Land Report

Number 118, Summer 2017 · The Land Institute

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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

Perennial sorghum, from breeding annual grain sorghum with a wild relative. Land Institute researcher Stan Cox wants these hybrids to pollinate themselves rather than be fertilized by neighbors; bags over the heads are assurance. This year Cox found in his perennials a leap in seed size. See page 28. Scott Bontz photo.

"In English we think of life as an 'it,' an organism or object or noun. But the feeling and reality of life might more aptly live as a verb," said Aubrey Streit Krug, right, a Land Institute staff member working to advance ecosphere studies. The institute's June ecosphere meeting took up the ecology and philosophy of process – of how the universe is not so much about things as about relationships – and is creative. "Botanist and plant ecologist Robin Wall Kimmerer writes that 'water, land, and even a day,' when reflected in her people's Potawatomi language, mirror 'the animacy of the world, the life that pulses through all things'." Here Streit Krug planned with Kirk Cusick how to bring ecosphere studies to teachers.

Different than its parts

Seeing the universe less as material things, more as their creative rapport

SCOTT BONTZ

Wind at a table in Wes Jackson's barn scattered papers randomly across the dirt floor. Then it floated dirt outside to rejoin structure and life, as soil.

Also tousled in the barn were two dozen educators and scientists. For a third June they'd gathered to challenge the dominant view of Earth as mere resource, to be mined. They see the world as creative, stacking inventions over a time we find hard to fathom, and achieving complexity we cannot fully measure.

The wind's relation to the barn's walls and poles organized as eddies.

The barn wood came from trees formed by relation of genes, water, sun, and rock.

The rock-become-soil had long ago become cells, no longer mere pattern of crystal, but organized with a genetic history. The soil and cells live on even after the founding molecules move away.

All these processes make up the ecosphere, the global house. But it is arguably the amalgamation that creates the smaller processes; they can't exist alone. The people in the barn discussed teaching that process and our relation to everything else are crucial to how we can live. This year the conference-goers stopped trying to nail down a single formal curriculum, yet were surer about where to go and what to say, honing as they go.

"I am never fully prepared when I teach a new course. I learn the most after having taught it the first time," said Bill Vitek, a philosopher at Clarkson University in upstate New York. He helps Jackson organize the conferences, and said this in correspondence about making the new worldview stick, when people struggle to unlearn beliefs instilled since they were toddlers.

"We have to keep digging into this material to get clearer about it, but we won't ever be able to say we've got it just right," Vitek said. Those who started transformational changes – Jesus, Buddha, Copernicus, Darwin – didn't have things just right. "It took generations of followers and thinkers to build upon their ideas, no doubt getting it wrong along the way. … But somehow the ideas persisted. I think we have to be honest that we are just beginning, but that we believe the ideas behind ecosphere studies have serious fulcrum power to shift things."

In the offing are a workshop model and six to eight sessions based on it, including a three-day event next summer at Western State Colorado University, for teachers in that state. Future workshops could also be for students and activists, and for children and others not at universities.

Talk at the ecosphere meeting included how a system changes, and how it changes its participants. Another conference organizer, Aubrey Streit Krug, wants to keep this strategically in mind as the new schooling develops, and to keep the educators together for a clear ecosphere story. Streit Krug is The Land Institute's new postdoctoral fellow for ecosphere studies, fresh from earning a doctorate in American and indigenous literature and Great Plains studies from the University of Nebraska.

Jackson, former president of The Land Institute, pushed this general idea as core for ecosphere studies: fuse the sciences' verifiable reality with the humanities' subjective creativity. Because, he said, in a story lies transformative power.

Jackson and Vitek picked four books for the June 10-13 meeting at The Land Institute. They explore emergent properties and process, and offer theoretically and stylistically differing takes on how the universe and life are unfolding. Two of the authors came to talk it through with ecosphere studies planners. Here are reviews of the books, and thoughts from conference participants.

In "Journey of the Universe," Brian Thomas Swimme and Mary Evelyn Tucker tell us to imagine seeing for the first time Earth's beauty and the vastness of its cosmological setting. Then to ask ourselves, "Can we find a way to sink deeply into these immensities? And if we can, will this enable humans to participate in the flourishing of life?"

This 118-page story of nature's unfolding is in language of immensities and profundities. Above all the writers want to convey an inspiring story of creativity. Even subatomic particles clumping into hydrogen and helium shortly after the Big Bang some 14 billion years ago are creative – they could have remained homogeneous broth. Tucker and Swimme counter the Enlightenment vision of nature as machine. They do not even want to define the universe as a place. It is unfinished saga.

For more than 20 centuries we have had Homer's "Odyssey," the Hindu "Mahabharata," and the Bible's Garden of Eden story, which Jackson sees representing the dawn of agriculture, with its thorns, sweat, and pain. Literature, history, art, music, philosophy, and religion: humans' search for meaning has been dominated by the humanities.

Swimme and Tucker find new meaning in the story told by science. This story far predates myths, novels, and poetry, though much of it has been revealed only in recent decades. After realizing in the 18th century that the human mind and society were not static, but emerging, and in the 19th century that life forms themselves radically altered, in the 20th century, "We came to see that the stars too had changed dramatically, as had the galaxies, and, most astonishing of all, the entire observable universe had passed through a series of irreversible transformations."

Swimme, who teaches evolutionary cosmology at California Institute of Integral Studies, and Tucker, in both environmental studies and divinity at Yale, spent a decade making this book, a movie, and a "Journey" web site, and said they took great care for scientists to vet the texts. The aim isn't for science to triumph over traditional stories, but for a wedding, to help serve humans' unique need for meaning. They think science's grand addition to the story opens us to meaning until now scarcely touched.

But for all that, they avoid the technical in favor of passion; "Journey" is less treatise than hosanna. "This story has the power to awaken us more deeply to who we are … the universe in the form of a human," the writers say. "And every time we are drawn to look up into the night sky and reflect on the awesome beauty of the universe, we are actually the universe reflecting on itself. And this changes everything."

After telling how stars, galaxies, life (and death), and humans came about, Swimme and Tucker talk of rethinking matter and time, and of seeing humanity as the universe's groping soul. Devotion to commerce now clouds our search for depths. But looking in wonder at stars opens us to primal energy, and the unique human ability of empathy – for any being – can give us a "comprehensive passion in the midst of an ocean of intimacy," the direction for becoming more fully human. Revere creation, sink into its immensities, as the pinnacle – so far – of its self-awareness.

The last few pages of the book note our time as one of vast destruction, but also call it a moment of profound creativity. It's time to build livable cities and grow healthy food in ways congruent with Earth's patterns. "Our role is to provide the hands and hearts that will enable the universe's energies to come forth in a new order of well-being." Their story says no more as to how.

Harold J. Morowitz doesn't consider dire straits in "The Emergence of Everything: How the World Became Complex." But he calls this new, self-reflective force in the universe transcendent, with "the awesome power to choose good or evil." And he thinks that creation of optimal ethics and movement to the spiritual will come by way of science.

