Also by David R. Montgomery

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Dirt: The Erosion of Civilizations

King of Fish: The Thousand-Year Run of Salmon

GROWING A REVOLUTION

Bringing Our Soil Back to Life

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FERTILE RUINS

Civilization itself rests upon the soil.

—Thomas Jefferson

What if I told you there was a relatively simple, cost-effective way to help feed the world, reduce pollution, pull carbon from the atmosphere, protect biodiversity, and make farmers more money? If this was true, you might assume that governments around the world would race to embrace it. Well there is, and they aren't. Not yet anyway.

Why not? Because the solution challenges a century of conventional wisdom and powerful commercial interests, and requires a profound shift in how we think about and treat the least glamorous resource of all—the soil beneath our feet.

But before we get to the good news, let's look at where we are and how we got here. It's not a rosy picture. We have already degraded at least a third of the world's agricultural land. A *third*. And though we rarely hear about it, degradation of farmland presents as great a threat to civilization as global conflict, our exploding population, climate change, and dwindling supplies of fresh water.

In 2015, the United Nations Food and Agricultural Organization released a report by a consortium of scientists from around the world that estimated soil degradation erodes almost half a percent of our global crop production capacity each year. By any accounting, such a trend can't go on for long without serious consequences. Indeed, we are already seeing foreign interests buy up farmland in developing nations. Not to grow food for the local populace, but for export back home. With food shortages already fueling violence in drought- and conflict-plagued regions like Nigeria, Somalia, and Syria, such arrangements will not favor global stability.

Among the classical elements of earth (soil), air (climate), fire (energy), and water, it is the first that consistently gets overlooked or short-changed in public discourse and policy. Yet we might consider fertile soil as the ultimate strategic resource. For there is no substitute as there is for oil, and it cannot be distilled, as fresh water can be from seawater, nor cleaned by filters as air can. And because we do not fully recognize the value of what's beneath our feet, we risk repeating ancient mistakes on a global scale.

From the Roman Empire to the Maya and Polynesia's Easter Island, one great civilization after another sank into poverty and eventual demise after destroying their topsoil. But the effect of soil degradation on human societies is not simply a historical footnote. We too are facing challenges these once-thriving societies faced, only now simultaneously from North Carolina to Costa Rica, India, and Africa. And if we don't implement solutions soon, we'll find ourselves in the same dire circumstances globally as did our regional predecessors. For with even less fertile soil, how will we feed several billion *more* people in the future?

Unlike other environmental problems such as dwindling water supplies and loss of forests, the degradation of soil fertility has gone relatively unnoticed. It happens so slowly that it rarely becomes the crisis du jour. Therein lies the problem. The once-Edenic, now-impoverished places that spawned Western civilization illustrate one of history's most underappreciated lessons: societies that don't take care of their soil do not last. We cannot afford to repeat the mistakes of the past now that there's nowhere left to go. We've already farmed, developed, or degraded and abandoned pretty much all the land well suited for agriculture over the long run.

Today, however, feeding the world is more of an economic and distribution (and therefore political) problem than an agronomic one. Even with the loss of a substantial amount of fertile land, we currently harvest enough food to feed everyone, in principle if not in practice. But we can't count on being able to meet the demand for long if fertile cropland continues to shrink while the global population continues to rise.

Of course, there are other dimensions to the problem of global hunger. Aside from population growth, there are issues of land tenure and how much of our harvests goes to feed livestock and cars (biofuels). But a far-too-neglected factor in thinking about how to feed the world of tomorrow is the potential to restore land to agricultural productivity. Could we really restore fertility to degraded farmland? If so, how much—and how fast?

A growing movement of farmers around the world is starting to turn ancient patterns around, restoring life and health to their land. Yet we don't hear much about this movement. With no products to sell, they tell a different story than that of conventional interests. This movement is gaining momentum because farmers who adopt its practices save time and money, and many increase harvests. These practices can work on large and small farms across the technological spectrum, from enormous farms in the Dakotas to small subsistence farms in Africa. And, if implemented well and globally, they could solve one of civilization's oldest problems.

THE PROBLEM OF THE PLOW

I confess I never thought I'd write an optimistic book about the environment. For many years I was a dark green ecopessimist convinced humanity was rushing headlong into self-inflicted disaster. While I still harbor some such fears, I've become far more positive about our long-term prospects. Over the past few years, I've traveled extensively, meeting visionary farmers who are restoring life and fertility to their land. These experiences convinced me that it's possible not only to restore soil on a global scale, but to do so remarkably fast.

At least I hope it is, since we face the confluence of the end of cheap oil, continued population growth, and a changing climate over the coming century. How farming will adapt remains uncertain, as political, economic, and environmental interests push competing visions, policies, and agendas. No matter how all this plays out, it will shape the fate of nations and define the world we leave for generations to come.

My perspective on this issue started to change a decade ago, after I did something some colleagues might consider unpardonable—I wrote a book about soil and titled it *Dirt*. You see, soil scientists consider it blasphemous to call soil *dirt*. This is because there are very important differences between soil and dirt. For one, soil is full of life, dirt is not. So why would a geologist like me write an irreverently titled book about the importance of what covers up rocks? While my primary focus of study is how landscapes are shaped by natural processes and changed by people, over the course of examining the evolution of landscapes around the world, I came to see how soil erosion and degradation influenced human societies.

Some geologists argue that people, directly and indirectly, now move more earth around than nature herself. Earth scientists have even proposed a new epoch, the Anthropocene, or "Age of People." Although we argue about when this epoch started, it is perfectly clear that of all our world-changing inventions, the plow was, and remains, one of the most destructive.

Yes, you read that correctly. The *plow*. That iconic symbol of our agricultural roots that helped launch civilization as we know it. The plow enabled few to feed many and set the table for the rise of commerce, city-states, and hierarchical societies with priests, princes, politicians, and all the rest of us who don't farm. The problem, in a nutshell, is that the plow makes land vulnerable to erosion by wind and rain.

Consider that you rarely see much bare earth in natural grasslands or forests. Where she can, nature clothes herself in plants because ground

stripped of plant cover—like a just-tilled field—erodes faster than soil forms. Tillage also pushes soil downhill with each pass of the plow. Thus, when plowed generation after generation, hillslopes gradually—and sometimes not so gradually—lose their natural endowment of topsoil. And so, storm by storm, with each pass of a plow, a millimeter at a time, the land slowly loses fertility.

Studying how erosion shapes topography in different settings around the world, I noticed how the prosperity of societies can mirror the state of their land. The point was driven home for me when I was doing fieldwork in the Amazon. Driving through an area of rainforest freshly cleared for subsistence farming, I saw how fast bare fields eroded down to nutrient-poor weathered rock. Where this happened, impoverished families could barely scratch a living from the earth. The farmers would soon move on to clear fresh fields from the rainforest, as ranchers moved their cows in behind to graze abandoned fields. This became a cycle of destruction with no end in sight. On another trip, this time to the South Pacific island of Mangaia, I saw how badly eroded soils barely fed a small population with a long history of fighting over ever-fewer productive fields.

Through fieldwork spanning three decades and six continents, I realized that long-cultivated regions that had lost their topsoil remained impoverished as a result. Telltale signs are etched in ragged gullies and slopes with subsoil exposed at the surface. The poor fertility of the soil that remains on the land is harder to see.

However, it's worth noticing—and reversing. For restoring the soil can help address the fundamental challenges of water, energy, and climate, as well as a number of important environmental and public health problems. Nitrogen pollution, born of our dependence on fertilizers, is affecting urban water supplies in the Midwest and creating a great dead zone in the Gulf of Mexico off the mouth of the Mississippi River. Algal blooms from excess phosphorus in agricultural runoff kill fish in the Great Lakes. Direct exposure to insecticides and indirect effects of herbicides that kill their food source contribute to crashing populations of pollinators, like bees and Monarch butterflies, with dire implications for crop production and biodiversity. Wholesale reliance on agrochemicals directly affects human health too, as increased risk of depression and certain cancers are associated with pesticide exposure. Restoring healthy, fertile soil would cast a broad net, helping to address all these problems. So how feasible is it?

After writing *Dirt*, I received invitations to speak about the history of soil loss and degradation at more farming conferences than I can remember. This gave me opportunities to travel to places I wouldn't otherwise go (geologists usually gravitate toward mountains rather than to flat farmland), and the chance to meet innovative farmers I wouldn't normally encounter. At first, I didn't fully appreciate this opportunity. But after hearing one story after the next of how farmers revived degraded land, I started seeking out their opinions on this pressing issue. In doing so, I began to realize that I shared more common ground with farmers than I thought. Many of them saw the destructive effects of plowing as clearly as I did, if not more so.

In 2010, Guy Swanson invited me to speak at a farming conference in Colby, Kansas. His company sells an attachment to no-till planters that helps farmers reduce the amount of fertilizer they use. No-till farmers don't plow, they use specialized planters that open a narrow slot in the soil about the width of a kernel of corn. Seeds drop down into the slot, disturbing much less of the surrounding soil than plowing it up would.

Swanson's system injects a uniform amount of fertilizer adjacent to and below each just-planted seed, putting nutrients right where plants need them—and only there. This uses far less fertilizer than spraying it all over the field. The farmer saves money and fewer chemicals run off to pollute streams, lakes, and oceans. That sounds like a win-win, except of course to fertilizer companies. Swanson had seen me talk at a no-till farming conference and wanted me to come speak about the civilization-killing problem of soil erosion to potential customers contemplating a shift to no-till methods and precision fertilizer use.

As Swanson and I drove into Colby in his well-traveled white Impala, an enormous billboard welcomed us with a larger-than-life, hippy-looking Jesus peering out over a field of wheat. I started to worry about how Swanson's audience would receive a professor from the far left corner of the country talking about how the plow had ruined the land for society after society throughout history. Would I be run out of town before or after lunch?

As I ended my talk, I looked out on a sea of baseball hats. One elderly fellow in the middle stood up, stuffed his hands down into his pockets, and said he'd taken one look at me and didn't think I could possibly say anything worth listening to. I braced myself for what was to come. But then he surprised me. He said the more I'd talked, the more sense I'd made. He'd seen what I was talking about on his farm. It no longer had the rich fertile topsoil his grandfather had plowed. Something needed to change if his own grandchildren were going to prosper working his land.

Time and again, at one farming conference after another, instead of walking out or lobbing verbal grenades at me, farmers readily acknowledged the possibility that plowing resulted in long-term damage to the soil. A surprising number said they knew this to be true from firsthand experience. Older farmers would share stories about how their soil quality had gone downhill over their lifetimes, too slowly to notice year to year, but plain as day in retrospect. One after another piped up to say that they'd noticed their soil decline under the now-conventional marriage of the plow and intensive fertilizer and agrochemical use.

In hindsight, I really shouldn't have been surprised that farmers recognized the twin problems of soil loss and degradation. After all, who knows the land better than those who work it for a living?

But the trip with Swanson was the first time I'd really had a chance to talk with farmers who were enthusiastic about reducing chemical inputs to save—and thereby make—money. Most liked the potential of using technology and precision fertilization to do more with less. And, while many expressed a desire to stop soil erosion, they all loved the idea of lowering next year's fertilizer bill without lowering crop yields. So I started paying more attention to what individual farmers thought it would take to carry on farming well into the future. I asked them what they were doing—and how they were doing it. It didn't take long to see common threads running through their answers.

When Swanson and I left Colby and drove south toward the heart of the 1930s-era Dust Bowl, I noticed both prosperous and dilapidated John Deere dealerships, depending on what part of Kansas we were in. Some of those we sped past held rows of shiny new green machines in clean, well-kept yards. Others featured broken-down fences surrounding lots full of rusted equipment. When I asked Swanson about this striking disparity, he said the thriving dealerships were in counties where farmers were going no-till.

This filled me with hope. After all, I figured the only way we could shift the dominant paradigm, as professors like to say, is to entice farmers with a combination of good stewardship and economic gain. If farmers saw that protecting and improving their soil left more money in their wallets, then we might break the age-old cycle of soil degradation that has destroyed societies throughout history.

I began to wonder what it would actually take to generate a resilient, productive, and permanent agriculture. I doubted there was a simple one-size-fits-all-farms answer. And I knew the answer wasn't simply organic farming. Many, if not most, organic farmers plow to suppress weeds and prepare the ground. I realized that the basic question that society needs to focus on is how farmers of all stripes can forgo the plow and leave their soil better off after a crop is planted and harvested—over and over again.

And one way or another, change will come—and already has. Think about where you grew up and the amount of land developed since you were a kid. Orchards or fields, rolling or flat, we've all seen productive farmland ripped up to make way for suburbs and strip malls. Back in the 1980s, as a newly minted geologist right out of college, I worked as a foundation inspector for a geotechnical engineering firm in the Bay Area. I quickly learned that carting off the topsoil was the first thing contractors did as they turned then-rich farmland into today's Silicon Valley. Loose, fertile soil doesn't offer much support for foundations. It

settles if you park a building on it. So, if you want to build a business park, the topsoil has to go. On project after project, I watched rich, black earth get loaded onto trucks and hauled off to be used as fill. None of those acres will grow food for generations to come. And there will be a lot more of us before our global population tops out sometime later this century.

Learning the story of past societies and seeing wholesale destruction of farmland made me seriously doubt humanity's ability to feed the future. After all, it takes nature centuries to build an inch of fertile topsoil, and we were inadvertently on track to destroy it all in a few generations. This sure seemed like a story that wouldn't end well. Until, that is, my wife decided we needed a garden.

