for ensuring stable yields. In collaboration with researchers at Kansas State University, the Crop Protection Ecology Program ran several lab and field experiments to develop a greater understanding of the behavior of the prairie moth *Eucosma giganteana*, the major pest impacting the growth of the perennial oilseed candidate silflower, or *Silphium integrifolium*. This work will greatly expand knowledge of the eucosma moth and the damage it can do to silflower crops and help identify the best methods for organically managing it in the field.

Disease resistance also can substantially impact the yields of perennial grains. For the first time, researchers in the Crop Protection Genetics Program collected yield loss data for both silflower and Kernza. Yield loss data is a critical first step to improving disease resistance research and will help prioritize which diseases to investigate next. The data set may ultimately give farmers and economists a way to gauge where the disease threshold might result in economic crop losses and indicate where new farming management practices or shifts in crop varietals would be needed for farmers to remain profitable.

These pathways for improving crop yields will aid The Land Institute in developing perennial grains that can produce adequate food to feed communities and deliver proven ecological benefits such as improved soil health and water quality to eliminate the trade-off between food production and healthy ecosystems. ▪





Silflower Archive

To expand seed production and create a pest-free silflower "archive," the Crop Stewardship and Perennial Oilseed Programs teamed up with a Pacific Northwest organic seed company and a Montana farmer. Because disease and eucosma moth pressure on silflower is high in the eastern half of the U.S., researchers needed a healthy population of plants grown in a disease and moth-free geography to produce large quantities of seed needed for agronomy experiments and testing silflower vegetable oil and other food products. ▪

Plant breeders

look for plants with large seed heads filled with ample, big seeds to understand which lines might be high-yielding.

Agronomists

test and adapt modern farm equipment in diverse farming environments and geographies to effectively plant and harvest crops.

End-use scientists

research how to clean, dehull, process the grain, and extract vital nutrients and components like starch, protein, and fats.

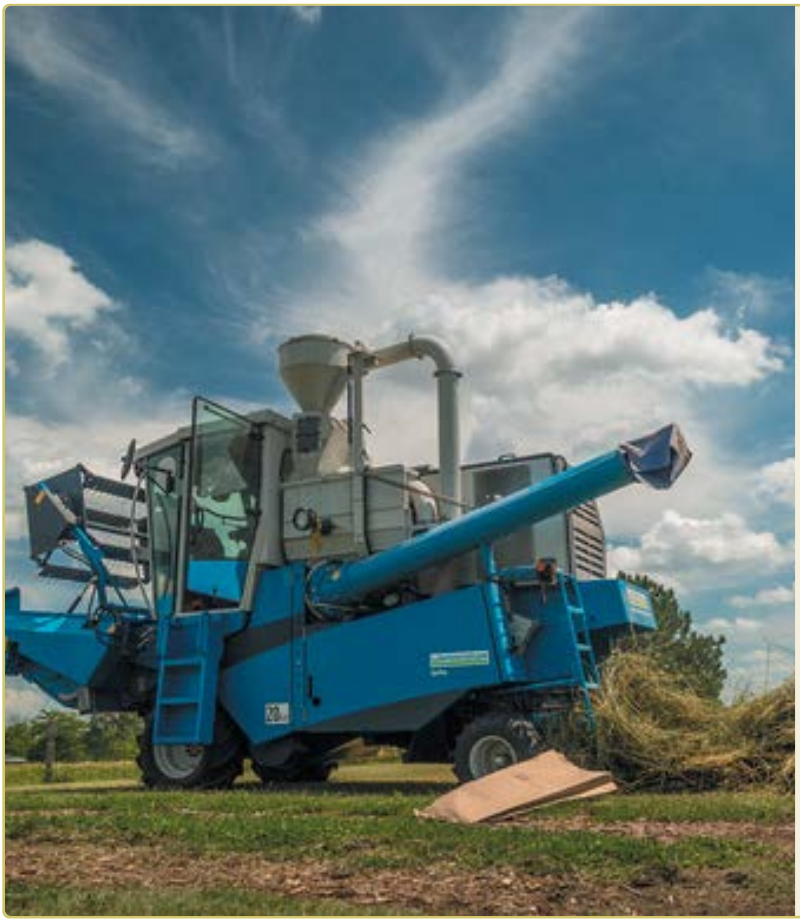
New Model Holds Potential for Accelerating Crop Development