The Yale-educated biophysicist served as a witness against teaching creationism. Until the end of 200 pages he explores only science, occasionally mentioning but never fully disclosing his God. The book uses two dozen of the most significant steps in the evolution of the universe to illustrate the new sciences of complexity and emergence, and to recognize that the old reductionism, which since the Enlightenment has parsed the world only to parts, won't give full understanding.

Morowitz's prose is like one of the book's illustrative emergences, the mysterious fluctuations in matter's density after the Big Bang. His technical surges might cast off readers who aren't scientists. About cells he says, "Since most enzymes are protein

"Thomas Berry said that we live in a community of subjects, but our education teaches us to think that we are part of a collection of objects," said ecosphere conference speaker John Cobb, from Claremont School of Theology. "If we know one another and the living world around us as a world of feeling, we can become more and more sensitive to one another, feeling one another's feelings. Perhaps compassion will change the way we think and act."

catalysts made from linear polypeptides, template catalysis is an emergent property of such arrays of amino acids." But his chapters each run just a few to several pages, and his sentences can be both commanding and concise.

And to the sometimes murky task of defining emergence he lends a helpful view: "Because all of the living world is generated from the same basic organic chemistry, it is often necessary to develop long and complex chemical pathways before the necessary molecules and the right structure are available for some macroscopic task." The world is an epic of dependent, expanding sequences.

"I am going to take these ideas and share them with my students," said Kirk Cusick, right, who teaches at Kansas Wesleyan University. "Then I will say, 'Take these ideas and consult with the prairie on their validity. Support them or refute them, and tell me how the processes of the prairie inspired your answers." Also pictured are Land Institute President Fred Iutzi, center, and Kenneth Levy-Church, an institute board member.

One such expansion led to the advent of human thought, although this is "not something very special," Morowitz says, just part of the unfolding. But he thinks humans are special. "The value of thinking in terms of emergence is that it frees us from separate creation, but also notes the great chain of emergences that had to occur to arrive at entities that can look back and try to understand the emergences."

This concludes the chapter on the great apes. Earlier chapters include how second- and third-generation stars fused particles to make the heavier elements necessary for life; how the neuron's innovation of communication by electricity allowed bigger and more mobile animals; and how the coming of agriculture brought unprecedented control of habitat by one species.

Morowitz argues that if *Homo sapiens* could be experimentally started over with right climate, grasses, and herbivores, agriculture would emerge again and again. He posits that the emergences before and since – even cities, philosophy – followed from laws of chemistry and physics.

Plus from the "enormous organizing potential inherent in the Pauli principle." This says no two electrons in an atom can have the same four quantum numbers. He explains it little more, but it is key to his view of the universe. The principle is "a pruning rule," the name for something deep within nature that selects from all possibilities only behavior of a certain symmetry. It begins to show how the whole can be different than a sum of parts – emergence. It says nothing about what one electron does, but always applies when there are two or more, in relationship: "it is as if the second electron knew what state the first electron was is in." It shows elemental physics already at something curiously like thinking.

This power sorts out the periodic table, and chemistry and biology follow. Emergences like DNA are not the "frozen accidents" seen by some scientists, Morowitz says, but instead result from laws and principles that "reduce the universe of chance to zones of the probable." The unfolding of the universe is neither totally determined nor totally random.

Crucial details of how there emerged complex novelties like metabolism, animals that suckle their young, and global finance remain unexplained by formulae. But now we can sort through such with computers. When he published this book in 2002, Morowitz, who died last year, believed computation would help answer deep scientific questions.

With expanding knowledge of the natural world came the nagging question of what it all meant. Morowitz's closing chapters cover emergence of philosophy, the spirit – where he throws in equations for thermodynamics – religion, science, and the job ahead. And as a "card-carrying scientist," he admits heresy. He says natural laws are God's immanence, and with our evolution of consciousness, understanding of consequences, and free will, we emerge as "the transcendence of the immanent God." Making a better world is our job, along with deciding what we mean by a better world.

"We dare not turn away from the task," he says. "There are no limits. Computers and genetic engineering give us whole new pathways in our transcendence. Emergence is not through with us or our universe. We must celebrate our divinity and go on with the nitty-gritty of the world."

This sounds much like Stewart Brand in the old "Whole Earth Catalog": "We are as gods, we might as well get good at it." (With climate change, revised to "we have to get good at it.") It is a philosophy that

Wes Jackson criticizes as dangerously arrogant about human know-how. But he chose Morowitz's book for illustrating emergence, and for thoughtfully wondering how it happens. With a purely atomistic worldview, how could there appear anything more than stacks of atoms, Jackson asked. "How is it that you get variety?"

Though the universe for Morowitz is neither totally deterministic nor random, and he thinks humans have free will, as a biophysicist he seeks his answers in deep organizing rules of energy and matter. In "A Third Window," Robert E. Ulanowicz flips this view. He argues that the complex living world comes from more than addition and multiplication of parts. It is in large measure run by processes. These are different than material, but just as real. They aren't as strict as laws, but they organize. They do so in a way that he calls top-down. Not top-down dictated by something transcendent, he insists through most of his 178 pages, but less about physics and chemistry, and more about how, beginning by chance, relationships form and counter entropy, the inevitable run of thermodynamics to disorder.

To show how real are such "autocatalytic" processes, he considers how all cells in a human body except neurons are replaced within seven years. And how only a small fraction of the atoms making up those cells were there 18 months earlier. "Yet, if your mother were to see you for the first time in 10 years, she would recognize you immediately," Ulanowicz says. Also see that after a blow from outside, the process that is your body, or a tree, or a forest, can heal itself, while mending a damaged machine demands a mechanic.

The subtitle of his book is "Natural Life Beyond Newton and Darwin." The first window implied by the main title is Newton's clockwork universe made of unchanging atoms that can be built up and taken down again. All is explainable – even if we're not done yet – by laws and equations. Equations require symmetry. And in this sense the universe can be said to have no irreversible histories, no arrow of time.