Right after I received tenure, Anne and I bought a house in north Seattle. The yard was a ratty, century-old lawn with nary a worm residing in the lifeless dirt below. But there was space for the garden Anne dreamed of and we weathered a yard demolition project to start over with a blank slate. And then I patiently endured Anne hauling all kinds of organic matter home to make mulch and compost to improve the soil in our new planting beds. It was only in retrospect that I realized our garden beds were miniature versions of farm fields. After a few years we started to notice the results. As the soil changed color from khaki to chocolate, life seemed to spring from the earth—worms, millipedes, spiders, and beetles. Pollinating insects and birds soon followed. A roar of life emerged from beneath our feet and rippled aboveground, transforming our yard and our view of the world.

We had rediscovered the tried-and-true practice of using organic matter to build fertile soil, leading us down the nearly forgotten path of working *with* nature. Much to my surprise, the soil degradation that had taken down ancient societies was running in reverse right in my own backyard. And it was happening far more quickly than I thought possible. Seeing the transformation of our urban soil firsthand confirmed for me that soil biology is not only central to building soil fertility, but that we can use it to restore soil much *faster* than nature makes it. This was not what I had learned in college, where I'd been taught that soil chemistry and physics governed soil fertility and that nature made soil at a glacial pace.

Long before Anne and I stumbled onto restoring life to our soil, the Dutch began diking off land from the sea and systematically proceeded to build up beach sand into the famously fertile, rich, black soils that still comprise some of Europe's best agricultural land. Their secret? Returning organic matter to the fields.

And long before this Dutch innovation, Amazonian Indians made fertile, black terra preta soil, burying organic waste with charcoal from cooking fires to create patches of rich topsoil around their villages in an environment with naturally infertile soil. In the Andes, the Inca built terraced fields, which after thousands of years of farming now host soils more fertile than the native hillsides. The Incan trick sounded familiar—hauling organic matter back to their planting beds. Across Asia, the long-standing practice of returning manure and "night soil" (human excrement) to the fields followed the same principle. These societies all built and sustained fertile soil through soil-building agricultural practices.

My own experience and looking at such history told me that people can build up soil organic matter, and thus soil fertility, far faster than nature makes fertile soil. But our agricultural policies hold us back, discouraging farmers from using tools right beneath their feet. Yet, I know farming practices can change. After all, they have many times in the past.

A NEW REVOLUTION

A look back at our agricultural past reveals a long series of innovations, and a few bona fide revolutions, that greatly reduced the amount of land it takes to feed a person. These changes led to a dramatic increase in how many people the land could support and a corresponding

decrease in the proportion of people who farm. By my reckoning, we've already experienced four major revolutions in agriculture, albeit at different times in different regions.

The first was the initial idea of cultivation and the subsequent introduction of the plow and animal labor. This allowed sedentary villages to coalesce and grow into city-states and eventually sprawling empires. The second began at different points in history around the world, as farmers adopted soil husbandry to improve their land. Chiefly, this meant rotating crops, intercropping with legumes (plants that add nitrogen to soil), and adding manure to retain or enhance soil fertility. In Europe, this helped fuel changes in land tenure that pushed peasants into cities just in time to provide a ready supply of cheap urban labor to fuel the Industrial Revolution.

Agriculture's third revolution—mechanization and industrialization—upended such practices and ushered in dependence on cheap fossil fuels and fertilizer-intensive methods. Chemical fertilizers replaced organic-matter-rich mineral soil as the foundation of fertility. Although this increased crop yields from already degraded fields, it took more money and required more capital to farm. This, in turn, promoted the growth of larger farms and accelerated the exodus of families from rural to urban areas. The fourth revolution saw the technological advances behind what came to be known as the Green Revolution and biotechnology breakthroughs that boosted yields and consolidated corporate control of the food system through proprietary seeds, agrochemical products, and commodity crop distribution—the foundation of conventional agriculture today.

What will the future hold as we burn through the supply of cheap oil and our population continues to rise alongside ongoing soil loss and climate change? A recent study authored by hundreds of scientists from around the world concluded that modern agricultural practices must change once again if society is to avoid calamitous food shortages later this century. Just how worried should we be? Well, consider the fate of Mesopotamia, ancient Greece, or other once-great civilizations undone by their failing land. This time we need to ask what agriculture would look like if we relied on building fertile soil instead of depending on chemical substitutes. What would this new, fifth agricultural revolution look like?

Those at the vanguard invoke a variety of names—agroecology, conservation agriculture, regenerative agriculture, and the Brown Revolution. While proponents of these approaches include those who passionately disagree about the roles of organic practices and genetic engineering in the future of agriculture, I am more struck by the common ground they share in placing soil health at the heart of their practices.[1]

When the United Nations declared 2015 the International Year of Soils, I received more invitations to speak at soil-themed conferences. Interest in soil health had grown rapidly among farmers compared to what I had seen just a few years before. The seeds of optimism took root as I listened to farmers tell of how they changed the way they farmed, restoring life and fertility to their land. After a while, I started to think we might actually get it right this time. Maybe we could reverse the ancient pattern of farming ourselves out of business. Was this the start of a new movement that could rewrite the ending to an age-old tale—one farm at a time?

Seeking to understand what an agricultural revolution centered on soil health might look like, I set off on a trip across several continents to visit farmers who were restoring life to their land. What I learned shattered central myths of modern agriculture and pointed to simple, effective ways to help solve some of our most vexing problems. Individually, their examples illustrate how changes in farming practices can transform both conventional and organic agriculture into more sustainable enterprises. Collectively, they build a compelling case that we can feed the world, start cooling the planet, and restore life to the land.

The story started to come together as farmers from different regions told me their reasons for restoring their soil. Stopping erosion was usually on the list. Saving money by consuming less water, oil, fertilizers, or pesticides always was. Alignment of these objectives offers an opportunity to break free from the cycle of land degradation that doomed ancient societies.

Not all the farmers I met did things the same way. How could they? They grew different crops in different regions with different soil and different climates. Some integrated livestock into their operations. Others favored cover crops. A few, perched in the cabs of space-age prairie crawlers, worked fields stretching to the horizon. Others labored by hand in the tropics to coax sustenance from small plots to feed a single family. As varied as their situations and practices were, they all viewed farming as working *with*, rather than against, nature. When I realized that they all operated according to a common set of principles, I knew that the foundation for a new agricultural revolution had already been laid.

This journey challenged my view of the usual debates—organic farming versus GMOs, conventional farmers versus environmentalists, cows versus the planet. I came away with a new appreciation for how some simple changes in practices can help farmers of all stripes, conventional and organic alike.

Perhaps most striking to me was the way this movement is growing bottom-up, fueled by individual farmers rather than governments, universities, or environmental advocacy groups. Naturally enough, farmers share their experiences of what works well for them, or not. And curious neighbors notice when the fool next door tries something different—and then outproduces them, making more money several years in a row. Eventually, I came to realize that this is precisely why this time around we might actually break the age-old cycle of land exhaustion and societal collapse. It is starting to make economic sense for individual farmers to adopt regenerative practices that reinvest in their primary long-term asset: the fertility of their land.

The singular message that came through loud and clear from farmers I visited was that restoring the productive capacity of the soil could be done quickly and profitably. But it meant doing things differently, a willingness to walk away from conventional practices and to take a chance on the idea that building healthy soil was the best investment a farmer could make. Most of all, it seemed, it took the courage to try new things in the face of regulatory disincentives and skeptical corporate and academic crop advisors. These farmers were not being encouraged to change. They were deciding for themselves that they needed to practice a radically new form of agriculture.

Seeing farmers across a wide range of social, environmental, and economic settings heal and improve their land faster than I thought possible motivated me to write this book. On this journey, I learned that it's not a matter of heeding the sirens of agribusiness versus the prophets of sustainability, or choosing between modern technology and a return to preindustrial farming. That would be far too simple—and misleading. For the most promising way forward lies in the marriage of agrotechnology and agroecology to rebuild soil fertility. Combining ancient insights and modern science, I believe, is the way to both sustain agriculture and use it to help slow climate change.

Most striking to me is how individuals who see the power—and promise—of thinking differently are driving the new movement. To be sure, ongoing technical advances in genetic engineering, precision agriculture, and microbial ecology offer distinct choices in approach, each with its own merits and pitfalls. But I've come away believing that the foundation for the next agricultural revolution will be rooted in how we think about soil. For that colors everything else—especially how we use the knowledge and technology at our disposal.

The degradation of soils and the loss of organic matter are the most underappreciated environmental crises humanity now faces. But the stage is set for ground-up transformational change, as the short-term interests of farmers increasingly align with preserving long-term soil fertility.

It is no coincidence that some of the oldest known works of art are representations of long-forgotten fertility deities. For millennia, people believed that ensuring bountiful harvests depended on humoring fickle gods. But since the days of ancient Egypt, Greece, and Rome, our views of soil fertility have evolved through dramatic shifts in perspective. Now they must do so again if we are to avoid eroding civilization's agricultural foundation.

Though already underway, the revolution still has a long way to go. Like all revolutions, it faces entrenched opposition from powerful interests and conventional thinking. Yet if it succeeds, it could solve one of humanity's most pressing problems: how to keep feeding us all on this lonely rock in space.

2

MYTHS OF MODERN AGRICULTURE

Nothing is so painful to the human mind as a great and sudden change.

—Mary Shelley

Projections of global oil supplies show we either have already passed, or will soon cross over, the peak in crude oil production. As we slide our way down the global supply curve, it will make less and less sense to continue relying on oil. And while there may be vast reserves of shale oil, tar sands, and coal yet to be mined, prominently published projections estimate that even burning a quarter of the world's currently known fossil fuel reserves could alter the world's climate enough to catastrophically reduce crop yields and destabilize agriculture. A 2015 paper published in the journal *Nature* estimated that in order to keep climate change below a highly disruptive 2° Celsius rise, we would need to refrain from using a third of global oil reserves, half of natural gas reserves, and more than 80 percent of coal reserves.

It's no secret that the debate over just how much shale oil, tar sands, and coal we need to leave in the ground to forgo disaster is a controversial one. While agriculture accounts for less than a quarter of global fossil fuel emissions, one way or another farming will be affected. And

experimental studies of crop growth predict that the yields of major grains will drop 10 percent for each degree of global temperature rise.

We've already seen what this looks like. The European heat wave of 2003 reduced crop yields by up to 36 percent as the summer average temperature rose 3.6°C above the long-term average for the prior century. So, if we keep burning fossil fuels and adding CO_2 to the atmosphere, it's likely that harvests will decline as population grows. Yet, were we to stop using fossil fuels to make fertilizers and operate farm machinery, we would have to give up what we now depend on to prop up harvests. This dilemma presents a recipe for regional instability and conflict, if not global disaster.

Over the past century, technology reshaped agriculture to the point where modern farming cannot persist without the one thing we're sure not to have in the not-so-distant future: abundant cheap oil. Any way you look at it, if we are to solve both climate change and food-shortage issues, we must wean agriculture off fossil-fuel–intensive methods.

The essential question is not whether agriculture will change, but *how*—and how resilient the land, and thus society, will remain after it does. In an era when we routinely have less than a year's supply of food on the planet, regional crop failures influence global food supplies. This means that agricultural resilience is paramount for maintaining food security and social stability.

The threat of food riots is quite real. Most cities today have a modest supply of food on hand at any time. And history shows that food is the currency of last resort, worth more than cash when both are in short supply. Riots swept ancient Rome when the government failed to provide free bread to the citizenry. Food riots in Paris ignited the French Revolution. But such crises are not just a thing of the past. In 2008, food riots broke out in Asia, Africa, and the Middle East. In 2013, hungry people resorted to violence in drought-ravaged areas of Egypt, Turkey, and Syria; likewise in Venezuela and Somalia in 2015. Starving people do not respect fences or borders.

It is not hard to imagine regional conflicts over fertile land if humanity fails to meet the coming challenge of reliably feeding 10 billion of us. Already many of today's global flashpoints reflect legacies of historical land degradation. For instance, conflict over fertile land has shaped tribal animosities in the Middle East since biblical times. As global population keeps rising, regional food shortages appear inevitable if we continue losing fertile soil.

The Reverend Thomas Malthus, a scholarly nineteenth-century English cleric, infamously predicted that an exponentially mushrooming population would eventually overwhelm steady growth in crop yields. While we might yet prove him right, so far things have not worked out according to the king of pessimists' playbook. For over the course of history, a series of agricultural revolutions allowed our numbers to keep climbing, despite periodic famines and disasters.

Can we pull another rabbit out of our collective hat? Maybe. But isn't it foolish to count on not-yet-existing technologies to solve looming problems? Especially when instead of relying on new technology, this time the key might be a fundamental change in thinking about soil and its fertility.

MODERN MYTHS

The amount of land it takes to feed a person has dropped throughout history, to the point where global agriculture now requires less than half an acre per person. Back in our hunting and gathering days, it took about 250 acres of land to support a single individual. If we still needed that much land per capita, it would take five hundred Earths to feed the current global population. Going back to a preagricultural food supply is simply not an option.

Of course, farming practices that boost crop output in the short term but degrade land over the long haul cannot be sustained either. After all, as Will Rogers famously quipped about land, "They ain't making any more of it." If we are to maintain a global civilization capable of

feeding billions of us in perpetuity, we must develop lasting methods of intensive agriculture. The question is, how?

