No-Till: *the Quiet Revolution*

The age-old practice of turning the soil before planting a new crop is a leading cause of farmland degradation. Many farmers are thus looking to make plowing a thing of the past

By David R. Huggins and John P. Reganold

NO-TILL PIONEER John Aeschliman began experimenting with the technique in 1974 out of concern over the soil erosion that was taking place in Washington State's sloping Palouse region, where his farm is located.

ANDY ANDERSON

John Aeschliman turns over a shovelful of topsoil on his 4,000-acre farm in the Palouse region of eastern Washington State. The black earth crumbles easily, revealing a porous structure and an abundance of organic matter that facilitate root growth. Loads of earthworms are visible, too—another healthy sign.

Thirty-four years ago only a few earthworms, if any, could be found in a spadeful of his soil. Back then, Aeschliman would plow the fields before each planting, burying the residues from the previous crop and readying the ground for the next one. The hilly Palouse region had been farmed that way for decades. But the tillage was taking a toll on the Palouse, and its famously fertile soil was eroding at an alarming rate. Convinced that there had to be a better way to work the land, Aeschliman decided to experiment in 1974 with an emerging method known as no-till farming.

Most farmers worldwide plow their land in preparation for sowing crops. The practice of turning the soil before planting buries crop residues, animal manure and troublesome weeds and also aerates and warms the soil. But clearing and disturbing the soil in this way can also leave it vulnerable to erosion by wind and water. Tillage is a root cause of agricultural land degradation—one of the most serious environmental problems worldwide—which poses a threat to food production and rural livelihoods, particularly in poor and densely populated areas of the developing world [see "Pay Dirt," by David R. Montgomery, on page 76]. By the late 1970s in the Palouse, soil erosion had removed 100 percent of the topsoil from 10 percent of the cropland, along with another 25 to 75 percent of the topsoil from another 60 percent of that land. Furthermore, tillage can promote the runoff of sediment, fertilizers and pesticides into rivers, lakes and oceans. No-till farming, in contrast, seeks to minimize soil disruption. Practitioners leave crop residue on the fields after harvest, where it acts as a mulch to protect the soil from erosion and fosters soil productivity. To sow the seeds, farmers use specially designed seeders that penetrate through the residue to the undisturbed soil below, where the seeds can germinate and surface as the new crop.

In its efforts to feed a growing world population, agriculture has expanded, resulting in a greater impact on the environment, human health and biodiversity. But given our current knowledge of the planet's capacity, we now realize that producing enough food is not enough—

KEY CONCEPTS

- Conventional plow-based farming leaves soil vulnerable to erosion and promotes agricultural runoff.
- Growers in some parts of the world are thus turning to a sustainable approach known as no-till that minimizes soil disturbance.
- High equipment costs and a steep learning curve, among other factors, are hindering widespread adoption of no-till practices.

—The Editors

[HISTORY]

AGRICULTURE MILESTONES

The roots of both no-till and tillage-based farming methods run deep, but eventually the latter approach predominated, thanks to the evolution of the plow. Over the past few decades, however, advances in herbicides and machinery have made no-till practical on a commercial scale.

8000 B.C.

Planting stick, the earliest version of no-till, enables the planting of seeds without cultivation.

Scratch plow
the earliest plow, clears a path through the ground cover and creates a furrow into which seeds can be placed.

6000 B.C.

Draft animals replace humans in powering the plow.

3500 B.C.

Plowshare, a wedge-shaped implement tipped with an iron blade, loosens the top layer of soil.

1100 A.D.?

Moldboard plow
has a curved blade (the moldboard) that inverts the soil, burying weeds and residues.

Mid-1800s

Steel moldboard plow
invented by John Deere in 1837, is able to break up prairie sod.

Early 1900s

Tractors
can pull multiple plows at once.

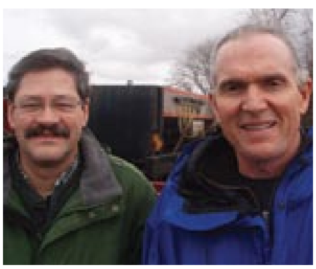
1940s–1950s

Herbicides such as 2,4-D,atrazine and paraquat enable farmers to manage weeds with less tillage.

1960s

No-till seeders
slice open a small groove for seeds, keeping soil disturbance to a minimum.

[THE AUTHORS]



David R. Huggins (*left*) is a soil scientist with the USDA-Agricultural Research Service, Land Management and Water Conservation Research Unit in Pullman, Wash. He specializes in conservation cropping systems and their influence on the cycling and flow of soil carbon and nitrogen. John P. Reganold (*right*), Regents Professor of Soil Science at Washington State University at Pullman, specializes in sustainable agriculture. This is his third article for *Scientific American.*

it must also be done sustainably. Farmers need to generate adequate crop yields of high quality, conserve natural resources for future generations, make enough money to live on, and be socially just to their workers and community [see "Sustainable Agriculture," by John P. Reganold, Robert I. Papendick and James F. Parr; Scientific American, June 1990]. No-till farming is one system that has the potential to help realize this vision of a more sustainable agriculture. As with any new system, there are challenges and trade-offs with no-till. Nevertheless, growers in some parts of the world are increasingly abandoning their plows.