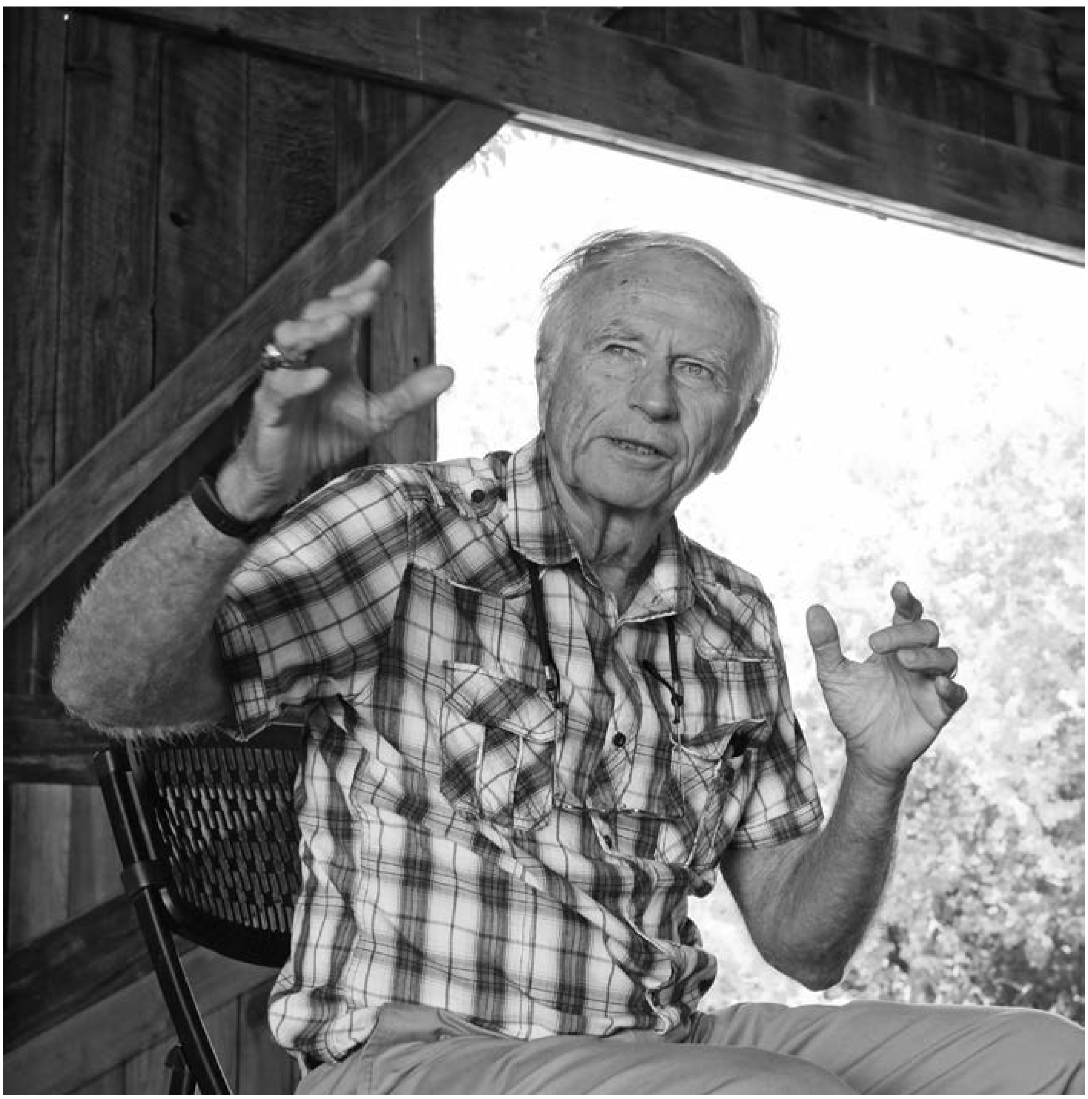
Ulanowicz, who attended The Land Institute conference, quotes Charles Darwin as aiming to become "the Newton of a blade of grass." But what the naturalist realized in his famous five-year voyage around the world aboard the Beagle was that life develops not out of immutable laws of physical order, but rather from processes that create order out of chaos.

Darwinism isn't a law, it's a theory – not for uncertainty about evolution happening, but for impossibility of a predictable end. Gregor Mendel's addition of genetics to evolution implied in this process the work of chance, and "raised the specter of irreversibility." What brought the bison and its prairie can never be seen again.

But scientists, even ecologists, who study complex relationships, still love Newtonian certainty, despite that worldview being in tatters, Ulanowicz says. They seize on the spectacular advance of molecular genetics to reinstate philosophical mechanism. They embrace computing's metaphor for mechanical action, the algorithm. "All of biology suddenly appeared to be scripted," Ulanowicz says, "at the expense of interest in the overall system."

He grants the benefits of scientific reductionism, of understanding and using parts. But as a college chemical engineering student who also discovered philosophy, he felt out of place in a parts-only universe. As a self-educated ecologist he found a third window broader than Newtonian material causes and Darwinian species history. He saw how various species formed mutually beneficial feedback loops to build things such as coral reef from what had been marine desert.

Autocatalysis can start with relationships initially random. Ulanowicz does not mean by random that physics or chemistry can't yet explain the event, but someday might. They are truly chance. For an example he offers an exploration called, after a mathematician, Polya's urn. In the urn are one red ball and one blue ball. You make a blind draw. If the ball extracted is red, you return it to the urn with another



"My vision of the living world is definitely not one of dead objects moving according to universal laws," said ecologist Robert Ulanowicz. "Rather, I discern process activities that relate to one another within groups of mutually beneficial harmonies."

red ball. Shake the urn and repeat the process of draw and add. In the book's graphed results, the color in early draws is erratic, and in later draws the red/blue ratio settles down. But if you start over, where it settles after 1,000 draws can range from near 50/50 to as high as 97 percent one color.

So Ulanowicz sees these principles about processes: that they are subject to random effects; that what happened before affects what happens next; and that through this history change becomes constrained – what began randomly can become regular. From chaos comes order. (But when regularity becomes constraining, when it approaches a law, the system becomes brittle to pokes. A healthy portion of randomness keeps the process resilient.)

Process reactions cannot always be predicted with certainty. Here is emergence. This is mysterious only in a Newtonian, Enlightenment world, Ulanowicz said at the conference. "In process thinking it's bread and butter."

"*Life itself is an emergent property of the ecosphere, a vast system encompassing minerals, soils, societies, flora, fauna, atmosphere, sunlight, and stardust,*" *said John Hausdoerffer, from Western State Colorado University.* "*Since we emerged from this living system, it is always and already our home. We are compelled to live humbly as members of this home, for the sake of all human and more-than-human members.*"

He says that at work in evolution of the universe is a dualism not of mind and body, but hierarchical, with explanations at the microscale primarily bottom-up physics, and at higher levels like the ecosystem more top-down, "transaction between feedback and complex chance." Near the fold between the camps comes ambiguity. Just on the physical side are complex phenomena such as tornadoes, which develop much like living systems but cannot record their histories. Just on the other side are structures like viruses, with the history of genetic information but with no metabolism.

Though he might not assume quite as much as Morowitz does about his readers' science knowledge, Ulanowicz's writing is often wordy, with bits like "the search for efficient agency among the enzymatic/proteomic system of reactions that interface with and interpret the genomes." But he is enthusiastic and thorough in opening a worldview radically different from clockwork, and one that is subversively encouraging.

One of Ulanowicz's inspirations was systems theorist and polymath Gregory Bateson. He says Bateson eschewed the transcendental, but despaired of how the modern mindset denies of nature the sacred. To flip the Newtonian outlook for one of evolving, creative processes, Ulanowicz works vigorously to maintain intellectual coherence and to avoid going transcendental. Still, in the last chapter he talks of God, calls himself a theist, and though a scientist, "not above asking 'Why?'" Process ecology has loads of "wiggle room," he says, and gaps are part of the formal structure of science, including, from quantum physics, the Heisenberg uncertainty principle and the Pauli exclusion principle. "[S]uch necessary gaps make it impossible to preclude immanent divine action."

Ulanowicz hopes that process ecology can bring together theologians and scientists. (This tack is common for his book's publisher, Templeton Press.) For scientists to admit that life is more than the action of dead molecules would be like shedding "rose-colored spectacles of mechanism," he says, to see anew the world's dazzling color. "Confronting agency more fundamental than matter itself should exhilarate and inspire us to rework and renew our entire social, artistic, political, and economic ethos in the light that it is living creatures and not molecules that transform the immediate world."