Listening to farmers who are already restoring life to their land unveiled some major myths of modern agriculture for me. They repeatedly told me that they had increased the fertility of their soil and restored profitability to their farms by walking away from conventional practices. Their stories helped shatter the ideas that industrialized agrochemical agriculture feeds most of us in the world today, is more efficient, and is the only way to feed the world of tomorrow. None of these pillars of conventional wisdom are true. So let's look at each a little more closely.

MYTH No. 1: Industrialized Agrochemical Agriculture Feeds the World Today

According to the U.N. Food and Agriculture Organization, family farms produce 80 percent of the world's food, and almost three-quarters (72 percent) of all farms worldwide are smaller than one hectare (about 2.5 acres or the size of a typical city block). In other words, much of humanity eats food grown on small farms. Of course, large industrialized farms allow relatively few people to feed the rest of us living in the developed world. Today, only about 1 percent of Americans are farmers. But most of the world's farmers work the land to feed themselves and their families. So, while industrialized agriculture feeds the *developed* world, it does not feed humanity. Still, we need large-scale agriculture unless we all want to live on—and work—our own farms. But bigger farms are not necessarily more efficient, which leads us to the second myth.

MYTH No. 2: Industrialized Agrochemical Agriculture Is More Efficient

Most industries have economies of scale that lower production costs per unit output for larger-volume operations. But efficiency can also be viewed in terms of input use per unit of production. An authoritative 1989 National Research Council study concluded that "well-managed alternative farming systems nearly always use less synthetic chemical pesticides, fertilizers, and antibiotics per unit of production than conventional farms."[2]

And do larger farms produce more food per acre? No. They may produce particular crops more cheaply, but they don't produce more food overall.

When then U.S. Secretary of Agriculture Earl Butz advised farmers to "get big or get out" in the 1970s, it had more to do with the capital requirements of modern commodity farming than how much food could be produced per acre. Unlike most production processes, farming has an inverse economy of scale in terms of total output. The common misconception that big, mechanized farms produce more food is based on yields per hectare for *individual* crops. Farms that grow a *diversity* of crops produce more food per hectare overall. Small, diversified farms produce more food from a given amount of land than large industrialized monocultures.

When it comes to farming, we've known for decades that bigger does not mean more efficient in this regard. This is no secret, and it's not counterculture propaganda. According to a 1992 U.S. agricultural census report, small farms produce more than twice as much food per acre than large farms do. Even the World Bank endorses small farms as the way to increase agricultural output in developing nations where food security remains a pressing issue.

Another way to think about the efficiency of modern agriculture is that we burn ten calories of fossil fuel to grow one edible calorie. Because of this, it's been said that we are eating oil. But it would be more accurate to say that we are eating natural gas. For industrial fertilizer production not only depends on the ready availability of cheap energy, it also consumes a lot of natural gas as feedstock. It is axiomatic that for any organism to be viable over the long run, it must get more energy from eating than it expends acquiring food. That modern societies don't hold to this simple test of biotic viability should concern anyone with an interest in the future. This leads us to a third myth of modern agriculture.

MYTH No. 3: Intensive Agrochemical Use Will Be Necessary to Feed the World Of Tomorrow

In recent years, the rate of increase in crop yields that characterized the second half of the twentieth century has started to stall. Simply using more fertilizer isn't going to produce bigger harvests since we already add a lot more than our crops take up. And plant response to fertilizers is greatest on degraded soils with little soil organic matter. In other words, adding fertilizers to already fertile soils does not really boost crop yields. The often-repeated line that intensive agrochemical use will be necessary to feed the world overlooks the potential to increase crop yields through adopting practices to restore soil fertility and boost yields on both low-input conventional and organic farms.

Beyond the three foregoing myths, there are several other things worth considering. Organic agriculture can prove as unsustainable as conventional farming when tillage is a regular practice. After all, it was farming without synthetic chemical inputs that impoverished ancient societies. And could there really be enough organic manure available to replace all the chemical fertilizers farmers apply to fields today? How else might we do it? As we'll see, a viable option is to grow cover crops, especially nitrogen-fixing species, as green manure.

In addition, the projected need to dramatically increase global crop production is based on the assumption that Western-style diets rich in grain-fed meat and processed foods will become more prevalent as incomes rise around the world. However, research findings and popular media increasingly link the modern rise in chronic diseases to the Western diet. This has begun to change consumer behavior in the Western world and it is plausible that the people of other nations will not prove as eager to adopt a Western diet as predicted. If both the developed and developing worlds adopted healthier diets with modest meat consumption and an abundance of fiber-rich whole plant foods, it could go a long way toward solving the problem of feeding us all and improving global health.

Another way to slow projected increases in global food needs is to reduce food waste. Thirty to 40 percent of all crops are lost to pests and disease before harvest—despite heavy use of pesticides.[3] And about a quarter of all food produced worldwide gets lost after harvest or wasted between production and consumption. Add those together and half the crops we plant don't end up feeding anyone. The United States alone wastes 133 billion pounds of food each year, more than enough to feed the 50 million Americans who regularly face hunger.

What all this means is that the simple metric of crop yields is too narrow a lens through which to assess strategies for growing enough food for our rising population. So what other factors must we take into account in order to feed the world of tomorrow? Naturally, good places to begin include adopting a healthier diet and reducing waste. Still, the bottom line remains finding and practicing ways to grow more food with fewer inputs. We need to lower the environmental impacts and carbon footprint of agriculture without compromising harvests—and continue doing so in perpetuity. Shifting to low-carbon energy, like wind and solar, is feasible, both technically and economically, if not yet politically. While we may well need to use some fertilizers to feed the world, we will need to figure out how to get by with less of them. And I'm confident we can. I've met farmers who already are doing it.

In fact, the more I learned, the more perplexed I became as to why agricultural policymakers seem to focus exclusively on agrochemistry and biotechnology as the future of agriculture. This is not to say we shouldn't take advantage of technological progress. But we should not let faith in it blind us to effective practices. For restoring life and fertility to the soil is possible right now using existing technology and practices that we know already work to improve soil health. Unfortunately, these practices buck conventional positions that dominate the world of agricultural policy.

THE GMO SIDESHOW

Decades ago, proponents of genetically modified (GM) crops promised increased yields and reduced need for fertilizers and pesticides. Did they deliver?

A 2016 report from the National Research Council Committee on Genetically Engineered Crops found that "nation-wide data on maize, cotton, or soybean in the United States do not show a significant signature of genetic-engineering technology on the rate of yield increase."[4] It's a mixed record for pesticide use. Herbicide-resistant crops led to greatly expanded use of the broad-spectrum herbicide glyphosate since 1996. And the resulting spread of glyphosate-resistant weeds is now leading to increased use of other herbicides as well. In contrast, the introduction of genetically modified Bt crops reduced insecticide use by more than 25 percent, and helped remove from widespread use some of the most environmentally damaging insecticides.[5] Still, overall pesticide use in the United States increased by about 7 percent as a result of adopting GM crops, according to a 2012 study. So claims of increased harvests and reduced pesticide use do not appear to hold up.

Studies also report, however, that GM crops have had some environmental benefits, notably reduced soil erosion from the increase in no-till farming due to simple, flexible, and effective weed suppression using glyphosate. And adoption of BT crops lowered use of some highly toxic, broad-spectrum insecticides. Yet GM crops have also created new and unexpected problems. Just several decades after widespread adoption of GM corn and soybeans, herbicide-resistant weeds and voracious Bt-resistant nematodes (microscopic worm-like creatures that can devour plant roots) are fast becoming serious problems. This means that farmers today are spending more and working harder simply to stay even, fighting battles they can't hope to win and can't afford to lose.

Yet debate over the future of agriculture is misrepresented when cast as the simple choice between organic methods and agrotech approaches like GMOs. Instead, it really comes down to the philosophical rift between agricultural practices based on enhancing nutrient cycling and soil health versus those that mine soil fertility and attempt to replace or compensate for degraded soil health with technology and commercial products. All too often the latter makes short-term economic sense, especially once the soil is already degraded. Therein lies the real dilemma at the heart of our modern crisis: the immediate financial interests of corporations that supply farmers do not necessarily align with our collective interest in maintaining the health and fertility of our agricultural soils.

How might we align farmers' short-term interests with society's long-term needs? By updating traditional ideas into modern practices that define a new system of agriculture. And to do this we need to revisit another myth about soil—that soil organic matter doesn't feed plants. It doesn't directly, of course. Plants get their carbon from the atmosphere via photosynthesis. But organic matter indirectly feeds the soil life that we now know plays an essential role in plant nutrition and plant health. Oddly enough, the potential to restore life to soil comes down to how we view dead stuff and invisible things—organic matter and microbes.

3

ROOTS OF THE UNDERGROUND ECONOMY

To be a successful farmer one must first know the nature of the soil.

—Xenophon

For much of human history, the role of organic matter in soil fertility was no secret. Farmers and philosophers alike believed that humus—soil organic matter—nourished plants. Until, that is, two key discoveries undercut this long-held belief. The first was the discovery of photosynthesis—that plants obtained their carbon, and thus most of their mass, from the air and not the soil. The second was the observation that most humus was insoluble and could not be sucked up by plant roots. So soil organic matter didn't feed plants.

What replaced the humus theory was the idea of the soil as a chemical reservoir from which plants drew sustenance. In the first half of the nineteenth century, German chemist Justus von Liebig demonstrated that a lack of availability of key nutrients could limit plant growth. He also established that adding elements in relatively short supply dramatically boosted plant growth. Farmers working degraded fields found that adding calcium, phosphorus, or potassium could bring crop yields back up to levels not seen since their grandfather's day.

So did the addition of nitrate- and phosphate-rich guano, bird

5

DITCHING THE PLOW

The plowshare may well have destroyed more options for future generations than the sword.

—Wes Jackson

A couple of years after visiting Guy Swanson in Kansas, I accepted an invitation to address the 2014 World Congress on Conservation Agriculture in Winnipeg, Manitoba. I gave one of my *Dirt* talks and figured I'd get the usual questions. Instead, I encountered something unexpected—heated arguments between conventional and organic farmers about the best practices for restoring soil.

In my presentation, I advocated combining no-till and organic practices as a recipe for preserving the soil and its fertility over the long run. I knew from my research and travels around the American Midwest that no-till methods were needed to reduce erosion, and I thought that organic methods had the best shot at maintaining fertility in a postoil world. But while fielding questions afterward it became clear to me that although everybody in the audience endorsed no-till farming as a way to restore degraded soil, they were bitterly divided over whether to do it organically or with agrochemicals and genetically modified crops.

Passions flared as conventional farmers squared off against their organic brethren. A charismatic Australian fellow claimed organic no-till didn't work down under, and that he had to use herbicides and fertilizers to grow his crops. Guys from small-town Pennsylvania and Europe rose to swear organic no-till not only worked really well, it could work *anywhere* and prove cost-effective to boot. It was not lost on me that, despite these disagreements, they all agreed on one thing: ditching the plow.

I came away from the conference with a new appreciation for the way the philosophy underpinning conservation agriculture bridges different practices and perspectives. All too often, it seems, conflict gets characterized as between organic Luddites and genetic engineering automatons. While such posturing can rally partisans, it also distracts us from the potential for progress. Such as how the young science of microbial ecology is providing insights into what really matters—soil health.

At lunch the day after my talk, Howard G. Buffett, the farmer-son of financial wizard Warren Buffett, shared his vision of what he calls the Brown Revolution. With grace and humor, he highlighted inspiring stories of farmers restoring fertility and profitability to their farms. He wasn't defending ideological turf; he neither argued for organic practices nor pushed biotechnology. Instead, he argued for adopting practices that built soil fertility and thereby reduced a farmer's need—and expenses—for agrochemicals.

I was intrigued by this perspective. Buffett's Brown Revolution sounded like fertile middle ground between organic and agrochemical farming. But how well did it really work? As I looked into it, I began to realize that the principles of conservation agriculture could dramatically and rapidly reform conventional agriculture. Could putting soil health at the center of every type of farming offer a path to real progress that was both rapid and profitable?

A NEW WAY

Conservation agriculture is a system of farming that rests on three simple principles: (1) minimum disturbance of the soil; (2) growing cover crops and retaining crop residue so that the soil is *always* covered; and (3) use of diverse crop rotations. These principles can be applied anywhere, on organic or conventional farms, with or without genetically modified crops.[10]

Despite the heated debate among proponents who have different ideas about how to implement the three fundamental practices, all sides agree on one thing. We need farming methods that are far less harmful to beneficial soil life. For soil health is built upon the backs of soil organisms, from the common earthworm to specialized bacteria, mycorrhizal fungi, and other microorganisms. At its heart this is what conservation agriculture is all about—practices that promote and protect the tiny multitudes that we now know help crops grow and keep soil fertile. It's worth a few words on how conservation agriculture's three principles accomplish this.

Daring to question the plow may seem heretical, but using one guarantees major-league soil disturbance. That's why going no-till is at the heart of conservation agriculture. It leaves nonharvestable plant parts—crop residues—as a soil cover. This means that, after a crop is harvested, plant remains, whether cornstalks or wheat stems, are not removed or burned. They decompose in the fields where they form a carpet of organic matter at the ground surface—mulch. Soil microbial biomass increases rapidly after conversion to no-till. So do soil fauna. Mulched plots have higher bacteria, fungi, earthworm, and nematode populations. Frequent tillage, in contrast, reduces soil microbial biomass and disrupts mycorrhizal hyphae that help deliver phosphorus to plants, among other negative impacts.