Plowing Ahead

People have used both no-till and tillage-based methods to produce food from the earth ever since they started growing their own crops around 10,000 years ago. In the transition from hunting and gathering to raising crops, our Neolithic predecessors planted garden plots near their dwellings and foraged for other foods in the wild. Some performed the earliest version of no-till by punching holes in the land with a stick, dropping seeds in each divot and then covering it with soil. Others scratched the ground with a stick, an incipient form of tillage, to place seeds under the surface. Thousands of farmers in developing countries still use these simple methods to sow their crops.

In time, working the soil mechanically became the standard for planting crops and controlling weeds, thanks to the advent of the plow, which permitted the labor of a few to sustain many. The first such tools were scratch plows, consisting of a frame holding a vertical wooden post that was dragged through the top-

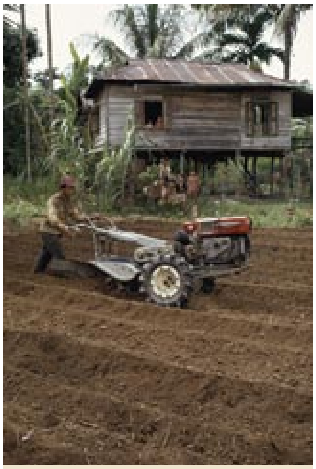
STEWART HIGGINS *Washington State University* (*Huggins and Reganold*); WU HONG *EPA/Corbis* (*scratch plow*); RALF ROLETSCHEK (*moldboard plow*); HUGH TALMAN *Smithsonian Images* (*John Deere plow*); LANE LAMBERT *iStockPhoto* (*tractor*); ANDY ANDERSON (*no-till seeder*)

soil. Two people probably operated the earliest version of this device, one pulling the tool and the other guiding it. But the domestication of draft animals—such as oxen in Mesopotamia, perhaps as early as 6000 B.C.—replaced human power. The next major development occurred around 3500 B.C., when the Egyptians and the Sumerians created the plowshare—a wedge-shaped wooden implement tipped with an iron blade that could loosen the top layer of soil. By the 11th century, the Europeans were using an elaboration of this innovation that included a curved blade called a moldboard that turned the soil over once it was broken open.

Continuing advancements in plow design enabled the explosion of pioneer agriculture during the mid-1800s; farmers cultivated grass-dominated native prairies in eastern Europe, South Africa, Canada, Australia, New Zealand and the U.S., converting them to corn, wheat and other crops. One such region, the tall-grass prairie of the Midwestern U.S., had resisted widespread farming because its thick, sticky sod was a barrier to cultivation. But in 1837 an Illinois blacksmith named John Deere invented a smooth, steel moldboard plow that could break up the sod. Today this former grassland, which includes much of the famous Corn Belt, is home to one of the most agriculturally productive areas in the world.

Agricultural mechanization continued through the early 1900s with the development of many tools that helped farmers cultivate the earth ever more intensively, including tractors that could pull multiple plows at once. Tillage practices were about to undergo profound scrutiny, however. The Dust Bowl era between 1931 and 1939 exposed the vulnerability of plow-based agriculture, as wind blew away precious topsoil from the drought-ravaged southern plains of the U.S., leaving behind failed crops and farms. Thus, the soil conservation movement was born, and agriculturalists began to explore reduced tillage methods that preserve crop residues as a protective ground cover. Spurring the movement was the controversial publication in 1943 of *Plowman's Folly,* by agronomist Edward Faulkner, who challenged the necessity of the plow. Faulkner's radical proposition became more tenable with the development of herbicides—such as 2,4-D, atrazine and paraquat—after World War II, and research on modern methods of no-till agriculture began in earnest during the 1960s.

Considering the pivotal role the plow has come to play in farming, conceiving a way to do without it has proved quite challenging, requiring the reinvention of virtually every aspect of agricultural production. But specially designed seeders have been evolving since the 1960s to meet the unique mechanization requirements of no-till farming. These new seeders, along with chemical herbicides, are two of the main technologies that have at last enabled growers to effectively practice no-till on a commercial scale.



DEAN CONGER *National Geographic/Getty Images*

ADOPTION HURDLES

Although no-till is theoretically applicable to most farmland around the world, the cost of the requisite equipment and herbicides is prohibitive for many growers, most of whom have small farms. Necessary costs aside, poverty itself leads these farmers to use crop residues and animal dung for fuel, for example, and to till the land for short-term gains rather than investing in long-term stewardship.