The language of C. Robert Mesle throws out that the universe is made of things at all, if a thing is something that never changes. Everything changes. And the future doesn't exist. That snapped into place for Mesle while walking along a gray, choppy Lake Michigan. He was a graduate student struggling to understand process. What if the world was not in process? Could the lake somehow wait for its waves to break? No: always it was in process of becoming. On feet that only existed in the moment, he says, "I practically skipped home, watching the sidewalk and my feet (and my watching self) become."

Mesle is a philosopher, and the philosophy he struggled with that day was Alfred North Whitehead's 1929 book "Process and Reality." Whitehead didn't think current words, or at least their current meanings, could sufficiently express his way of thinking about the world, so he stretched and invented language. Mesle aims to help with "Process-Relational Philosophy: An Introduction to Alfred North Whitehead," another book from Templeton. Not counting the 18-page "Getting Technical" appendix about Whiteheadian language, it is half the length of Ulanowicz's book and, like

Swimme and Tucker's work, geared better for the lay reader.

Like Ulanowicz, Mesle, who also attended The Land Institute conference, wants to tear away the West's clinging old sense of the universe of materially, statically being, rather than always novelly becoming. And both hope that if we understand and respect that flow, we can better play our part in it.

This applies to how ecosphere studies should be taught. John Cobb, a process philosopher at Claremont School of Theology, talked at the conference of teaching as an "event," an event of relationships.

Scientist Ulanowicz's main target is the Newtonian clockwork. Philosopher Mesle tackles the Christian/Cartesian view of the human mind and soul as something outside the natural world, and, behind that, Plato's argument of reality lying beyond our full view, perfect and unchanging. Mesle shows no doubt of a world right there for us to perceive, even if he rejects wishing like Plato and Rene Descartes for mathematical certainty in understanding it.

Whitehead emphasized emotion. For Mesle this is "the great ocean on which the thin layer of rationality precariously floats." And the source of all this feeling? He suggests our human style of consciousness is unique in degree, not kind, and "goes all the way down."

Imagine how a single-celled amoeba seeks food and flees danger. Isn't it having experience, albeit at a simpler level? How else can its actions be explained? "If we acknowledge that feeling is not supernatural reality injected uniquely into human beings, then doesn't it make sense to see it as permeating the world in varying degrees?" Mesle says. (He thinks it now hard to believe, as Descartes did, that dogs and dolphins don't feel pain.)

Then he suggests imagining down even further, to subatomic particles. Morowitz wrote of how electrons somehow relate to one another. Physics – after "tremendously speculative flights of imagination" – in the 20th century established this field of causal relationships. Mesle suggests considering that an electron could be a "drop of feeling," not conscious, but aware of other bundles of energy and experience in the world around it. Out of compilation and organization might come higher levels of experience, much like atoms have come to build bodies. "Consciousness is only a tiny, but brilliant, flicker in the sea of experience that constitutes this world," Mesle says.

This picture frees us of Cartesian mind/body dualism, to finally see ourselves as "100 percent natural instances of the larger world around us." What can be called mind, soul, or psyche is the flow of the body's experience, channeled in higher animals through the body's central command, the brain. In this sense Whitehead saw plants as cellular democracies, and animals more like monarchies. Rocks aren't organized to channel experience beyond that of the molecules that form them. (For change, Wes Jackson has said, "You've got to organize!")

But then Mesle allows for a different kind of duality in our minds. Fellow process philosopher David Ray Griffin, like Ulanowicz with his scientific descriptions, calls this duality hierarchical. We have experience beyond that of our bodies: it is our thoughts, about things such as love, death, and philosophy. "There are not two kinds of substances – minds and bodies," Mesle says. "There is one kind of reality – experience. But experience has both its physical and mental aspects." Pages later he allows that you are not just what you've experienced, but that personality comes in part by inheritance.

Order or novelty alone could not make the world. In balance together they make Whitehead's universe of relational processes. "The ordinary objects that we live among, which we see, feel, and touch, as well as our minds, are simply more or less stable 'societies' of such relationships and events," Mesle says.

He devotes two chapters to real societies' distribution of power, arguing against unilateral – coercive – power, and for relational – persuasive – power as the enriching course.

Then he talks about Whitehead and God. He thinks here Whitehead might've drifted too far from his touted empiricism. But Mesle presents the case. Whitehead was an atheist who finally came to think the universe couldn't function without what he could only call God. This God is not supernatural. But in addition to the world, with its past, there must be a source of novelty. All possibilities lie in the "primordial nature of God." God and the world jointly provide each new drop of experience with possibilities for becoming. God is perfect relational power, knowing what it's like to be everything. But God is not omnipotent, coerces no creature, and is not certain of what choices we will make – the future doesn't exist. All possibilities do, however, with God's call toward the better.

Whitehead saw the essence of dramatic tragedy lying not in unhappiness, "but in the remorseless inevitable working of things." The unhappiness would be our experience, Jackson wrote to conference-goers. He sees our agriculture, population growth, and machines at the historic point of tragically degenerating processes of soil, sea, and air, and so of the ecosphere. We won't end Earth's creativity any more than did the asteroid that smashed the Yucatan 66 million years ago. But we can badly damage what has made for wondrous lives and living. We could even bring our own extinction. Of that the ecosphere might not care, but Jackson said, "This part of the sidereal universe will have lost the only species that has become matter and energy's way of having gained self-recognition, the only species to know of its journey since the Big Bang."

Jackson and others would not have organized the conference if they did not think something could be done for the better. He thinks that first the human endeavor needs to work with more humility. "We also need better knowledge and better solutions than at any past time if we are to act on what we already know and what we hope to discover." The biggest challenge for checking the current human juggernaut, he suggests, is building constituencies to change public policy.

This entails changing our thinking context. Jackson gave for an example how President Obama described renewing relations with Cuba. It was not to take the United States "out of the equation," but "to remove it as an excuse for Cuba feeling trapped in its past." Especially those of us in industrial societies are trapped in our past, Jackson said. "We have to learn to redefine our problems."

For an example of that he gives The Land Institute. Beginning in the late 1970s, the institute shifted from thinking of the problems of agriculture on its own, 10,000-year-old terms, and changed the reference point to nature's prairie ecosystem, a process less constricted and brittle, more resilient, self-repairing, self-sustaining.

Farming – and other human endeavors – might never fully match this. But perhaps the groundwork is laid for radical, even emergent, becoming.

Tim Crews, The Land Institute's research director and lead ecologist, here with agriculture students, examined with environmental historian Brian Rumsey studies of how to increase carbon and organic matter in farm fields, and so improve soil health and lessen climate change. Tactics include the popular no-till, which relies on herbicides, and potent but so-far impractical biochar. Sorting through the methods showed two requirements for full success: that plants put much of their growth belowground, in roots, and that the roots be left undisturbed. What delivers both are perennials. The Land Institute is developing perennial grain crops. Scott Bontz photo.