Cover crops planted in seasons between commercial crops, and that

are either mowed down or killed before or during subsequent plantings, help suppress perennial weeds and return nutrients to the soil as they decay. Covering the ground also promotes aboveground biomass and biodiversity, particularly beneficial insects that help keep pests in check. Crop rotations also help prevent insect pests and plant pathogens from gaining a toehold. Complex rotations that vary the sequence of cash crops and cover crops deny pests and pathogens opportunities to take hold and help break up cycles of insect pests and crop diseases. This, in turn, helps reduce the need to use conventional pesticides.

The benefits of increased activity and diversity of soil life include increased water infiltration and soil organic matter, which improve runoff water quality and soil structure. Soils with high microbial diversity are also a tough place for pathogens to take hold and persist. This translates into healthier plants. Fewer crop diseases strike, and if they do, they are not so devastating. Crop rotations also increase microbial diversity, reducing the risk that pests and pathogens will dominate a soil ecosystem. The net effect of adopting all three conservation agriculture elements is to maintain or increase crop yields (to varying degrees depending on, among other things, the initial state of the soil) and decrease fuel, fertilizer, and pesticide use. Conservation agriculture also takes less labor than conventional tillage. This translates into substantial savings for farmers because they spend less on inputs.

This set of farming principles turns contemporary conventional farming wisdom on its head. The now-conventional view considers plowing essential to control weeds, that erosion is an unavoidable result of rainfall, that cover crops and crop rotations are optional, and that chemical pest control is a necessity. Under conservation agriculture plowing is avoided and crop residues are left on fields as mulch to prevent erosion, cover crops and crop rotations are essential rather than optional, and biological pest control becomes a practical and effective option.

Conventional tillage does provide weed control, but under conservation agriculture herbicides or cover crops accomplish the same thing *and* dramatically reduce soil erosion. Mulch protects the soil surface from raindrop impacts and erosion by overland flow, and no-till farming reduces topsoil erosion as much as fiftyfold. Nitrogen-fixing microbes, legumes, and cover crops that build up soil organic matter can largely, if not completely, replace conventional fertilizers.

The three parts of conservation agriculture work together as a system, but farmers don't always adopt them all. Results are highly variable for partial adoption and a number of review studies report mixed effects on yields and soil organic matter from adoption of no-till. While few of the studies in such reviews addressed outcomes of adopting *all three* system components, the ideas behind this new system have deep roots.

Japanese farmer Masanobu Fukuoka was on to conservation agriculture in the late 1970s. His book, *The One-Straw Revolution* urged the organic agriculture movement to incorporate several ancient practices. He described planting directly into prior crop stubble at harvest time as farming in nature's image. Fukuoka challenged farmers to treat the sequence of annual activities on a farm as an integrated system of applied ecology. His recipe for plentiful harvests with less work was to cooperate with nature and schedule planting and harvesting so that each crop would set the stage for the next. This kept the fields occupied by desired plants, denying weeds the chance to get started in the first place.

Both the emerging conservation agriculture movement and Fukuoka's philosophy embrace a set of principles that, if put into practice, can improve soil quality and boost soil health—and crop yields. When I first learned of them, I was struck by how they lead to thinking about farming differently—as feeding the soil so it will in turn feed us. It boils down to investing in fertility through enlisting trillions of microbial helpers, agriculture's living foundation. Proponents argue that adopting all three principles of conservation agriculture, and adapting them to the circumstances of individual regions and farms, can transform soil-mining farms into soil-building ones. Imagine if the farmers of the Roman Empire or biblical times knew to employ these

methods. How might that have changed the course of human history? Perhaps the answer to one of our longest-running problems is really pretty simple after all.

THE ROAD TO THE DUST BOWL

For centuries, the plow has been used to control weeds, prepare the seedbed for planting, and mix fertilizers (chemical or manure) into the soil. Tillage promotes uniform seed germination, and can allow the crop to germinate before weeds and grow without competition. Tillage also exposes organic matter to air, spurring decay that releases nutrients that promote crop growth. These effects benefit the farmer over the short run, but result in a long-term cost to the fertility of the soil, through soil erosion and accelerated degradation of organic matter.

Over time, farmers and the rest of us came to associate tillage with good farming, and to see the plow as a revered agricultural icon. Farmers loved the burst of fertility that came from plowing. But they overlooked or were unaware of the side effects—soil erosion and loss of soil organic matter, soil structure, and soil life—all of which degraded soil fertility over time.

The earliest "farming" by hunter-gatherer societies used no-till-like methods, scattering seeds on the ground or placing them in shallow holes. A farmer could use a forked branch or digging stick to scratch a hole into the fine silt of a floodplain or delta soil, then drop the seeds in. It is no coincidence that these are the environments where early farming—and the earliest civilizations—took root.

The plow evolved from simple tillage tools pulled by animals, used between 5000 and 3000 B.C., to the iron Roman plow, the forerunner of our modern plow. The soil-inverting plow arose about a thousand years later, at the close of the first millennium, and in 1784, Thomas Jefferson designed the moldboard plow that graces the seal of the U.S. Department of Agriculture (USDA). Jefferson's plow moved so readily through the soil that the French Society of Agriculture awarded him their gold medal. Decades later, in the 1830s, a blacksmith by the name of John Deere began marketing a cast-iron plow based on Jefferson's design. Readily pulled by a pair of horses or mules, Deere's plow opened the Midwest to homesteaders, becoming affectionately known as the Prairie Breaker.

Decades later, high prices for grain exports to Europe during the First World War enticed American farmers to plow up everything they could. Mechanized versions of Deere's handiwork opened up the semi-arid prairie in the heart of the continent. Then the drought hit. The years of 1934 to 1936 were extremely bad—rainfall was less than half the normal amount.

Though drought may have triggered it, the Dust Bowl was a man-made disaster. For thousands of years, comparable droughts occurred in the Great Plains every few centuries, without resulting in wholesale soil erosion. But when farmers plowed up the plains, the soil lost its living anchor of deep-rooted prairie plants. The land fell apart under high winds when the next major drought hit.

This didn't come as a complete surprise. Throughout the 1920s, soil conservationist Hugh Hammond Bennett labeled soil erosion a "national menace." He preached the gospel of soil husbandry, of caring for the soil as an intergenerational trust. In September 1933, President Roosevelt appointed Bennett director of the newly established Soil Erosion Service. A natural showman with astute political instincts, Bennett didn't waste opportunities to marshal support for soil conservation. And the Dust Bowl gave him plenty to work with.

He'd been in his new position less than a year when a towering three-mile-high cloud of dust blocked out the sun from Texas to the Dakotas to Ohio. Twelve million tons of dirt rained down on Chicago. It was no way to herald spring. A short time later, on May 12, dust descended on the nation's capital. A dark cloud drifted through the Oval Office windows, covering Roosevelt's desk with midwestern dirt—surely capturing his attention.

Tipped off by field agents who would call in to report on a dust

storm's progress across the country, Bennett planned strategically. On March 6 and 21 of 1935, great black clouds of dust once again blew through Washington, just in time for congressional hearings on soil conservation legislation. And on April 2, as Bennett testified before the Senate Public Lands Committee, leaden shadows filled the sky and blocked out the daylight, providing Bennett with the perfect dramatic visual to accompany his call to save America's soil.

Several weeks later, President Roosevelt signed the Soil Conservation Act, establishing the Soil Conservation Service.[11] Bennett was appointed chief of the new agency. Two years later, Roosevelt authorized formation of soil conservation districts to serve as the front line in the battle against erosion.

The national disaster of the Dust Bowl also prompted heated debate about plowing. Initially, no-till proponents ran into deeply entrenched skepticism—and public controversy. But eventually their success at reducing both soil erosion and farmers' input costs fueled an ongoing shift to no-till practices, used today on roughly a third of U.S. cropland.

Edward Faulkner was an early leader in the no-till farming movement. His 1943 book *Plowman's Folly* contended that plowing was unnecessary and counterproductive over the long run. He advocated planting directly into the surficial layer of organic matter, where plants naturally germinate when they fall to the ground. After several decades working as a county agricultural agent in Kentucky and Ohio, he concluded that not only was there no good reason to plow, it did more harm than good.

He'd come to this heretical belief much the way I had—through spending time in the backyard. After the crash of 1929, Faulkner tried to grow corn in his brick-like soil. Throughout the Depression, he dug organic matter into the ground, mixing leaves into the uppermost six to eight inches of soil to mimic the effects of plowing. He wasn't impressed with the results. So, in the fall of 1937, he tried a new tactic and simply left the leaves on the ground surface to mulch by default, instead of expending the effort to till.

The next spring, his previously stiff clay soil could be raked like sand, its texture granular instead of brick-like. He grew his best crops yet, only this time without any fertilizer and with hardly any watering. All he did was weed.

Faulkner was excited by these results, but he knew that an anecdotal challenge to conventional wisdom wouldn't convert skeptics. Extension agents, farm papers, and almost every source of farming advice encouraged farmers to plow deep down into the subsoil. He wasn't completely surprised that Soil Conservation Service agents didn't see the relevance of his backyard experiment to full-scale farming.

So Faulkner leased a field to see for himself if planting through a ground cover of chopped-up crop stubble would work on a larger area, the same way it had in his backyard garden. Sure that Faulkner was a fool to forgo plowing, fertilizers, and pesticides, neighboring farmers were shocked when the madman's yields exceeded their own for several years in a row. Faulkner told farmers to stop tilling and start leaving organic matter on the ground. He sparked further controversy when he argued that fertilizers simply decreased "the devastating effects of plowing."[12]

In 1946, several years after Faulkner's book was published, Walter Thomas Jack published a rebuttal of sorts, titled *The Furrow and Us.* In it, Jack argued that farmers around the world found that plowing increased the fertility of their land. Bickering between Faulkner and Jack spilled over into the popular press. It even made it to the pages of *Time* magazine, which characterized their debate as the "hottest farming argument since the tractor first challenged the horse."[13]

Who was right? To some degree, both were. We now know that tillage accelerates decomposition of soil organic matter. What this means, of course, is that plowing gives crops a nutrient boost in the short run. But, if the nutrients aren't replaced, it runs fertility down over the long term. The development of powerful tractors compounded this situation. Mechanization eliminated the need for on-farm pasture and forage, displacing draft animals and reducing the return of their life-giving manure to the land.

Production of direct-seeding machinery in the 1940s allowed planting without tilling, but the lack of herbicides for weed control handed the first round of the debate to Jack and the plow proponents. The development of the herbicide 2,4-D after the Second World War, and paraquat a couple decades later, increased interest in various forms of no-till farming. With chemical herbicides replacing tillage as a primary means of weed control, low-till and no-till methods began to catch on.

No-till farming proved attractive once coupled with easy weed suppression. It cut erosion down enough to keep the soil in place, even under intensive cropping. Retaining more ground cover on fields helped rainwater sink into the ground, which helped crops weather droughts. And no-till reduced diesel bills due to fewer passes of machinery across the fields. Eventually, adopters that left crop stubble on their fields found that outlays for fertilizer dropped too, as soil organic matter gradually rebuilt soil fertility.

RELEARNING OLD LESSONS

I learned that there's more to this story of no-till farming and conservation agriculture when I ran into Rattan Lal again at a conference in Malmö, Sweden, in the spring of 2015. Lal is thin and soft-spoken, with big glasses, a self-effacing manner, and a sparkling laugh. I figured that he probably has more experience than anyone in terms of conservation agriculture in the tropics, so while waiting to meet our hosts in a hotel lobby, I asked him how he came to focus on agriculture.

Lal explained that he grew up on a small farm in Punjab, in what is now the Indian state of Haryana, after his family had fled from Pakistan upon partition in 1947. They'd left behind a 9-acre farm, so when his father received only an acre and a half, he thought the village revenue officer who'd evaluated their land had cheated them. But years later, Lal realized that his family actually got a good deal, exchanging an old farm with a high water table and salinity problems for high-quality irrigated land. By then he knew the quality of the soil was as important as the size of a farm.

A lifelong vegetarian, Lal looked after cattle as a child. His mother passed away when he was two, and he often went to live with his aunt in town. After completing, and excelling in, the village high school in 1959, he gained admission to Punjab Agricultural University, where he landed a scholarship for Pakistan refugees that paid 12 rupees a month (about $1 a week). When he completed college in 1963, knowing how to plow a straight furrow and identify weeds, his farm community was not impressed. "It was a big joke," he said. "This child we sent to college has been learning how to plow!" Yet the experience had lifelong impact, setting Lal on the path to question why farmers plowed in the first place.

Having earned the highest grades in his graduating class, a fertilizer company offered him a 100-rupee scholarship to continue his studies. But his professor told him, "Don't you sign that damn agreement—it will make you work for them for years. I'll send you to Ohio State." Lal was admitted in 1965, just as no-till began attracting renewed academic interest.

He found himself at the school where Faulkner and Jack had argued over plowing twenty years before. Most farmers still habitually relied on the plow for weed control, yet Lal couldn't see why farmers should risk all the erosion tillage can cause when better ways to put seeds into the ground and manage weeds were available.