Researchers at The Land Institute and Danforth Plant Science Center developed a project with significant time and cost-saving potential for perennial grain crop breeding efforts. Phenomic Breeding Technician Eric Cassetta helped facilitate a phenomic selection project to develop insights around disease resistance in silflower and breeding for agriculturally significant traits in the perennial grains silflower, sainfoin, and Kernza. This project sought to help researchers understand if certain features can be predicted in adult plants before they reach maturity.

For silflower (*Silphium integrifolium*), researchers analyzed disease resistance across four locations to see if the disease was predictable in advance based on environmental conditions. This was accomplished by tracking disease along all phases of the plant life cycle. Silflower blooms in the second year and researchers can only make informed breeding crosses in the third year. Phenomic selection allows researchers to plant thousands of seedlings, feed data into an algorithm, determine which individual

plants and plant families might have the most disease resistance, and then proceed breeding promising plants. This research also allows researchers to make selections at the seedling stage after weeks rather than having to wait multiple years to physically see the results in the field, unlocking the ability to make selections for plants where genomic data is limited, as is the case with silflower.

If proven effective, this model could be applied to any up-and-coming crop that doesn't possess much historic genomic data. The model could be instrumental when applied to perennials, such as nut crops that take up to 20 years to mature, creating space for researchers to make selections far before the crop's maturity. This research also applies directly to other perennial grains in development at The Land Institute, such as Kernza and sainfoin, which rely on genomic selection techniques for breeding and crop improvement. Results from the phenomic selection project could provide a 1:1 comparison of the cost-effectiveness of each method and help researchers determine the best path forward based on economic viability and scientific accuracy. ▪