Carbon in soil: why and how

Crops left to grow for years will be best at restoring healthful organic matter

Soil health hangs on what scientists call soil organic matter. Without fossil fuels to make fertilizer, so will the health of food plants and people. The variety of organic matter molecules is great. What they have in common is that an organism joined their atoms, and that the atoms include carbon. The molecules come from air, water, worn rock, plants, animals, and, in one underground acre, microbes that can equal the mass of two cows.

Organic matter is more than just molecules, it is process, constant depletion and replenishment, of a melange that is constantly shifting. All of those components in relation make for the soil's health, which also means the vegetation's productive wealth.

A wealthy Western economy could not rebuild from depression and blasted infrastructure every year. But every year the grain farmer must work with a ravished soil economy. Planting and cultivating annual grains undercuts how soil carries nutrients and water, how it holds together, how this greatest of underground economies works, and how much leaf, fruit, and seed it can give to us. The wealth came from soil undisturbed, and covered mostly by thickly rooting perennial plants. It built over years, decades, or centuries. The farmer of annuals can never get that back.

Farmers once worked to keep soil organic matter under annual crops by laying manure and letting fields lie fallow. Hauling dry stalks from land to barn, and excreta-charged bedding back, ended for many farmers with the advent of synthetic fertilizer. Fossil-fueled nitrogen beat replenishment by plants that run only on sunlight of the present day. With manufactured ammonia and help from plant breeders and irrigation – more fossil fuel – grain yields rose dramatically. But for soil the subsidy brought neglect. And so most work toward farmland health makes organic matter the grail.

Now the aim is doubly important: bring back to earth the prime component of soil organic matter, carbon, by disassembling the number one greenhouse gas, carbon dioxide. Soil can hold only so much carbon, and only a fraction of the carbon emissions expected before humans stop burning coal, oil, and gas. So allaying climate change demands more than putting carbon in soil. But to do so is key, not just to lessen climate change, but also to buffer agriculture against that and farming's other, endless vagaries. This will be especially important in countries without good soil or money for fertilizer.

Using purchased fertilizer and pesticides to farm can be called "input intensification." An alternative proposal is ecological intensification. This means learning from natural ecosystems to run farms – agroecosystems – with more sophistication and resourcefulness. As tighter ships. One example is planting diversely, erecting hurdles to pests that favor particular species.

Advocates of ecological intensification have called soil organic matter the key. It strengthens microbial underpinning for

John Holmquist with seedlings of silphium, an oilseed crop candidate whose taproot draws deep water and allows the plant to weather drought. The roots also reach minerals and help build soil organic matter. Scott Bontz photo.

plants, feeds them more nutrients, holds and delivers to them more water, and suppresses their diseases. But changes on the farm even in our modern, seemingly well-informed time have not restored the soil quality we had before the plow.

Soil organic matter begins with photosynthesis. Plants take carbon dioxide from the air to build tissue. Eventually tissue decays. So do mutualist fungi at the plants' roots. Worms and microbes eat the remains, and this breaks down into a larger web of microbes. There finally accumulates something called necromass, once living microbial tissue that stably binds to soil particles and resists further decay. It looks darkly rich, and much of it is carbon.

While the bacteria, nematodes, and other soil dwellers eat, they respire back to the atmosphere carbon dioxide and other carbon compounds. In an established natural economy such as prairie, this primary element of life cycles in balance between earth and sky.

The first few feet of the planet's soil hold almost three times the carbon in the atmosphere. Farming has cut soil's share dramatically, and burning fossil fuel makes the atmosphere even more of a greenhouse.

How the many organic matter compounds mix with microbes varies, and this was long thought to govern how much soil organic matter formed in a place. Now scientists think that just as important might be climate. Deserts and tundra are in the same league of plant growth, but tundra soil runs almost four times richer than desert soil, because warmth favors microbes, decay, and carbon loss.

Whether replacing tropical savanna or temperate grassland, annual grain cropping leaks soil organic matter. The loss can reach 70 percent. Even growth aboveground often declines with annuals, though the plants' investment in seed goes up – to justify the work of farming. And even if growth aboveground doesn't fall, growth belowground does, by as much as two-thirds.

Most soil scientists now think the biggest builder of soil organic matter is root secretions and root decay. Fallen stems and leaves are what we surface dwellers see, but they are bit players. Microbes, sun, and oxygen take their carbon back to the air. Perennials, which dominate most natural landscapes, tend toward longer and thicker root webs than annuals, and constantly slough root tissue while building anew. Nature's other standard, so contrary to how grains are grown, is species mixing in diverse neighborhoods. Differing roots fill niches to make soil tighter and richer.

Annual crops also lose soil organic matter because tillage with plow or disc disintegrates the stable bonds between carbon molecules and minerals, especially clay particulates. Microbes feast on the freed carbon and respire carbon dioxide. Released to plants are nutrients such as nitrogen and phosphorus. Early crops cut into the American prairie enjoyed fertile ground, and helped make the nation rich. But molecules unbound, with a diverse, conservative plant community busted up for a monolithic, acquisitive one, meant molecules lost, and crop yields fell. The loss of organic matter can continue for decades before flattening as a shadow of former wealth. Today's high yields – and the lives of much of humanity – depend on fertilizer made with trainloads of fossil fuel.

Changing how we use land could take carbon back from the atmosphere and restore soil organic matter to 90 percent of the pre-agriculture bank, according to one calculation. Another reckoning is that farming's long degradation of soil, especially by erosion – material is not just worse, it's gone – might limit the reclamation to half.

One seemingly obvious way to see soil gain carbon is to stop the microbe frenzies that follow plow and disc. No-till farming began, with the advent of herbicides, as a way to cut labor costs and erosion. Then it gained credit for also raising soil organic matter. But the gain tends to be near the surface. An average of studies showed no accrual deeper than about a foot. This might be because annual roots cannot penetrate as well a soil that is no longer turned upside-down by the plow to air out and warm in the sun.

What about coaxing more carbon from the crop plants? Leaves, stalks, and stems left after grain harvest have been burned to fight pests and disease, or hauled away for fodder or livestock bedding. Now they may go to make biofuel. Leaving them in the field might help soil carbon. But study shows that gains are often insignificant: decomposition aboveground mostly sends carbon straight back to atmosphere.

More soil carbon accrues if, in a place with enough soil moisture, grain harvest is quickly followed by planting for green manure, or to grow a second crop. This supplement makes a scene more like perennials. But it still starts from scratch twice a year, and the annual crops used still allocate less carbon belowground than do perennials. And even under no-till the soil suffers a little trench for every row of seed.

Could annual grains be bred to build soil carbon by growing deeper roots? Until now breeders have aimed instead for more grain and easier harvest, and most annual roots are no longer than about 3 feet. Perennial grasses can push 10 feet. Some annuals might be bred to reach 6 feet, and tap more water and nutrients. But if their genes keep total aboveground growth constant, larger root mass could exact a tradeoff in grain yield. This kind of breeding has just begun, with little yet to report.

Farmers long nursed field fertility by hauling in compost and manure. Compost can enrich soil organic matter directly, and often indirectly by boosting plant growth. But after such subsidy ends, microbe respiration likely will vent more carbon than plants add, until the field reverts to the steady state before compost.