He completed a soil science Ph.D. in just two and a half years, graduating in September of 1968 at the ripe old age of twenty-four. Taking an appointment as a research fellow in Australia at the University of Sydney, he landed in a different school of thought amid different soils. There he worked on vertisols, soils that expand and contract enough upon wetting and drying to produce big cracks every dry season. Lal wanted to know why these soils produced so much runoff and erosion when plowed, despite the expectation that rain would just sink down into the cracks.

Through a series of clever experiments, he found that when the soil dried out it became impermeable because the heat produced from water condensing within the soil during the process of infiltration caused the soil to break into tiny pieces that then quickly sealed up the ground surface in the next rainfall. This promoted rapid, highly erosive runoff instead of allowing water to sink into the earth where plants could drink it in.

The solution proved remarkably simple: keep the soil covered in mulch so it didn't heat up so much and dry out. Time and again, over the next several decades, Lal's research led him back to the value of protecting the land surface with a cover of living plants and organic matter—nature's recipe for sustained fertility.

The next chapter in Lal's journey started when Dennis Greenland, a professor from the University of Reading, came to visit the University of Sydney and left impressed with Lal's work. After Lal accepted a job at the newly established International Institute of Tropical Agriculture in Ibadan, Nigeria, Greenland was appointed director of research at the institute.

By early 1970, Lal started to investigate solutions for the problems of subsistence farmers. The age-old practice of clearing a patch of forest, farming it for a few years, and then abandoning it back to the forest for decades allowed soil fertility to rebuild during long fallow periods. But population pressure had increased to the point where most of the land was under more or less continuous cultivation. And while the Green Revolution had increased yields on large farms, subsistence farmers lacked the means to buy expensive fertilizers and agrochemicals. They needed something else.

With a visit from the board of trustees looming, Lal helped the staff to hurriedly clear forest and plant their first crops. But the day before the bigwigs arrived, intense rainfall washed out all the freshly cleared plots, leaving horribly gullied fields in its wake. The disaster convinced Lal that Western-style plowing and continuous cultivation was a serious mistake for the fragile soils, intense rains, and resource-poor smallholder farmers of the tropics.

His new boss agreed. The only soil scientist in the Royal Academy at the time, Greenland had seen this before. In the 1950s, the British government hatched a development scheme to address the postwar shortage of cooking oil in Europe. Sure that Western equipment could outcompete and outproduce traditional farming practices, Parliament spent 25 million pounds in Tanganyika (modern Tanzania) to clear 150,000 acres of forest and plant peanuts to make peanut oil. They recruited veterans into a "Groundnut Army," equipped with surplus U.S. Army tractors and odd half-tractor, half-Sherman-tank hybrids. The campaign proved disastrous.

They had little idea how erosive the region's intense rainfall could be on freshly disturbed soils. To clear the whole area in one go, they dragged ships' anchor chains, stretched between tractor-tanks, across the land to clear the vegetation. In short order, intense storms washed away much of the topsoil. In the next hot season, the now-bare fields baked, ruining the peanut harvest. While the project caused a scandal in Parliament, it was not unique. In Nigeria, Ghana, and across the tropics, bulldoze-and-plant schemes ended in similar fashion when predictably savage rainfall ravaged freshly plowed fields.

The failure of Lal's first plots seemed all too familiar. "Rattan," Greenland exclaimed, "it's the Groundnut Affair all over again!" With support from the Rockefeller and Ford foundations, they set up a series of experiments to investigate where well-intentioned Western farming efforts fell apart.

Conventional wisdom at the time held that the degree of the slope was the primary control on erosion. Everyone knew that steeper slopes eroded faster. Lal's data confirmed that slope was indeed the primary driver of erosion *if* the ground was bare, as it was after plowing. But he also found that steep slopes didn't erode if covered with mulch. Lal's experiments showed that the biggest influence on erosion was whether or not you left mulch on the fields after harvest.

At the time, West African governments subsidized plowing schemes. Farmers and agronomists believed that plowing helped water sink into the ground instead of running off over the surface and causing erosion. But Lal found the opposite was true. Less runoff—and therefore

less erosion—occurred on plots that were not plowed. Leaving more than 4 tons of plant residue per hectare completely eliminated erosion on all but the steepest slopes. And after an initial year to establish the ground cover, no-till methods proved just as effective as heavy mulch. Where crop residue stayed on the fields earthworms were abundant and the water sank into the ground instead of running off. Plowing wasn't the solution—it was the problem.

As in Australia, another major effect of clearing and plowing was that bare ground heated up when exposed to the sun. In Nigeria, plowed fields had soil temperatures more than 20 degrees higher than adjacent forest soils. But no-till practices kept soil temperatures close to those of forest soil and also retained more water.

Lal was shocked. He knew soil life shut down when soil temperatures rose above about 90°F in plowed fields. And once biologic activity stopped, fertility fell as soil structure declined and erosion ensued. The best thing to do, it seemed, was to keep the ground covered and let the worms and termites do the plowing. But to do that they needed to be fed. And what they ate was organic matter—mulch.

This new view did not find favor among agronomists, however. When apprised of Lal's results, the French chairman of the institute's board said he simply could not believe that Lal would seriously recommend not tilling. What kind of madness was that? The foundation experts and development agency guys—everyone whose opinion mattered—all knew that more plowing was better. So Greenland and Lal were sent off to consult colleagues who could correct their misguided views. But what they found instead convinced them of the validity of their findings all the more.

Particularly informative was a visit to influential scientists who advocated plowing at the end of each rainy season based on experiments comparing tilled and no-till plots. They told Lal that after harvesting, they carefully removed the crop residue from their no-till plots to simulate the grazing practiced by traditional farmers throughout the Sahel. This left no mulch, exposing bare ground. They didn't use herbicides on their no-till plots, so weeds proliferated and crowded out the crops. They then compared the resulting feeble harvests to those from the plowed plots where tillage had suppressed the weeds.

Lal considered this a misleading comparison. Leaving crop residue on the fields was the whole point of not tilling—the reason it worked to stop erosion. And plowing suppressed weeds much like an herbicide did. The agency scientists' rationale for their study design was that African farmers didn't use herbicides and often removed crop residue to use as cooking fuel. But Lal saw that the experiment did not evaluate whether no-till worked if crop residues stayed on the fields—as his own experiments had done. Here was what the agency scientists were missing—their comparison was no comparison at all.

Lal came to the conclusion that resistance to getting no-till adopted in Africa stemmed from the general belief that herbicides were necessary for weed suppression if one didn't plow. And at that time the primary herbicide available was paraquat, which was too expensive for subsistence farmers. That left using cover crops and mulch as the only options to suppress weeds.

Based in part on Lal's experiments, Greenland published a prescient paper in the journal *Science*, titled "Bringing the Green Revolution to the Shifting Cultivator." After Lal mentioned this 1975 article to me, I looked it up and saw that Greenland had spelled out the essential principles of conservation agriculture. He pointed out how the Green Revolution excluded traditional subsistence farmers, who lacked capital and could not afford new equipment, chemicals, and patented seeds. Changes in practices—new ways of thinking—offered subsistence farmers their best shot at continuous cultivation. Farmers needed to eliminate tillage to reduce erosion, and plant a diverse mix of high-yielding crops that included legumes (like cowpeas).

Greenland anticipated criticism of his recommendations, which ran counter to the prevailing view that the path to agricultural development lay through mechanization. To liberate farmers from "the drudgery of the hoe," he recommended the use of herbicides spot-applied by low-cost backpack sprayers. Then he went on to emphasize how proper mulching could be just as effective for weed suppression. Greenland

thought that minimizing disturbance of the ground and planting a complex mix of cover crops could not only move subsistence farmers from traditional shifting cultivation to continuous cultivation, but double or triple their yields in the process.

After five years of experiments, Lal and Greenland concluded that what matters most is not what farmers grow but how they grow it. Lal developed guidelines, based on soil moisture and texture, for the most appropriate types of farming for different environments and soils. Eventually, after a decade of work in the tropics, Lal boiled his experience down to two key recommendations: don't clear the forest if you can avoid it, but if you do, make sure you leave the ground covered with vegetation or mulch.

By the time he left Africa in 1987 to take a position back at Ohio State University, Lal had worked on soil problems in fourteen countries on four continents. Although the settings, soils, and climates differed greatly, his experiments all pointed to the value of ground cover and mulch for preventing destructive erosion and for keeping soils fertile. In subsequent publications he emphasized the importance of mulching and cover cropping for sustaining the productivity of tropical soils.

Within two years of his departure from Africa, trees were growing through his experimental plots. The grand experiment was over. He'd figured out something that would work for subsistence farmers. So why were his findings all but ignored?

Funders and aid agencies alike wanted breakthroughs and rapid revolutions, not gradual improvement of the soil. Commercial interests pushed to develop solutions that could be commodified; they wanted agrochemical products, not practices that anyone could adopt for free. No modern, forward-looking foundation or agency wanted to hear about mulching or growing a diversity of crops. Such simple answers did not—and still don't—fit the technophilic narrative of progress.

APPLES TO ORANGES

Though disappointed with the lack of interest in his African experiments, Lal saw his ideas find more fertile ground in South America, where intense tropical rain routinely devastated plowed fields. In 1971, Herbert Bartz began experimenting with reduced tillage on his farm in southern Brazil. It didn't go well at first. The next year Bartz visited the United States and Europe to learn about no-till planting through straw to promote infiltration and reduce erosion. He also learned that agronomist Rolf Derpsch was conducting field trials in Brazil. Eager to demonstrate that no-till technology could work in Brazil, Derpsch sent a seeder to plant a half-hectare plot of wheat on Bartz's farm. The no-till crop was a little greener and looked better than the rest of the crop. After Bartz ordered his own no-till planter, he and Derpsch kept experimenting.

Over the next several decades, South American scientists and farmers put together the system of farming we know today as conservation agriculture. Its popularity really started to grow in the 1990s, and today no-till is approaching 100 percent adoption in Argentina and southern Brazil. Because of this, the problems of serious erosion and degraded soils have been vastly alleviated across South America.

However, less than half of no-till farmers in South America use all three principles of conservation agriculture. Some leave crop stubble on their fields, others use it for cooking fuel or sell it as feedstock for biofuel production. And in response to government policies favoring commodity production, many no-till farmers in South America opt to continuously cultivate soybeans and forgo crop rotations.

When I was born, in the early 1960s, few American farmers used no-till methods. Back then more than 75,000 plows were sold each year. Yet slowly but surely, America's reliance on the plow began to wane. By 1990 fewer than 3,000 were sold annually, and in 1991 less than half that many were sold. What drove this decline?

The development of new farm equipment that could manage crop residue and plant through a surficial layer of organic matter certainly facilitated forsaking the plow. And rising fuel prices in the 1970s further spurred interest. But easy chemical weed control from Monsanto's development of Roundup (glyphosate) and genetically modified glyphosate-tolerant crops in the 1990s accelerated the adoption of no-till. And this, in turn, helped open the door for conservation agriculture as farmers began gradually adopting the other two principles as well.

Globally, conservation agriculture was practiced on less than 3 million hectares in the early 1970s. By the early 1980s, it had more than doubled to over 6 million hectares, and by 2003 it increased another twelvefold to 72 million hectares. By 2013, it had doubled again, to 157 million hectares. And yet, despite this rapid pace of adoption, only about 11 percent of global cropland is under conservation agriculture. More than three-quarters of the farmland under conservation agriculture is in the Americas, with almost half (42 percent) in South America and about a third (34 percent) in the United States and Canada. In the United States, some 35.6 million hectares of land—21 percent of the nation's cropland—was farmed using conservation agriculture in 2013. But conservation agriculture accounts for just a few percent of cropland in Europe, Asia, and Africa. In other words, there is still a lot of room for adoption.

As Lal and I talked in that Swedish hotel lobby, we kept coming back to the topic of conventional versus no-till farming—and the inadequacy with which these methods are studied, compared, and ultimately recommended. One such recent study questioned the ability of no-till practices to increase soil organic matter; another concluded that crop yields under conservation agriculture were lower than under conventional practices. Lal thought that these studies involved a fruit salad comparison—apples versus oranges versus bananas—as many of the cited studies did not leave crop stubble on the fields, and thus didn't adopt full conservation agriculture methods. It was just like the early comparisons in Africa.

A 2014 paper published in the journal *Nature* reflected some of this skepticism in conservation agriculture. This meta-analysis of 610 previous studies compared conventional practices to no-till practices, in various combinations with the other principles of conservation agriculture (cover cropping and crop rotation). Averaged across all the data, no-till practices decreased crop yields by almost 6 percent. In drylands, however, adoption of all three conservation agriculture principles increased yields by up to 10 percent over conventional practices. And after three years of no-till, crop yields from fields that followed all three principles (no-till, residue retention, and crop rotations) were indistinguishable from conventional fields. In other words, after an initial several-year transition period, there was no yield penalty for adopting conservation agriculture practices. Yet the authors of the paper emphasized, and media coverage trumpeted, that no-till farming reduced crop yields.

This, of course, riled Lal. The real test, he said, was to measure the performance of conventional farms against those that adopted *all three* principles of conservation agriculture. As it was, the wide range of practices described under the umbrella of "no-till" painted a misleading picture of conservation agriculture.