Of 525 million farms worldwide, roughly 85 percent are less than five acres. The overwhelming majority of these small farms—about 87 percent—are located in Asia (*above*); Africa is home to 8 percent. The adoption of no-till farming in these regions, where the potential benefits are the greatest, is practically negligible.

Signing Up for No-Till

Farmers today prepare for planting in ways that disturb the soil to varying degrees. Tillage with a moldboard plow completely turns over the first six to 10 inches of soil, burying most of the residue. A chisel plow, meanwhile, only fractures the topsoil and preserves more surface residue. In contrast, no-till methods merely create in each planted row a groove just half an inch to three inches across into which seeds can be dropped, resulting in minimal overall soil disturbance. In the U.S., no-till agriculture fits under the broader U.S. Department of Agriculture definition of conservation tillage. Conservation tillage includes any method that retains enough of the previous crop residues such that at least 30 percent of the soil surface is covered after planting. The protective effects of such residues are considerable. According to the USDA's National Resources Inventory data, soil erosion from water and wind on U.S. cropland decreased 43 percent between 1982 and 2003, with much of this decline coming from the adoption of conservation tillage.

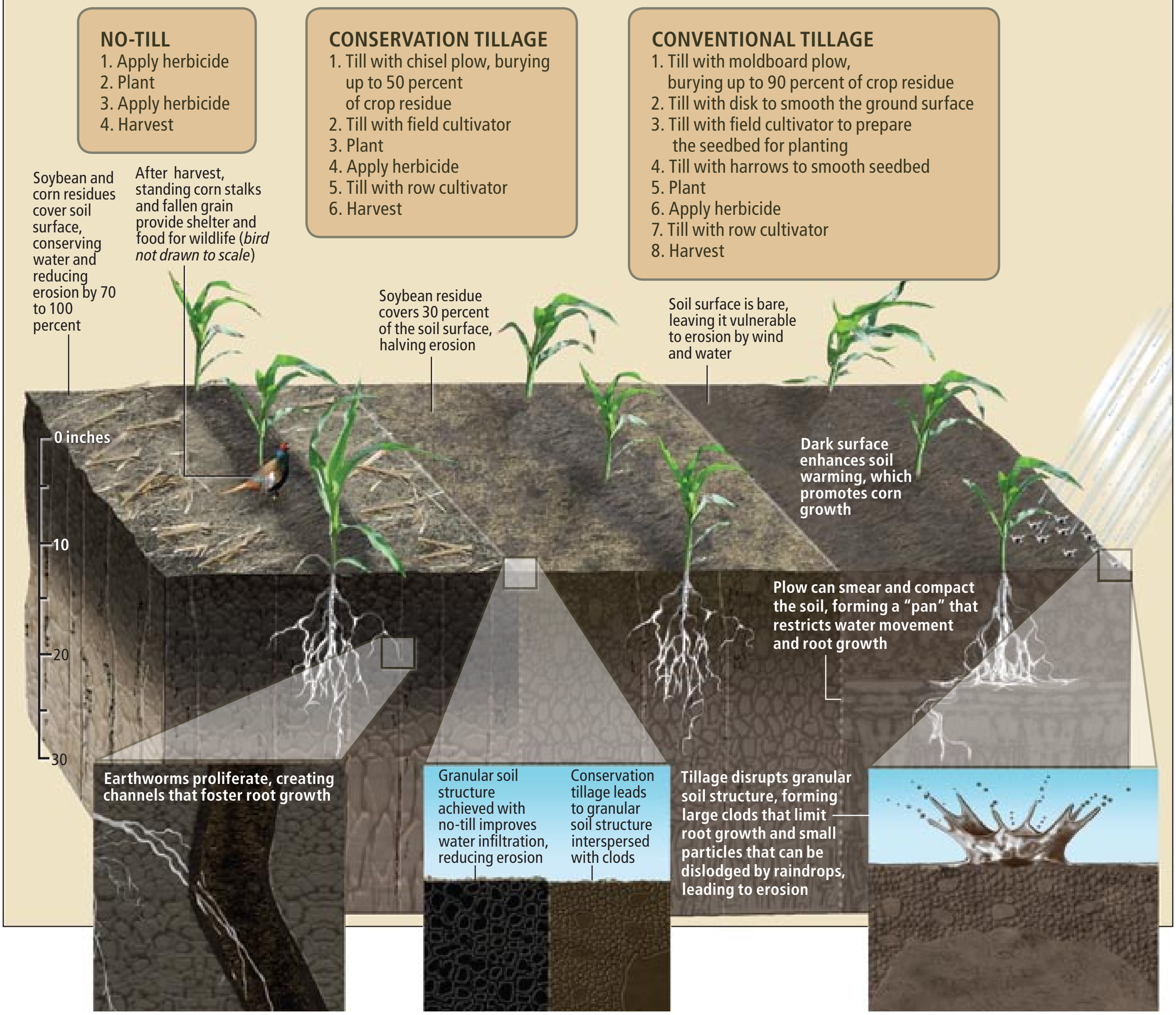
Soil protection is not the only benefit of no-till. Leaving crop residues on the soil surface helps to increase water infiltration and limit runoff. Decreased runoff, in turn, can reduce pollution of nearby water sources with transported sediment, fertilizers and pesticides. The residues also promote water conservation by reducing evaporation. In instances where water availability limits crop production, greater water conservation can mean higher-yielding crops or new capabilities to grow alternative crops.