Importing organic matter to one system means taking it from another, which doesn't help in the global scheme of returning carbon to soil. The exception is when putting waste to use in the field keeps it from cooking up the potent greenhouse gases methane and nitrous oxide in a landfill or slurry pond.

There is also potential exception to the rule of soil organic matter being limited by

Sarah Hamilton, left, and Sheila Cox transplant from greenhouse to field some of the perennial legumes being screened for development as a seed crop like beans, and as a complement to perennial grain crops. Legumes and bacteria at their roots make atmospheric nitrogen useable by plants, which makes for more growth, which means plants adding more carbon to soil. Scott Bontz photo.

Lee DeHaan works outside his office on a GPS system that can lead him to individual plants, each with a pedigree of breeding, in an array of thousands. Here the lawn is mowed and the trees trimmed, but relative to a field of annual grain, the place is much nearer an ecosystem found in nature: more than one species thrives, and perennials dominate. Perennials' thick, deep roots in undisturbed soil make it rich and productive. Scott Bontz photo.

relationship of plants and microbes in a particular place's raw soil material and climate. Partly burning organic matter with little fueling by oxygen makes biochar, a carbon compound resistant to decay. Biochar can raise a soil's carbon as well as improve its tilth and nutrient keeping – though the nutrients in biochar itself are low. Theoretically almost all cropland could be treated with biochar. But its faces challenges in energy, harvest, manufacture, and distribution.

The agriculture that builds soil organic matter to nearest the standard of displaced grassland or forest likely will be the one that most resembles their workings. Nature is dominated by perennials and diversity. Grain farming has been about annuals in monocultures. In these two ways – how a plant grows and what it grows among – the two worlds differ dramatically. Perennials themselves put more carbon underground, doing so even better in species mixtures, and lack of soil disturbance keeps the carbon there. When agriculture based on soil mayhem yields to a more peaceful, perennial order, fields should bank more nutrients and water, see more good from microbial dark matter, and naturally check weeds, in addition to welcoming home wayward carbon.

Agriculture's pioneers put us on the odd path of annuals because of what they knew about biology and what they had in tools and energy 5,000 to 10,000 years ago. Over the past century all of that has greatly changed. Land Institute researchers, and increasingly colleagues around the world, think we are ready to breed and develop ways of farming perennial cereal, legume, fiber, and oilseed crops – to see perennials produce well enough that they can often replace annuals.

Perennial grains now are only protocrops, their building of soil organic matter not yet fully measured. Two other perennial systems have been better studied and hint at the potential. Converting ground from annual crops to diverse, perennial grasslands for grazing or conservation adds each year about 300 to 900 pounds of carbon per acre. High-yielding, low diversity perennial grasses grown for bioenergy add about twice as much. The latter generally enjoy better climate, breeding for productivity, and more nitrogen fertilizer, which boosts not just yields, but also soil microbes and necromass. With the same benefits, no-till farming of annuals at its best adds organic matter – at least in the soil shallows – at a rate near the low end of grasslands.

The variety of depths sampled in the many studies considered here is one reason why such figures range so much. There are many more differences: in climate, in what rock begat the soil, and in research method including even what was counted as organic matter: Only necromass? Including microbes? Roots? We shouldn't take the numbers too concretely, but consider what they point to.

We can't know yet how deeply the new perennial grains will sink carbon, how long they will do so before reaching a balanced carbon cycle between atmosphere and earth, and how near they will get to that historical high of native carbon stock value. What we can say is that the two standout criteria for achieving rich soil organic matter are high root growth and low soil disturbance. And that no proposal including annual grain crops delivers both.

Rough carbon calculations can be made for future perennial grains. They used United Nations' Food and Agriculture Organization data for land area devoted to grain crops, and for soil organic matter measured to about a foot deep, along with estimates of what carbon has been lost.

Considering all this, then over 30 to 90 years we can hope to add to soil 14 to 59 billion tons of carbon. The best end of this is at the low end of what others have estimated cropland offers as a carbon sink to check climate change. So our figures could be considered conservative. Others might not reckon how tillage has cost soils not just carbon, but other ingredients to combine with it and build.

Billions of tons are hard to envision. A second calculation offers something more easily grasped: perennial grain crops building soil organic matter in the range already found with restored grassland and biofuel crops. This while feeding people, not animals or machines, and feeding soil far better than do annual crops.

This story has mostly been about comparing annuals and perennials. Also to consider is how a crop of just one species – including, and maybe even especially, a perennial species – eventually produces less, because living shoulder-to-shoulder with one's own makes an easy march for germs, rusts, and pests. Pairing two or more quite different plant types, such as a legume and a grass, can not only stem such losses, but also promote gains: different root architectures fill soil niches, and symbiotic microbes around the roots can prove complementary.

Soils replanted to perennial C_4 grasses – a classification of how the organism uses carbon dioxide, and into which fall maize, sorghum, and many American prairie grasses – actually lost carbon over three decades, one study found. Soils planted to forb-grass mixes gained as much as the grass monoculture lost, and forb-rich ground gained doubly. This might be because the particular way that forbs exude carbon makes better soil chemistry for microbes – a feedback loop.

To wean agriculture from an industrial formula that takes many times more fossil energy to operate than the food energy it serves up, and further costs soil, water, air, and sometimes people; to see farms snug their way nearer to that of a natural economy, an economy more resilient and fueled by contemporary sunlight: this depends greatly on soil organic matter. But organic matter has proven hard for farmers to build back to what natural economies had made of soil before it was broken. The problem is complex, but scientists know that two big requirements are for plants to put much of their growth belowground, in roots, and for undisturbed development of a loosely compacted mass of disparate elements for soil to secure organic molecules.

Perennials deliver both. In fact they are essential almost everywhere for land to develop complex, productive soil. Annual crops give less to the ground, and demand tillage to break soil aggregates and exhaustingly feed microbes to feed the plants. Or they must resort to better living through synthetic chemistry. Annual crops make stocking soil organic matter difficult; cover crops, deep-rooting plants, and biochar amendments largely are only attempts. Annuals make difficult not losing carbon through disturbance. Building soil goes against annuals' very nature.

Both theory and evidence, the evidence from tilled ground brought back to long-lived plants, support that perennial grains will accumulate organic matter and build soil similarly, if not quite equally, to nature's expertise. The climb includes daunting pitches. For example, we know that even perennial crops will occasionally need replacement. How will farmers replant without tillage untethering soil organic matter? This is why The Land Institute works not just to breed perennial grains, but also to build for them an eco-system, from the Greek *oikos*, for house or family. Such a diverse economy might build soil organic matter so agriculture not only dampens climate change, but also develops resiliency to change we are already bound to face.

This depends on even wider attention. Progress will be slow as long as government subsidies promote large-scale industrial production of a handful of annual grains; as long as a handful of corporations market seeds and supplies, and a handful buy and process grains; and as long as government and economic structures do not align. The food system is embedded in something much bigger.

Adapted from an article in the science journal Sustainability. See http://www.mdpi.com/2071-1050/9/4/578/htm.