Such concerns led Rolf Derpsch and a team of leading researchers to argue for the standardization of no-till research methods to avoid just such confusion. They noted that crop yields increased where farmers experienced in conservation agriculture practices guided the conversion process, whereas yields decreased in inexperienced hands. They pointedly recommended that scientists "master the no-till or conservation agriculture system" before "attempting to research the system."[14] In their view, it seems, academics with little experience in the full system of conservation agriculture had drawn inaccurate conclusions from studies with ill-defined variables. Like Lal, they were concerned that studies reporting lower yields under conservation agriculture were making flawed comparisons.

At his talk in Malmö, Lal said our agricultural problems—and their solutions—are rooted in the way we manage soil and its world of living organisms. He showed a diagram with overlapping circles to illustrate the processes, factors, and causes of soil degradation. Erosion, salinization, and nutrient depletion were the primary processes, and the factors that drive these processes mostly lie beyond an individual farmer's control—climate, topography, socioeconomic forces, and cultural issues. But the *causes* of soil degradation were the particular practices of deforestation, plowing, and irrigation. These were the things that farmers had the power to change.

He went on to describe soils as ecological systems with thresholds or tipping points, which, after being reached, trigger significant change. One of the most important of these, he said, is when soil organic matter drops below 1 percent. Many tropical soils are already degraded to less than half this level, due to extractive farming with indiscriminant plowing and removal of crop residues. Time and again, Lal has seen this combination produce a spiral of soil degradation, human desperation, and social unrest.

Conversely, conservation agriculture could restore degraded soil and reverse the spiral to restore social and political stability. Agriculture could become a solution instead of a problem. Lal argued that while making adaptations for every site is specific and exacting, the principles of sustainable soil management are universal and simple. Putting these principles into practice requires a systems approach—just what conservation agriculture provides.

For me, Lal's take-home message was that, when it comes to farming, practices as well as the condition and quality of the soil are as important as agricultural technology.

PERENNIAL CHANGE

A couple of weeks after I talked with Lal, I caught up with charismatic septuagenarian Wes Jackson at a conference on the future of civilization at Pomona College in Claremont, California. I'd known of Jackson's work since reading his visionary 1980 book *New Roots for Agriculture* as an undergraduate. In it, he laid out another strategy for ditching the plow—growing crops that don't need to be planted each year. Ever since, he and his colleagues at the Land Institute in Salina, Kansas, have worked on breeding perennial crops.

Jackson talks like a Methodist preacher, mixing biblical metaphors, personal stories, and home-style humor, generally at his own expense. He paints agriculture as a dramatic tragedy, one in which the way we grow our food undercuts our ability to keep feeding everyone. He may look like a grandfatherly Kansas farmer, but if you get him talking about the need to save agriculture from itself, he glows with the fire of a young radical.

For forty years now, his team has worked to domesticate wild perennials and cross annual grain crops with perennial relatives in the hope of replacing conventional annual crops with deep-rooting perennial crops. In other words, Jackson's team creates GMOs, only they do it the traditional way, through plant breeding. The advantages of developing perennial crops from annual crops is huge. Not plowing to plant each year would be the ultimate in no-till agriculture, since the best way to stop using the plow is to grow crops in fields that never need plowing.

Why has he invested decades in the painstakingly incremental, old-school genetic modifications of plant breeding? A perennial ground cover is nature's recipe for reducing erosion and building soil organic matter, and thus soil fertility, over time. Developing perennial crops would not only eliminate soil erosion; it would greatly reduce the need for agrochemical fertilizers and fossil fuels.

Born on a farm near Topeka, Kansas, Jackson considers himself "objective in just the right way." After establishing the environmental studies program at California State University in Sacramento in 1971, he came to see neglect of basic principles of ecology as the Achilles heel of agronomy. Forty years old, with tenure, he returned to Kansas and started the Land Institute in 1976 to develop farming methods to build and protect soil. Appalled by erosion reminiscent of the 1930s, he began the pursuit of natural systems agriculture—the use of ecological principles to emulate natural productivity in agricultural production. On the Great Plains, that meant looking to undisturbed prairie. It soon became clear that the secret to an unplowed prairie's productivity lay in a mix of warm- and cool-season grasses, legumes, and members of the sunflower family.

Jackson realized that the prairie had remained productive since the Ice Age by keeping the ground clothed in greenery year-round, denying the bullying efforts of wind or rain. Subject to repeated fires and buffalo grazing, the prairie relied on rootstock tucked away belowground for its continuous regrowth. Reminders of how far we've gone astray since that time were on display all around the new institute, in neighbors' fields that bled brown runoff in spring storms.

But how to transform this land? Jackson wanted an herbaceous polyculture founded on perennial grains instead of annuals. Yet all of humanity's major grains were annual grasses. If he wanted perennial grains, he'd have to make them.

So the Land Institute set about trying to transform wild perennial wheatgrass into a perennial grain, their goal to build a domesticated prairie that would produce grain. Jackson predicted it would take fifty to one hundred years to do the research and breed the plants. As it turns out, his team is ahead of schedule—way ahead.

That's a good thing. Time is not on our side. Lately, Illinois corn yields have been dropping by a bushel per acre a year. Modern fertilizers have proven inefficient, as grains take up just 40 to 70 percent of the nitrogen farmers apply to fields. Producing nitrogen fertilizer through the Haber-Bosch process is both energy-intensive and requires a catalyst, a temperature of 400°C, and 350 times atmospheric pressure. Global pesticide production doubled after Rachel Carson published *Silent Spring* and then doubled again in subsequent decades. Modern agriculture may not be terribly efficient, but it has proven quite effective at degrading the soil and the life it supports.

Right from the start, experts thought that Jackson's idea that perennials could produce high yields simply would not work. But he saw deep roots as the best investment plants could make. So his team planted thousands of seeds each year, looking for plants that showed promise as grain crops. Then the breeding began. Doing this over and over, they produced a deeply rooted perennial grain that shows tremendous promise.

THE NEW PERENNIAL

With practiced flair, Jackson unrolled a large scroll across the conference table. People around the room gasped as a life-size photo revealed a side-by-side comparison of the root systems of conventional wheat and Kernza, the new wheatgrass variety. The three-foot-long, stringy root system of the wheat plant looked anemic next to the Kernza's beefy, ten-foot-long dreadlocked root mass. Behold, he proclaimed, the first perennial grain in history—and humanity's first new major crop in over 3,500 years. This achievement showed that wild perennials *can* become grain crops, an exciting possibility for farms across America, and potentially around the world.

Nearly forty years after his mission started, a thrilled Jackson showed off a video of the first mechanized harvest of a field of Kernza. The new grain had already been used to make beer, bread, and whiskey. Now Kernza was being harvested commercially, though on a limited scale. He seemed positively giddy.

As well he should. With more breeding, perennials will one day generally outyield annuals, given their longer growing season. Perennial crops also get a head start on developing a canopy cover and shading out weeds. Initially, Jackson worried that Kernza's success would cause it to be planted as a monoculture, but his crew has been making progress on other perennial crops. They now have perennial sorghum undergoing field trials in Central Africa. Perennial sunflowers and chickpeas are in the works too. The Land Institute is also experimenting with coplanting legumes with Kernza and allowing cattle to graze on Kernza stubble. There is still much left to do, of course, but Jackson

sees his dream of a domesticated prairie as a polyculture with multiple interplanted crops becoming an agronomic reality.

As I was writing this chapter, I got an email announcing that Jackson was stepping down as president of the Land Institute, just in time for his eightieth birthday. Not everyone gets to see big dreams bear fruit in their lifetime; Jackson is one of the lucky ones. He now is confident that, through applied ecology, we can harvest soil health as a consequence of agricultural production. This is revolutionary—the seeds of truly transformative change.

While Jackson's vision may be a sure way to solve the problem of soil erosion and sustain agriculture over the long run, plant breeding is a slow game. Even Jackson estimates it will take decades to finish his work. And there is no commercial support for development of perennial crops. No seed company will touch perennial crops, for obvious reasons: What kind of business model is it to only sell a customer seeds once? Seed companies, like drug companies, want repeat customers year after year. And this is what annual seeds guarantee those who sell them, especially proprietary and patented ones. So what can we do in the meantime?

In theory, conservation agriculture practices could be adopted tomorrow—without delay. But could they really work on farms large and small in both the developed and developing worlds? Few studies have examined the effect of adopting *all three* principles of conservation agriculture. So to find out, I decided to go and see for myself and embarked on a six-month tour of farms doing this on several continents. The first stop on this journey busted another myth of modern agriculture: the contention that no-till farmers *need* to use a lot of herbicides and fertilizers.

13

THE FIFTH REVOLUTION

The biggest barrier to agricultural progress is between the ears.
—Kristine Nichols

As I started working on what would become this book, my wife, Anne, and I visited the Eden Project in southern England—the world's largest greenhouse, made of enormous geodesic domes built in the open pit of an abandoned clay mine. One exhibit featured a twenty-foot-tall nutcracker designed by an industrial absurdist. Scrap-iron pulleys, chains, cranks, and levers launched big metal marbles down tracks to turn gears that slowly hoisted a wrecking ball into the air before dropping it onto a carefully positioned hazelnut. Kids competed to power the thing, turning a crank on the side of the enclosure that held the device. We joined an enthralled crowd and watched the intricate dance of parts designed to solve the problem of cracking a nut.

Upon leaving the pavilion, Anne pointed out plenty of perfectly good rocks lying around that could do the same job with little effort in a fraction of the time. Here was the exhibit's broader lesson. Even with simple solutions in plain sight, complex ones attract our attention—and interest.

But simple ideas that solve problems do catch on. And visiting farmers around the world who were doing well putting regenerative

agriculture into practice convinced me that building soil health offers a practical, cost-effective way to restore degraded land and maintain or increase crop yields with less oil and agrochemicals. Seeing how these innovative farmers restored their soil, their farms, and their bank accounts convinced me that we could avoid the fate of past civilizations. It's not a question of if we can, but whether we will.

Conventional wisdom says that fertile soil is not renewable, that it can't be replaced. But that's not really true. Fertility can be improved quickly through cover cropping and returning organic matter to the land. Soil-building is about getting the biology, mineral availability, *and* organic-matter balance right, rolling with the wheel of life instead of losing ground pushing against it.

As we've seen, restoring fertility to the world's cropland is not an either-or choice between modern technology and time-tested traditions. We can update traditional wisdom *and* adopt new agronomic science and technology. Solving the problem of land degradation is devilishly simple from a practices standpoint. The difficulty lies in marshaling the political wherewithal to stop subsidizing conventional farming and start promoting practices that build soil fertility.

The principles of conservation agriculture offer flexible, adaptable guidelines for restoring soil health, feeding the future, and ensuring that farmers can make a living without damaging the environment. Everywhere I went, from the tropics to the plains, I found that farmers who minimized soil disturbance and adopted practices to increase soil organic matter and cultivate beneficial microbes could build fertile soil on both conventional and organic farms.

Of course, the specifics vary. Every farm is unique to some degree. What works well in temperate grasslands may not work so well in tropical forests. We need to tailor practices to the land and be mindful of geographic and social context, as we seek to optimize the use of land, labor, chemical and organic inputs, and machinery to increase farm profitability *and* soil health.

The way to meet this challenge is to figure out how to get farmers to adopt practices covering all three principles that work for them on their farms. For it does take all three—minimal soil disturbance, growing cover crops, and devising complex rotations that work together as a system. Leave one piece out and it doesn't do what it's supposed to, just like a stool that needs all three legs to stay upright.

The farmers I visited are not pushing ideas to sell other farmers anything, land their next grant, fatten their reelection coffers, or please a funder or employer. They share a deep sense of community and want to pass on knowledge of a system that works well for them—and could for others too. And while they came to this viewpoint via their own experiences, they are not alone.

Both the United Nations Food and Agriculture Organization (FAO) and the World Bank recommend the three elements of conservation agriculture as the key to sustainable development for small farms in the developing world. The World Bank promotes these same principles as the basis for "climate-smart" agriculture to increase crop yields, reduce greenhouse gas emissions, sequester carbon in soils, and bolster agricultural resilience to climate change. Even agrochemical giant Monsanto now advertises soil health as central to the future of agriculture. If organizations across the ideological, political, and industrial spectrum agree on the need to adopt practices that enhance soil health, why aren't we promoting this with all the tools in society's policy toolkit?

Such a fundamental realignment of agriculture means big change across the board. There will be supporters and resisters. Who has the most to lose? Those who make and sell the agrochemical inputs on which conventional agriculture now relies.

Curiously, many of the arguments about conventional versus organic agriculture break down when viewed through the lens of soil health. Organic farms that adopt practices to boost soil health become more productive and conventional farms become more profitable. Recent reviews of nutritional studies report that organic foods not only have lower pesticide residue but higher phytochemical, antioxidant, and micronutrient density as well. What if we could get these health

benefits through minimal fertilizer and pesticide use, without going completely organic? Conservation agriculture offers such a possibility.

Converting conventional farms to lower-input practices also would help address problems of soil erosion, water retention, energy use, and nitrate, phosphate, and pesticide pollution. If improved soil health became a consequence of agricultural production, this would not only solve agriculture's oldest problem but help address some of the most pressing issues humanity now faces.

For soil restoration offers a triple harvest of societal benefits, along with better farm profitability. It simultaneously builds soil fertility to help feed the world and improve food quality, stores carbon to slow climate change and boost agricultural resilience to it, and conserves biodiversity on agricultural land. As a bonus, taxpayers could save money through reduced subsidies.