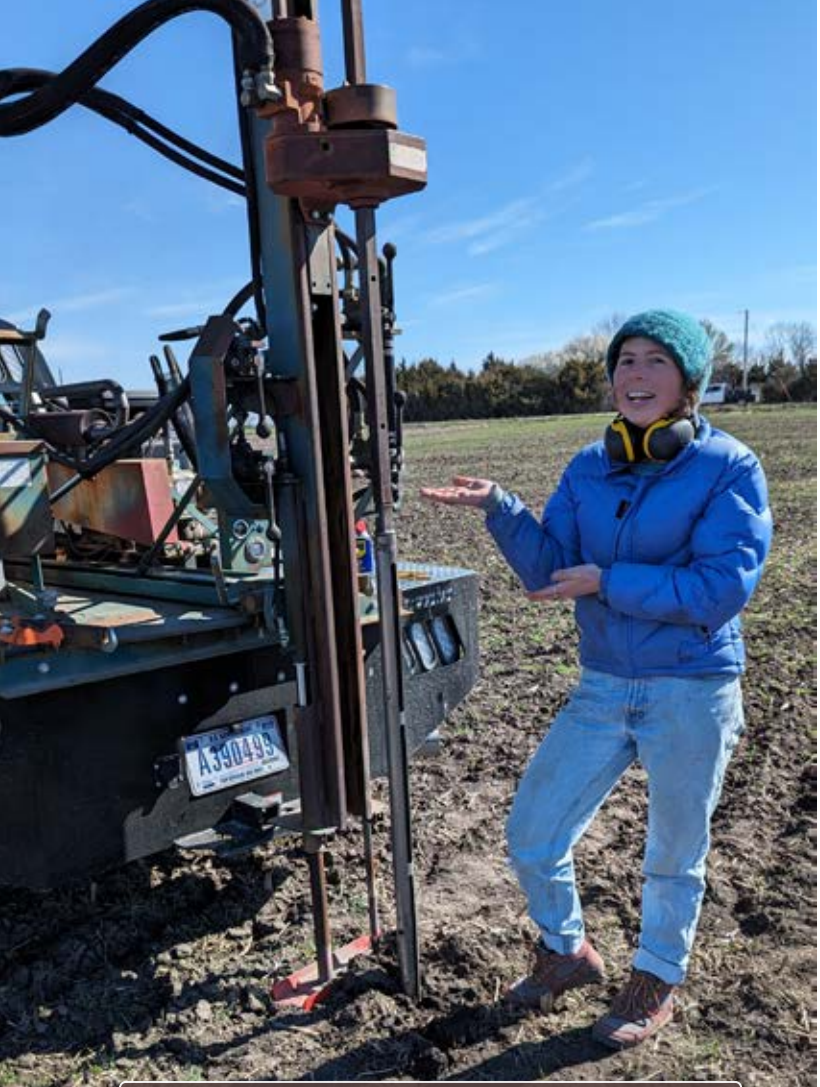
Perennial Wheat Update

New findings in perennial wheat genetics may help the crop live for more consecutive years on fields. The Perennial Wheat Program recently identified the exact chromosome locations controlling for perenniality and annuality in certain perennial wheat lines. With more research, the Perennial Wheat Program, led by Shuwen Wang, can determine if tweaking the annuality gene will allow the crop to regrow for multiple years, allowing the team to convert annual wheat to perennial wheat over time. Combined with field trials and civic science research efforts that witnessed the first perennial wheat varieties to survive for two years on fields, the team is hopeful that The Land Institute can achieve perennial wheat varieties that can persist for multiple years while producing ample grain. ▪

Building Capacity to Scale Impact

Leading a dynamic and adaptive movement that transitions to perennial grains while balancing resources requires adapting to new ways of planning for the future, taking calculated risks, and developing the organization's employees, programs, and processes. To support these efforts, The Land Institute evolved key departments to better leverage newly expanded expertise and capacity.

The Human Resources Program transitioned to the newly created People & Cultures Program, which reimagined the HR function as an engaged, proactive, cross-functional component of the employee experience. Led by Krista Robinson, SHRM-CP, Director of the People & Cultures Program, this function will build authentic relationships across the organization to foster a generative culture of learning, curiosity, whole science, and courage to advance staff success and well-being. Liberty Nichols, Operations Support Coordinator, Brenna Wilcox, Operations Project Coordinator, and Laura Froese, Senior Accounting Specialist, joined the team to expand the root system, undertake transformational projects, and enhance connectivity and staff engagement.



Soil Ecology Field Studies

Recent field studies explored how perennial grains could reduce the cost of farming inputs by minimizing fertilizer use. Soil Ecology Program researchers Madeline DuBois, Tomas Cassani, and Claire Wineman conducted extensive field work to determine if Kernza can receive its required nitrogen from alfalfa in an intercrop rotation, a configuration where these two crops are companion planted.

Like sainfoin, alfalfa is a legume that takes nitrogen from the atmosphere and reinvests it into the soil, a process which has the potential to significantly reduce or even eliminate the need to apply synthetic fertilizers. This team worked painstakingly to gather this data, collecting 2,000 pounds of soil core samples from six different locations across the country. ▪

The Crop Stewardship Program expanded its public policy, economic, agronomic, and food science research capabilities to support perennial grain agriculture implementation at the local, state, and federal levels. Kelsey Whiting joined The Land Institute as a Postdoctoral Researcher in Perennial Grain Policy and Government Affairs, the first official policy position at the organization. As a full-time researcher, Kelsey is dedicated to building a policy knowledge base and pursuing strategies to support perennial grain agriculture through legislative action, policy education, and advocacy. Economist Hana Fancher also joined the Crop Stewardship Program to collect and synthesize market data, resulting in the publication of the first-ever Kernza Demand Survey to aid with the Kernza commercialization process and engage with key stakeholders across the supply chain. In coordination with a collaborative Upper Colorado River Basin agricultural water use study, the team hired Hunter Doyle as the Intermountain West Agronomy Specialist to facilitate perennial grain field trials and expert advice. Evan Craine joined the Crop Stewardship Program as a Research Associate in End Use Science. His work to further our understanding of how sainfoin and Kernza can be used in different food applications allows The Land Institute to truly begin engaging with food companies and entrepreneurs interested in pursuing a perennial future.