Cindy Thompson serves croissants made with Kernza, The Land Institute's registered trademark name for products made from the grain of intermediate wheatgrass. One field converted from annual grain cropping to this perennial began putting into the soil 5 metric tons of carbon per year, and five years later still added about 1 ton per year. (For more, see page 30.) This cuts greenhouse gas and makes better soil. Scott Bontz photo.

Prairie Festival

Discussion of healthful farming in town and country

The Prairie Festival to be held September 22-24 at The Land Institute, just southeast of Salina, Kansas, will put individual speakers and panels to work on a theme, "Urban Agriculture and Rural Agrarianism: Toward a Perennial Future."

One discussion features contributors to the book "Letters to a Young Farmer," including Verlyn Klinkenborg, whose books include "Making Hay" and "The Rural Life." The panel moderator is Jill Isenbarger, leader of Stone Barns Center for Food and Agriculture, in upstate New York. The center published "Letters," and makes partners of "farmers, engineers, policy makers, chefs, conservationists, educators, and others" for agriculture and diet that help ecological health and community.

Other speakers:

Cathrine Sneed, who cut recidivism at San Francisco's jail by giving inmates a garden. She helps them after release with The Garden Project, which also trains young adults to grow food for local food pantries, and has planted in the city more than 10,000 trees.

Severine von Tscharner Fleming, who founded Greenhorns to recruit and support new farmers, and to "retrofit the food system" for the health of watersheds and the farm economy and culture.

Former Land Institute graduate school fellow Wylie Harris, a Texas rancher and writer, and his wife, Özlem Altıok, who teaches women's and gender studies, and international studies, at the University of North Texas.

Brian Donahue, who teaches environmental studies at Brandeis University, and who directed The Land Institute education and now serves on the institute board. He is author of books including "The Great Meadow: Farmers and the Land in Colonial Concord."

Fred Iutzi, Land Institute president; Wes Jackson, former president; and institute researchers.

Another panel will discuss marketing Kernza, a registered trademark for food products from The Land Institute's perennial crop plant intermediate wheatgrass. The panel includes Land Institute breeder Lee DeHaan and Aaron Reser, of Green Lands Blue Waters, which works for diverse, perennial cover on farmland in the Mississippi River basin.

Friday night will feature a barn dance and, weather permitting, a bonfire. There is free tent camping, but no RVs. Cost for the weekend is $30 for Land Institute supporters, $40 for others, $10 for students. Food trucks will sell lunch and supper Saturday.

For more, or to register, click the Events tab at landinstitute.org, or call 785-823-5376.

At left: detail of Karen McCoy's installation, "Seemingly Unconnected Events," for the Prairie Festival. McCoy combines plaster casts of product packaging and of natural forms such as sea worms. E. G. Schempf photo.

Finally, big sorghum seed

Since beginning development of perennial grain sorghum in 2002, Stan Cox has struggled to find among his results a candidate that can both live through winter and make the seed needed from a crop plant: big, palatable, profitable. He gets a survivor or a producer, but not two in one.

The perennial parent in his crosses is johnsongrass, *Sorghum halepense*, with seeds usually weighing 3 to 4 milligrams each. The other parent, the established annual grain called milo, *S. bicolor*, yields seed weighing 20 to 30 mg. The first progeny of Cox's crosses made seed of about 6 mg. Breeding these plants back to the annual sorghum bumped seed size of the best plants just into the double digits, but Cox said, "Among plants that survived the winter, I never found any that had weights over 11 mg. Most were down around 9."

Cox saw in the physiques of his new plants no obvious reason for perenniality and low seed size to go together. He suspected that genes for each were linked on the same chromosomes in *S. halepense.* Separation of the genes would be rare. But generations of selecting the best perennial plants and breeding them back to milo might break links. And last year, from a wide range of crosses and backcrosses, among about 800 winter survivors Cox was astonished to find a few dozen that yielded seed weighing 14 to 20 mg. Many of them also easily threshed free of their hulls – another desirable trait for a crop plant, and a challenge with tightly hulled wild plants.

"Now, it's true that 2015-16 was a warmer than average winter and that most of these plants came out of mulched plots, so we don't know how they would fare under harsher conditions," Cox said. "But I have never harvested a single plant with seed approaching this size after any previous warm Kansas winter, or in warmer locations, with or without mulching."

At left, seed of the perennial johnsongrass. Next, that of annual sorghum. A decade of breeding the two never made seed bigger than in the third set. Then last year some hybrids produced seed of double that mass. Scott Bontz photo.

Land Institute shorts

Accord, new program in China

The Land Institute and Chinese researchers signed a formal agreement to continue their nine-year-old collaboration, and the Chinese founded an International Joint Research Center for Perennial Crops. Our director of research, Tim Crews, was in China for the June events, part of an annual, international meeting for perennial rice. Back home, he called the center "The second place on the planet that has its focus on this work." We have other perennial-grain collaborators around the country and the world, but this is the only other one with a formal declaration. The center's infrastructure is not freestanding, but at Yunnan University. The center's prime mover is Yunnan's Fengyi Hu, who, with The Land Institute's help since 2008, has been developing perennial rice. (See page 22 of the spring Land Report.) Land Institute researchers see Hu and his rice work each year. Hu and other Chinese officials finally visited The Land Institute this February, and again in May.

Largest perennial grains event

More than 100 researchers, growers, and food makers gathered in St. Paul, Minnesota, to talk about developing intermediate wheatgrass and selling Kernza, The Land Institute's registered trademark name for flour and other food makings from intermediate wheatgrass. The July 6-7 event was the largest devoted to our perennial grain crop candidates. It attracted farmers trying wheatgrass, researchers from Canada, France, and Sweden, and representatives from General Mills, which is testing Kernza in foods; Patagonia Provisions and Hopworks Urban Brewery, which together use Kernza in the new Long Root Ale; Birchwood Cafe in Minneapolis, which has used Kernza flour in waffles and other food; and Dumpling & Strand of St. Paul, which sells Kernza noodles at farm markets. Lee DeHaan, our wheatgrass breeder and co-organizer of the meeting, was happy with what happened. One, because of participants' enthusiasm for this new food, including on the most important detail, flavor. And two, because they could see and were honest about the challenges remaining for wheatgrass to become a dependable, widely used grain crop. DeHaan likened the current moment to that of air travel in 1914, when the first scheduled passenger airline service offered a 21-mile hop over Tampa Bay.

A dash of wheat for a perennial

Land Institute researchers are domesticating the perennial called intermediate wheatgrass. They also cross it with annual wheat, to make perennial wheat. Now crossing results that keep the perennial parents' complete chromosome set – not all crosses have done so – are being bred back to wheatgrass. This is to add a small amount of wheat DNA for wheatgrass to grow more like the proven crop plant. (Working the other way, wheatgrass has long been used to imbue wheat with disease resistance.) The job has been tough but promising. Most backcrosses set no seed; almost no seed had endosperm, a seedling's first food; and wheatgrass breeder Lee DeHaan said the embryos were the tiniest he'd seen. Most didn't survive. But dozens of crosses did get about 10 plants going. Next year: more crosses.