Restoring fertility to the world's degraded agricultural soils would reduce our dependence on energy-intensive practices and help sustain high crop yields in a postoil world. The farms I visited showed that yields under fully established conservation agriculture systems can meet or exceed those from conventional agriculture. And while the transition may take several years to pencil out, it makes far more sense over the long run.

A 2006 assessment of low-input, resource-conserving agricultural practices in 57 countries in Latin America, Africa, and Asia evaluated 286 development projects that used cover crops for nitrogen fixation and erosion control, applied pesticides only when crop diversity and rotations were not effective for pest management, and integrated livestock into farming systems. For a wide variety of systems and crops, the mean increase in yields was 79 percent, not quite a doubling of harvests but enough to feed the world of tomorrow if achieved globally. For projects that had data on pesticide use, yields grew by 42 percent, while pesticide use declined 71 percent. Many of these changes were attributed to practices that improved soil and crop health, and thereby allowed effective pest control with minimal pesticide use. This is evidence that more diversified, low-input farming can work for many subsistence farmers.

As a general rule, ecologists find that systems with greater diversity are more resilient. Monocultures rarely exist in nature. If they do arise, ecosystems with a single dominant organism don't tend to persist. On farms they are just as unstable and vulnerable to pests and pathogens. In constract, greater on-farm biodiversity is a recipe for resilience against pests and pathogens that's been field-tested in nature for hundreds of millions of years.

We have rules and regulations to prevent industries from polluting rivers and streams. Farmers shouldn't be allowed to either. No one—least of all farmers—should be satisfied with agricultural practices that degrade and pollute our waterways. Using less fertilizer would go a long way toward addressing pollution problems, like the one that recently led the Des Moines Water Works, which supplies the city's drinking water, to sue three Iowa farm counties over the nitrates contaminating the water supply. It's safe to say that something is wrong with our agricultural system when neighbors collectively sue those who feed them for poisoning their water. Widespread adoption of conservation agriculture would help solve nitrate, phosphate, and pesticide pollution problems writ small and large, from individual on-farm water wells to the great dead zone in the Gulf of Mexico.

And it is worth considering the inestimable value of soil biodiversity to human health in light of the fact that most modern antibiotics came from soil-dwelling microbes. We are far from knowing all the mircoorganisms that live in native soil communities. Who knows which one may next prove transformational for agriculture or medicine? We need to stop relying on tillage and intensive fertilizer use that bankrupts nature's stores. The accompanying alteration of soil biota reduces diversity and shifts bacterial and fungal community abundance and compositions. Restoring organic matter to soils and adopting practices with less physical and chemical disturbance can counter these problems.

The promise of conservation agriculture to bring life back to the land and support biodiversity both above and belowground should appeal to environmentalists and farmers alike. For like it or not, a large part of nature will be what lives on farms, because we now use more than a third of the world's ice-free land area for growing crops and raising animals.

But just because we *can* restore degraded land rapidly doesn't mean we will. Under conventional practices, an individual farmer often faces a choice between prioritizing short-term profit or conserving soil and its fertility over the long run. Yet as a practical matter, conservation cannot come at the expense of economic viability—any truly sustainable agriculture needs both to align. One of the most promising things about practicing all three elements of conservation agriculture as an agronomic system is that it can save conventional farmers both time and money.

Unlike the fertilizer-intensive Green Revolution practices that developed top-down through government agencies and corporate research, conservation agriculture has largely evolved and spread through bottom-up farmer-led initiatives. Why? A key attraction is the opportunity to improve a farm's bottom line by lowering input costs.

But it's not just farmers who are interested. A number of prominent foundations have adopted soil health as a central theme of their efforts. Chief among them are the Howard G. Buffett Foundation in Illinois, the Noble Foundation in Oklahoma, and the Regenerative Agriculture Foundation in California. And dozens of nonprofit organizations around the world now promote soil health and restoration, including the recently established Soil Health Institute in North Carolina. Even corporate titan Shell Oil is supporting a major test to assess the potential for large-scale carbon sequestration in rangeland soils.

Who are the biggest laggards? From my outsider perch, I'd have to vote for the USDA. While there are influential voices within the agency who are true leaders in the soil health movement, overall the agency isn't vigorously researching or promoting practices to rebuild the fertility of our soil—the foundation for our nation's future.

Hopefully, they're just getting started. In 2012, the Natural Resource

Conservation Service (NRCS) kicked off a national soil health program to promote knowledge of how practices like no-till, cover cropping, and diverse rotations build soil carbon and the microbial activity that underpins higher profits and yields. While this is an influential and welcome development, I got the impression from farmers I talked to that, overall, USDA programs undermine practices that promote and restore soil health, and some indirectly discourage adoption of conservation agriculture practices. There's a lot of inertia to overcome in order to change conventional farming. Yet as I was finishing this book, the White House Office of Science and Technology Policy issued a national call to action, encouraging public and private efforts to protect America's soil. Hopefully the tide is turning, for establishing a national soil health policy should not be a partisan issue.

Still, most academic agricultural research focuses on improving current methods and practices, rather than investigating the potential of alternative systems. Research on soil health and conservation agriculture systems has been estimated to receive less than 2 percent of agricultural research funding in the United States, and less than 1 percent globally. An analysis of 284 projects in the USDA-supported $294 million Research, Extension, and Economics program budget for 2014 found that projects including cover-cropping for pest control or soil-conditioning received 6 percent, and projects involving complex crop rotations received 3 percent. Rotational or regenerative grazing received less than 1 percent, as did research on integrated crop-livestock systems.

The vast majority of funding went to support incremental adjustments to conventional methods. Most agronomic research remains focused on testing or developing new products and technical advances in conventional practices. Over and over, farmers emphasized to me how our public research system has been subverted to focus on commercial products at the expense of regenerative practices. And yet it is shifts in practices that could prove truly transformative.

Why isn't there greater policy support for encouraging wider adoption of conservation agriculture and regenerative farming practices? Asking this, I got various earfuls from farmers. One factor they mentioned is the proverbial revolving door between industry executives and political appointees that run government agencies. And career civil servants know better than to advocate for change ahead of the political winds. I might have gotten a glimpse of this in the look on the face of a highly placed USDA official when I asked what he thought about either making crop insurance available only to farmers practicing conservation agriculture, or simply ditching the program altogether.

Naturally, one of the greatest obstacles is the influence of agribusiness lobbyists who purvey chemical solutions to biological problems. When I asked farmers why there is relatively little federal support for adopting conservation agriculture, most answered along the lines of "follow the money" to the major industries influencing Congress and regulatory agencies. Few were shy about pointing to what they saw as the biggest obstacles to change—turf-defending government programs and commercial interests steering the policy show.

Change will not come easy. Agribusiness is now as much about selling products to farmers as selling what farmers produce. One person I interviewed for this book told a story about one of his graduate students who'd gone back to the family farm one summer. The student worked out that, between higher input costs and lower crop prices, his father and brothers harvested a net profit of just 50 cents an acre the prior year. They would have been better off buying a single packet of pumpkin seeds and hand-planting them, forgoing the cost of inputs. Assuming a single pumpkin survived to harvest on each acre, they could have sold it for six times what they actually ended up earning—and saved themselves all the work of plowing, fertilizing, and harvesting. This story illustrates how the people making most of the money from farming are not the farmers. It's those who sell stuff to farmers who are doing really well under the current system—the companies who sell the inputs on which conventional farming rests.

Today, the margin between losing the farm and staying on the land is pretty tight for most farmers. They can't choose the price they pay for fertilizer, diesel, and all their other inputs, or set the price they get for their corn, wheat, or soybeans. But they can change their practices to reduce their need and expenses for inputs. As I was writing this chapter, I came across a study projecting that 27 percent of row-crop land in Iowa would lose more than $100 an acre in 2015, due to high input costs and falling grain prices. Something is seriously wrong with our agricultural system if hardworking Iowans growing crops on some of the best agricultural soil in the world can't make money farming.

Yet, if conservation agriculture is more profitable, why do the majority of farmers still practice tillage-based high-input farming? There are barriers large and small. In many regions, lack of knowledge about how to adapt conservation agriculture methods to local conditions and crops remains a major obstacle to their adoption. A 2012 FAO review reported that the key to farmers making the shift to conservation agriculture is providing them with local examples of successful implementation at full-scale demonstration farms, coupled with training and technical support for early adopters. Of course, another barrier is the potential economic hit a farmer can take during the transition.

Adopting conservation agriculture involves changes in long-standing cultural practices and a change in mind-set. It represents a new system of farming, the success of which depends more on what farmers do than on their level of input use. Over the past decade, conservation agriculture has been increasingly promoted among smallholder farmers in the tropics. Yet adoption of all three elements remains low; smallholder adoption worldwide remains just a few percent.

Much of the argument around conservation agriculture is not over whether its principles work, but over whether the great number of smallholders around the world will adopt them. Communal grazing, removal of crop residue for cattle fodder, and the use of animal dung for cooking fuel all hamper adoption of conservation agriculture in Africa and Asia. These practices curtail residue retention and thus preclude realizing the potential of the full system. And converting to no-till without adopting the other two elements of cover-cropping and diverse rotations can *reduce* yields.

Lack of access to capital and credit can also limit farmer access to even minimal inputs and seeds for crop diversification and rotation.

Lack of access to direct seeding equipment designed for use with low power equipment can also be a problem. Such farm-level socioeconomic constraints mean that adoption of conservation agriculture practices in Africa often involves adopting just one or two of its elements. Expanded adoption of conservation agriculture would require addressing these and other social challenges.

Barriers in the developed world include misinformation among agricultural authorities trained and steeped in conventional practices and views, as well as farmer resistance to change and prejudice for traditional or conventional methods. In addition, commodity-based subsidies and price supports favor monocultures or simple rotations, and crop insurance rules can discourage farmers from planting cover crops.

While there appears to be a strongly held view among many agronomists that conservation agriculture depends on mechanization, high input levels, and herbicide-resistant crops, the farmers I visited showed me that this is not actually the case. There is a wide range of ways to adapt farming practices to the general goal of improving soil health. Perhaps the label of conservation agriculture has outlived its usefulness in this regard. A more general goal would be to develop agricultural practices that bolster soil health *and* increase yields. This can be done—I've seen it done—on farms large and small, rich and poor, conventional and organic.

So far, however, it's a bottom-up revolution, driven by individual farmers looking for a better margin as they're squeezed between input and commodity pricing beyond their control. I thought farmers would want some top-down help. So I was surprised to hear them argue that making soil restoration a natural consequence of agricultural production would not require government subsidies. Almost all of those I talked to said that if government simply got out of the subsidy business altogether, organic and conservation agriculture farms would outcompete conventional ones. As it is we now subsidize and incentivize practices that degrade soil health.

Crop insurance and government programs for food security started in the Depression Era to protect farmers and ensure a stable food supply. All too often, they now offer farmers an easy out for poor practices, discouraging the kind of innovation that many farmers are particularly good at—problem-solving on their own piece of ground. Farmers themselves consistently volunteered that farming practices would turn on a dime if crop insurance programs incentivized conservation agriculture.

New Zealand already showed that eliminating agricultural subsidies won't lead to catastrophe. Farmers fiercely resisted when the government decided in 1984 to end farm subsidies that accounted for more than a third of gross farm income. The disaster they predicted never struck. Twenty years later, the Federated Farmers of New Zealand published a retrospective report that concluded the move resulted in substantial productivity increases, more diversified land use, and more efficient use of fewer farm inputs, particularly fertilizers, which lowered their production costs. Farmers were no longer chasing subsidies and pursuing maximum yields at any cost. After two decades off subsidies, the farmers themselves concluded that the former subsidies had limited agricultural innovation and productivity.

We in the United States have our subsidies backward. Changing crop insurance programs and subsidies to promote building soil health could better align farmers' short-term interests with society's long-term interests. Why not financially backstop farmers for the first couple of years, during the transition period? At the very least, soil-building practices should get a better payout instead of automatic disqualification, as farmers I talked to repeatedly complained about. Revising commodity support programs to encourage, if not require, cover crops and diverse rotations offers another way to move toward practices that improve soil health. From a societal perspective, it makes sense to restructure agricultural subsidies to reward farmers for improving soil fertility—it makes none to continue subsidizing practices that do the opposite.

While no single metric can capture the complexity of soil health, soil carbon offers an essential, simple way to judge and measure it. Allowing farmers to bank carbon credits through increasing soil organic

matter would provide an incentive for investing in soil restoration. Carbon credits could provide an income stream for farmers based on the societal value of carbon sequestration, reduced water pollution, and maintenance of soil fertility and pollinator populations. A 2015 paper by a consortium of European researchers estimated that, on average, a 1 percent loss in soil organic carbon translated to a societal loss of natural capital amounting to about $66 an acre. Rattan Lal estimated the societal value of carbon at $120 per ton. I suspect that if farmers could make that much an acre per year they would flock to adopt soil-building practices.

Big changes in thought in both academia and agencies like the USDA tend to occur as people retire and new people come on board with different training and ideas. It is difficult for authority figures like professors, senior scientists, and technical staff to accept that what they taught for decades is, at best, only part of the story. The recent NRCS push to promote soil health as foundational to both good farming and our national interest should not only continue but receive greatly increased support.