Finally, the Soil Ecology Program also welcomed its new Lead Scientist, Laura van der Pol, following Tim Crews' transition to Director of the International Initiative. Laura brings a depth of soil ecology scientific knowledge and research experience, particularly with Kernza perennial grain, to the organization. Her collaborative and interdisciplinary approach will help expand The Land Institute's work in soil ecology to best support diverse perennial grain agriculture systems, like understanding how breeding has influenced root growth and turnover of perennial grains, legumes, and oilseeds and how these plants interact with soil and water. Laura's ability to communicate science to lay audiences will also assist in articulating the potential climate impacts of perennial grains.

The Land Institute's Salina, Kansas, headquarters has a critically important greenhouse system. The Greenhouse team underwent significant operational change, increasing its capacity to manage new research assistants, implement cutting-edge technologies, and maximize plant and human safety. Greenhouse Manager Tiffany Durr added Facilities Operations Manager to her role, and Glory Benacka advanced into the Greenhouse Supervisor position. Mercedes Santiago became a Greenhouse Specialist, lending her skills as a former Soil Ecology Technician to this growing team. The team also hired Todd Humiston, former Research Assistant, in the newly created Integrated Pest Management Specialist role to implement holistic and biological strategies to manage pests. The expanded roles, responsibilities, and expertise allowed the Greenhouse function to implement new and improved greenhouse best practices and support of these foundational facilities and the dedicated individuals who work within them.

This valuable expansion of The Land Institute's overall capacity and expertise positions the organization for growth to realize perennial grain agriculture for years to come. ▪

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Review all research publications at our website.

Research Presentations

SEPTEMBER 2022

Developing Pest Management Strategies for Novel Perennial Grains Cropping Systems presented by Ebony Murrell | Guest Lecture at Cornell University | VIRTUAL

Edible Plant & Wildflower Tour presented by Aubrey Streit Krug & David Van Tassel, Guided Tour | Marion County, KS

OCTOBER 2022

Rationing in the Polycrisis presented by Stan Cox, Web Presentation to Stanford's Millenium Alliance for Humanity and Biosphere | VIRTUAL

Perennial Grains as a Resource for Bee Communities presented by Ebony Murrell, Arizona State University Social Insect Research Group

NOVEMBER 2022

The Green New Deal and Beyond presented by Stan Cox

Intermediate Wheatgrass Chromosomal Regions Associated with Disease Resistance presented by Leah Treffer, Poster Presentation at the Tri Societies Annual Meeting | Baltimore, MD

Rapid Domestication of Perennial Grass for Food and Fodder presented by Lee DeHaan, The Ohio State University Department of Horticulture and Plant Science Fall Seminar Series

Umóⁿhoⁿ Ethnobotany presented by Kelly Kindscher, Vida Stabler, Pat Phillips, Aubrey Streit Krug, and Brye Lefler, Umóⁿhoⁿ Nation Public School | Macy, NE

Genomic Approaches for Rapid De Novo Domestication presented by Lee DeHaan, Kansas State University Center for Genomics

Sustainable Agriculture, Native Plants, and Perennial Grains presented by Aubrey Streit Krug, Northwest Arkansas Community College | Bentonville, AR

What Financial tools and incentives exist for land users to select conservation practices with multiple benefits: scaling climate and water smart cropping systems presented by Tessa Peters, Upper Mississippi River Basin Association (UMRBA) Workshop | St. Louis, MO

DECEMBER 2022

Biogeography of Intermediate Wheatgrass presented by Aubrey Streit Krug & Omar Tesdell, Keynote Presentation at the annual Kernza®CAP All-Hands Meeting

FEBRUARY 2023

Realizing Roots: Toward More Just, Diverse, and Perennial Grain Agroecosystems presented by Aubrey Streit Krug, Union College Environmental Science, Policy & Engineering Program Winter Seminar Series, Schenectady, New York

APRIL 2023

Learning the Roots of the Plants We Live By presented by Aubrey Streit Krug, University of Nebraska Center for Great Plains Studies Conference, Plant to Table: Food Production, Culture, and Consequences on the Great Plains

Research Awards and Honors

"Changes to architecture of Silphium integrifoliumMichx. during domestication reveal new trade-offs for yield," published in Crop Science, was selected as one of the **2023 Outstanding Papers — Honorable Mention in Crop Breeding and Genetics**