General Mills funding plan

In collaboration with intermediate wheatgrass researchers at the University of Minnesota, The Land Institute will use a $500,000 grant from food giant General Mills to study the greenhouse gas consequences of growing intermediate wheatgrass in different ways, such as with legumes, under grazing, and managed organically. Since announcement of the General Mills grant in March, farmers and buyers from across the US and overseas continue to call us. French researcher Christophe David visited in April, and plans test plots, amounting to about 15 acres, across his country.

Perennial run on soil carbon

A new field of intermediate wheatgrass at The Land Institute initially moved from air to soil about 5 metric tons of carbon per hectare per year. That's a healthy rate for slowing climate change. In about five years since, annual carbon buildup dropped to about 1.2 tons, and there's good reason to expect decline to half a ton. Years of tillage costs land much of its carbon. When a field is planted back to perennials like wheatgrass, root growth quickly restocks carbon. After the roots fill out, plants slow to maintenance mode, and slough as much old tissue as add new. Decomposition sends some of the carbon back to the atmosphere, and net gain for the soil slows. In collaboration with the University of Minnesota, we plan to disturb the wheatgrass field to stimulate plant growth, and to see how this affects soil carbon. (For more about perennial crops and carbon, see page 16.)

In good conditions, big seed

Breeding select intermediate wheatgrass plants with each other in the greenhouse made many plants with excellent seed set and big seed. One plant's seed size reached about 80 percent that of wheat, up from the approximately 15 percent size seen in wild wheatgrass. In the field the select plants will

Researcher Brandon Schlautman launched field work to judge perennial legumes as candidates for making food seed and growing with perennial grains as a nitrogen source. From the greenhouse came thousands of transplants: clover, lupines, and alfalfa.

probably see seed size fall by about half. But the greenhouse results show the potential in good conditions.

A new lead fundraiser

By far most of The Land Institute's funding comes from individuals, families, and foundations. Several staff members spend much or most of their time cultivating this constituency. Their director for more than five years, Jayne Norlin, retired June 30. The new development director is Amy Cole. Norlin, 67, said now was the time because the institute is financially healthy and has made the transition to its first new president in 40 years, and because she wants to enjoy other things while still healthy herself: gardening, canning, reading, knitting, travel, hiking, and perhaps running a half-marathon. "I just feel like all the stars have aligned," she said. Norlin grew up in Oklahoma City, earned bachelor's and master's degrees in English and a minor in ancient Greek, and for most of the time from 1980 until joining us worked at Bethany College in nearby Lindsborg, Kansas, in jobs from teaching freshman English to fund raising. Cole, 36, grew up in Gypsum, even nearer The Land Institute. She has always known the place; her family was friends with the family whose house now serves as our office. Cole earned a degree in journalism/public relations at Kansas State University, with a minor in French, and for more than four years directed development for the university's polytechnic campus in Salina. She has also worked for St. Francis Community Services, Cox Communications, and, soon after graduation, at making cold calls to match executives and corporations. She lives in Salina with her husband and two boys, ages 7 and 9.

Norlin

Cole

Wheat passes third winter

Plants made by crossing annual durum wheat with the perennial intermediate wheatgrass survived a third Kansas winter. On another tack toward perennial wheat, in the greenhouse this spring three kinds of perennial wheat progeny, each with a different mechanism for promoting perennial growth, were crossed to each other with the goal of stacking the desired genes.

A new board chair

Angus Wright, for eight years the chair of The Land Institute's board of directors, will remain on the board but let someone else run the meetings. The board elected to that job Pete Ferrell, a cattle rancher in southern Kansas. Wright is professor emeritus of environmental studies at California State University in Sacramento. Both have been board members for more than two decades.

Publications and presentations

The April issue of the journal BioScience features The Land Institute's work. Our staff members spoke in Wisconsin, Arizona, China, Denmark, Germany, and Minnesota.

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______	Experiences of former interns and fellows	Panel led by Michelle Mack
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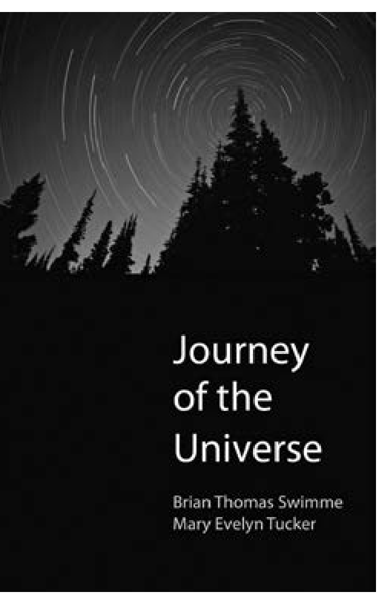

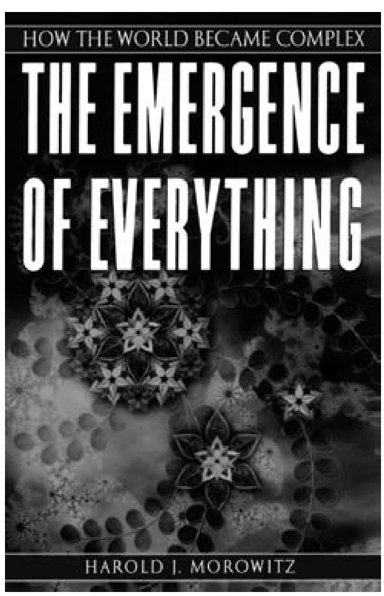

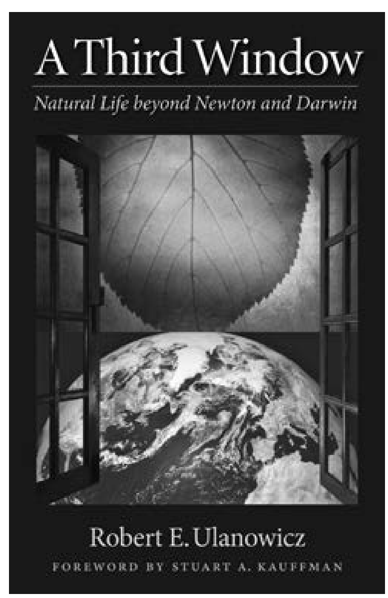

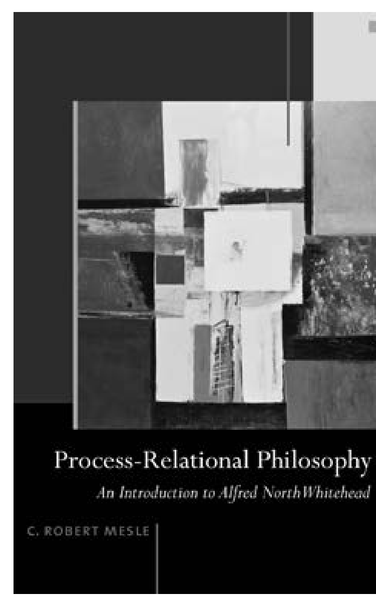

The universe is not so much made up of things as of creative processes – that formed the heart of The Land Institute's third gathering to advance what's being called ecosphere studies. Reading material for the conference were these four books of science and philosophy. For the story and reviews, see page 4.