When we were driving across Kansas, Guy Swanson told me that he thinks the key to increasing adoption of no-till is to start with younger farmers who don't already believe they need to plow. It would also help to expand agronomy curricula to include teaching and research on conservation agriculture practices as a viable system of environmentally attractive, economical alternatives to conventional practices. A parallel effort is needed to develop educational literature on conservation agriculture practices to provide to farmers, agricultural universities, and schools around the world.

We also need programs to put young people back on the land—and reward them if they build soil health. The average age of American farmers is about sixty. As the current generation of farmers retires, we need to encourage a new generation to return to the land—and train and equip them to adopt regenerative practices.

When Anne and I were in England, we learned of a novel program to save family farms and establish a new generation on the land. The program paired farmers nearing retirement who had no family member interested in taking over the farm with young people who wanted to be farmers but lacked the means to buy a farm. The older farmers would teach the younger ones, and the younger farmers would build equity through their labor and eventually buy out their retiring mentors.

A North American version of such a program might be thought of as a twenty-first-century Homestead Act. Another possibility would be to set up a public land bank for foreclosed farms and agricultural land to facilitate young people buying a farm with a long-term investment of labor. The deal might be that if this new kind of homesteader-farmer improves their soil enough over twenty years, the farm becomes his or hers. Such a program could be used to help preserve enough fertile farmland near cities to feed urban populations well into the future, something in everyone's interest.

Another idea would be to update what worked well for centuies and reintegrate crop and livestock production on farms small and large. In particular, this offers a major opportunity to turn manure from hazardous feedlot waste into a valuable tool for building soil health. In this case, concentration really is the problem, and dilution really is the solution. We need to work manure back into the soil on *a lot* of farms instead of dumping it all in centralized locations to form toxic lagoons.

Of course, spreading composted manure back on agricultural fields should motivate rethinking what we feed cows. Most immediate and critical is ending the use of antibiotics for growth promotion and other unintended purposes. And as far as feeding the world goes, it's obvious that grazing cattle on crop stubble is better than raising them on crops we humans can eat.

The path to promoting the return of livestock to smaller diversified farms lies in rebuilding decentralized infrastructure like small-scale slaughter facilties to make meat production and processing easier for small farms. Streamlined permitting and regulatory processes for small farms and packing facilities would also help. Gabe Brown pointed out to me that big salmonella outbreaks tend to come from large meat processors whose constantly running, large-scale operations are challenging to clean. In this arena, I can see sound policy and public health reasons for favoring the little guy over big operators. Of course, the big packers have more money and lobbyists than do small farmers.

Finally, another obstacle is that at present there is no way for consumer demand to support soil health, other than by consumers buying organic. But this doesn't always match up well. After all, organic practices do not necessarily improve or maintain soil health—it depends on the organic farmer's practices, especially tillage. Informed consumers are one of the best and fastest ways to move the commercial dial in market economies. If consumers realized that their health is intimately connected to the quality and fertility of soil—for better or worse—this could help move conventional farming toward more sustainable, organic-ish practices. So how can we brand soil health to provide consumers the information necessary to make the well-informed choices they deserve and desire? I suspect that the best approach would be some kind of "soil safe" certification from a national association of regenerative, soil-building farmers.

Achieving the full potential of a soil health revolution will take every tool in our agrotechnology toolkit—and a lot of open-minded experiments to adapt and amend the general principles of conservation agriculture to specific farms, soils, and crops. Farmers typically say they want to leave the soil better than they found it, but they don't always know how to go about doing it. What makes for a good rotation in Missouri will not necessarily work well for Pennsylvania, or eastern Washington. Still, however one looks at it, corn-soy is not a complex rotation. But if that's what you've been growing—what your crop advisors have recommended you grow year after year—what should you grow instead? A common element in the successful adoption of conservation agriculture in regions I visited was the value of regional demonstration farms in promoting farmer adoption.

Farms like Dakota Lakes and Kofi Boa's No-Till Center offer models for how to make agricultural research more relevant to farmers' needs. Demonstration farms can show farmers how to adopt new systems without betting their own farms. What is the best way to establish demonstration farms focused on soil health? In addition to the farmer-owned co-op model of Dakota Lakes, another is to use the national network of conservation districts. Almost every county in the United States has one, established under state law and known by different names in different states. Menoken Farm in Burleigh County, North Dakota, shows how well this can work. A private-sector model offers a third—like Kofi Boa's No-Till Center and the Rodale Institute—and publicly supported farms are potentially a fourth model. What is universal is the need to establish such farms. A global network of demonstration farms dedicated to pursuing regional recipes for regenerative agriculture is one of the best investments humanity could make in our own future.

On my travels I heard a lot about how most current agricultural research is largely irrelevant to practicing or adopting conservation agriculture. A common complaint is that academic researchers shun applied research or won't try to adapt methods to new areas or settings. Another called out small-scale research plots that farmers find unconvincing, and the organization of agronomic science into disciplinary silos that discourage the type of cross-disciplinary, system-level thinking, insights, and research that underpin conservation agriculture. We need more agronomists and soil scientists working together with soil biologists, entomologists, and others. These are all things that demonstration farms could facilitate and do well.

When Soviet premier Nikita Khrushchev flew nonstop from Moscow to Washington on September 15, 1959, Americans were stunned. Our planes couldn't do that! At dinner that evening Khrushchev went a step further and gave President Eisenhower a replica of the Soviet Lunik 2 probe. To much fanfare, it had landed on the moon the day before. How could we top that? Three years later, President Kennedy declared that America would put a man on the moon by the end of the decade—and bring him back safely.

As I write this, we're approaching the fiftieth anniversary of Apollo 11, and I see some parallels. We need to bring the same intensity and focus to bear on transforming conventional agriculture.

How can we do this? Adopt policies that promote soil-building practices. We need a soil health moonshot, an era of public investment in research and incentives to change the business of agriculture and secure the living foundation for our future on this planet. Obviously, the private sector would be involved in such an endeavor, but private corporations are unlikely to spearhead and support research into practices that use fewer of their products. Yet soil health should serve as the new lens through which to evaluate agricultural science, practices, and technologies. We need to train a new generation of systems thinkers and support research on practices as well as products—with an emphasis on strategic partnerships with farmers, the people who actually grow our food, fodder, and fiber.

Our understanding of the world—and of soil—has changed dramatically over time, and could do so again. Since the dawn of agriculture, people have seen soil as something to be worked, an arena in which human labor could harness and tame nature. Societies around the world cast the great mystery of soil fertility as a gift of the gods, with harvests subject to change on a whim or a prayer to the Greek Demeter, the Roman Ceres, or the Hindu Lakshmi. And for many today, as then, the fertility of the soil remains the key to a livelihood.

With the advent of the Renaissance, soil offered a decipherable mystery that could be understood through the application of reason. As natural philosophers began to contemplate its secrets, Leonardo da Vinci famously wrote, "We know more about the stars overhead than the soil underfoot." His words still ring true today, more than five hundred years later.

When early agronomists began investigating soil fertility and husbandry, crop rotations and animal manure became central to improving land and building fertile soil. But these ideas lost their luster in the nineteenth century with the discovery of the power of chemical fertilizers to boost crop yields on degraded land. The near-miraculous effects of these new chemical supplements gave rise to the view of soil as little more than a physical receptacle for agrochemicals, a reservoir or gas tank to be topped off as needed. The mechanization that then reshaped agriculture led people to increasingly view soil as the least expensive—and least valuable—input in industrial crop production. As we've seen, this perspective has done grievous harm to the world's soil—civilization's foundation.

Views of soil fertility are changing once again as we begin to accept that it depends on soil biology as much as soil chemistry and physics. And while we still have much to learn, recent discoveries reveal that soil ecology holds the key to nutrient availability and cycling, and to maintaining soil fertility. Now that we know the critical role of soil life, we can see the necessity of viewing soils rich in organic matter as an essential part of nature's grand cycle of growth and decay.

Perhaps we can turn to history for some inspiration. Our founding farmers Jefferson and Washington followed two out of the three principles of conservation agriculture, but relied on the plow for planting and weed control. They almost got it right. Today we have no-till planters and other means of weed control, the third leg we need to stabilize the agricultural stool.

The essence of this new revolution-in-the-making isn't complicated. It boils down to two words—soil health. On the ground this means prioritizing agricultural practices that build soil organic matter. Yet farmers don't need to go organic to lead the charge or play a supporting role. Agrochemicals can be useful tools—when used wisely. But relying on them to substitute for healthy fertile soil really does live up to the "more on" moniker. We need to embrace a new philosophy that evaluates farming practices by assessing whether they build or mine soil fertility.

After centuries of degrading the soil upon which our continued livelihood depends, we need to reinvest in our most fundamental resource if our global civilization is to avoid the fate of prior regional ones. At a basic level this sounds pretty simple. The problem is that we have to do it on national and global scales. And for this we need a new system of farming, an agricultural system that yields not just bountiful harvests but improved soil health.

Part of the reason the Green Revolution worked so well was that we'd already seriously degraded soil fertility through killing off soil life with mechanical disturbance and chemical inputs. Substituting fertilizers and pesticides for soil life compensated for this lost fertility. Now, we need a new philosophy of conventional farming, a fundamental rethinking of the basic principles behind how we do it. Brain transplants, as Dwayne Beck more colorfully puts it. We need changes in practices as much, if not more, than we need new technologies. Of course, technology and agrochemicals can help, but they provide tools that can be employed in a good or bad system. And I know we can farm smarter. Farmers I visited already do.

Their revolutionary approach might best be captured as: ditch the plow, cover up, and grow diversity. These regenerative agricultural practices don't require cutting-edge technology or waiting to invent something new. They are ready to go and scalable to small- and large-sized farms using existing technology in both the developed and developing worlds. As we've seen, innovative farmers already following these principles demonstrate that they can work better for both the land and those who work it.

The convergence of new science, declining resource availability, and a rising population calls for creative solutions. Fortunately, conservation agriculture offers an already demonstrated way to increase crop yields that is not yet widely used. Its transformative potential lies in adopting all three of its underlying principles and recognizing the need to develop practices well suited to different soils, climates, crops, and even individual farms. And while soil health is no silver bullet, it's becoming less of a secret weapon as the farmers that have abandoned conventional agriculture for regenerative practices see that this allows them to grow more with less.

Yes, we really can change the world and write a new ending to an ancient story. For fertile soil can be lost through—or result from—how we farm. I find it fitting that *humus* and *human* share the same Latin root, as restoring healthy soil to the world's agricultural lands is one of the best investments we can make in humanity's future. And so as we grapple with the daunting problems of how to feed the world, cool the planet, and stem losses in the natural world, let's not lose sight of a simple truth. Sometimes answers we seek are closer than we might think—right beneath our feet.

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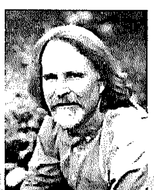

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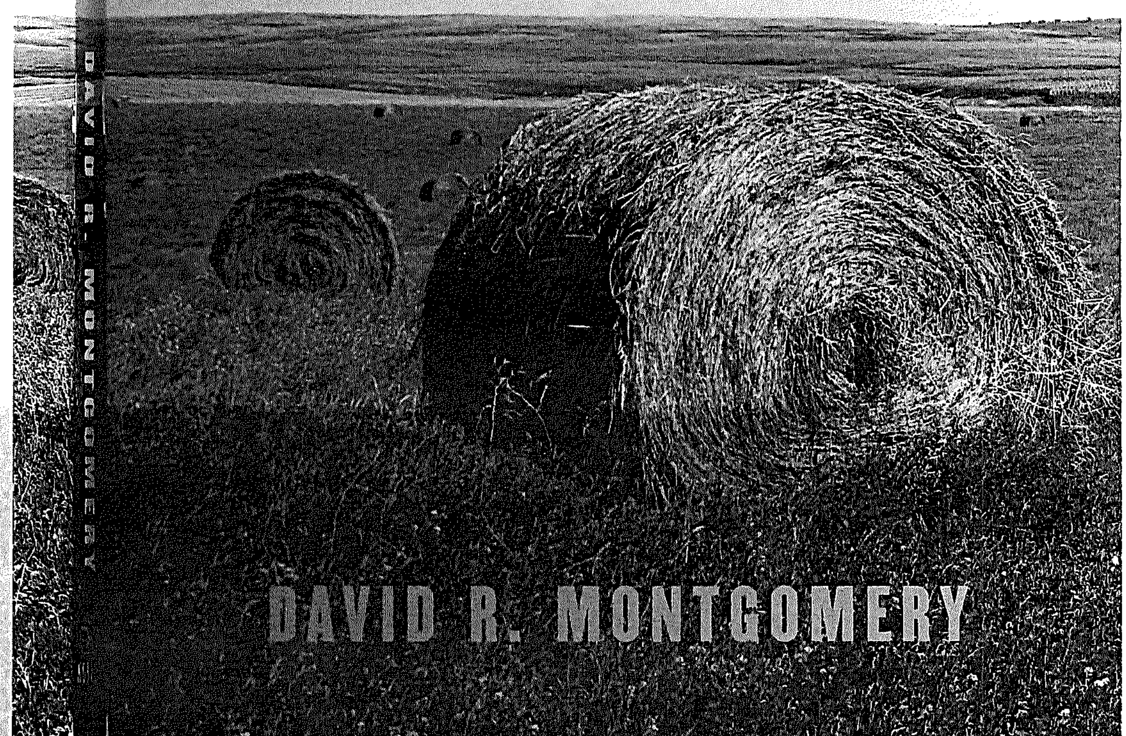

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