"Native Flowering Border Crops Attract High Pollinator Abundance and Diversity, Providing Growers the Opportunity to Enhance Pollination Services" was recognized and awarded with **The Entomological People's Choice Award in August 2023.**

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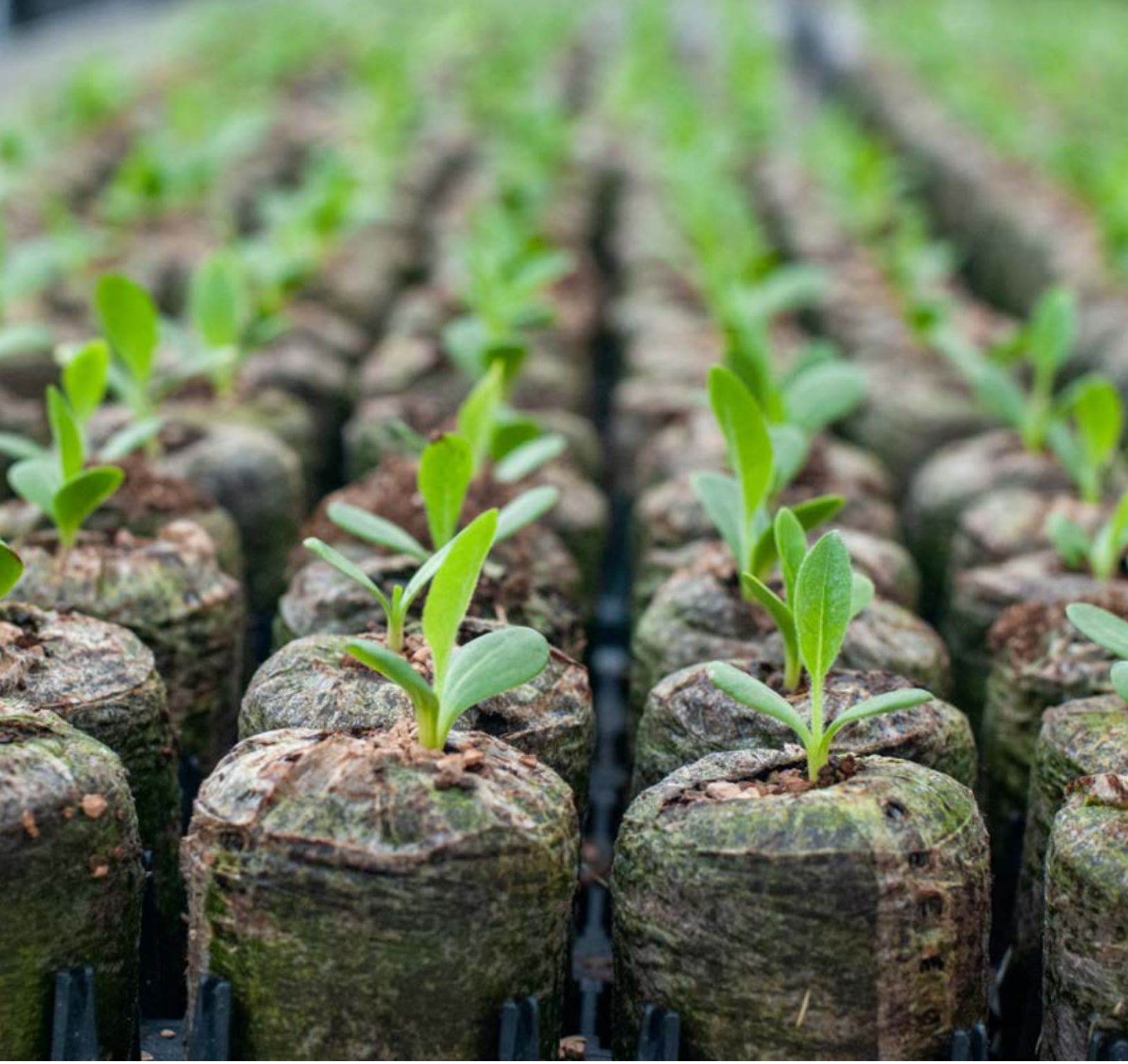

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