The no-till approach also fosters the diversity of soil flora and fauna by providing soil organisms, such as earthworms, with food from the residues and by stabilizing their habitat. Together with associated increases in soil organic matter, these conditions encourage soils to develop a more stable internal structure, further improving the overall capacity to grow crops and to buffer them against stresses caused by farming

[A PRIMER]

HOW NO-TILL STACKS UP

Three farming systems for a corn-soybean crop rotation in the U.S. Corn Belt are contrasted here. No-till requires the fewest passes over a field.



operations or environmental hazards. No-till can thus enable the more sustainable farming of moderately to steeply sloping lands that are at elevated risk of erosion and other problems.

Wildlife, too, gains from no-till, because standing crop residues and inevitable harvest losses of grain provide cover and food for upland game birds and other species. In a study published in 1986, researchers in Iowa found 12 bird species nesting in no-till fields, compared with three species in tilled fields.

Furthermore, reducing tillage increases soil carbon sequestration, compared with conventional moldboard plowing. One of agriculture's main greenhouse gas mitigation strategies is soil carbon sequestration, wherein crops remove carbon dioxide from the atmosphere during photosynthesis, and nonharvested residues and roots are converted to soil organic matter, which is 58 percent carbon. About half of the overall potential for U.S. croplands to sequester soil carbon comes from conservation tillage, including no-till.

In addition, no-till can offer economic advantages to farmers. The number of passes over a field needed to establish and harvest a crop with no-till typically decreases from seven or more to four or fewer. As such, it requires 50 to 80 per-

KEVIN HAND

cent less fuel and 30 to 50 percent less labor than tillage-based agriculture, significantly lowering production costs per acre. Although specialized no-till seeding equipment can be expensive, with some sophisticated seeders priced at more than $100,000, running and maintaining other tillage equipment is no longer necessary, lowering the total capital and operating costs of machinery required for crop establishment by up to 50 percent. With these savings in time and money, farmers can be more competitive at smaller scales, or they can expand and farm more acres, sometimes doubling farm size using the same equipment and labor. Furthermore, many farmers appreciate that the time they once devoted to rather mundane tillage tasks they can instead spend on more challenging aspects of farming, family life or recreation, thereby enhancing their overall quality of life.

Betting the Farm

No-till and other conservation tillage systems can work in a wide range of climates, soils and geographic areas. Continuous no-till is also applicable to most crops, with the notable exceptions of wetland rice and root crops, such as potatoes. Yet in 2004, the most recent year for which data are available, farmers were practicing no-till on only 236 million acres worldwide—not even 7 percent of total global cropland.

Of the top five countries with the largest areas under no-till, the U.S. ranks first, followed by Brazil, Argentina, Canada and Australia. About 85 percent of this no-till land lies in North and South America. In the U.S., roughly 41 percent of all planted cropland was farmed using conservation tillage systems in 2004, compared with 26 percent in 1990. Most of that growth came from expanded adoption of no-till, which more than tripled in that time, to the point where it was practiced on 22 percent of U.S. farmland. This no doubt partly reflects the fact that U.S. farmers are encouraged to meet the definition of conservation tillage to participate in government subsidy and other programs. In South America, adoption of no-till farming has been relatively rapid as a result of coordinated efforts by university agricultural-extension educators and local farm communities to develop viable no-till cropping systems tailored to their particular needs.

On the other hand, adoption rates are low in Europe, Africa and most parts of Asia. Embracing no-till has been especially difficult in developing countries in Africa and Asia, because farmers there often use the crop residues for fuel, animal feed and other purposes. Furthermore, the specialized seeders required for sowing crops and the herbicides needed for weed control may not be available or can be prohibitively expensive for growers in these parts of the world. Meanwhile, in Europe, an absence of government policies promoting no-till, along with elevated restrictions on pesticides (including herbicides), among other variables, leaves farmers with little incentive to adopt this approach.

Changing from tillage-based farming to no-till is not easy. The difficulty of the transition, together with the common perception that no-till incurs a greater risk of crop failure or lower net returns than conventional agriculture, has seriously hindered more widespread adoption of this approach. Although farmers accept that agriculture is not a fail-safe profession, they will hesitate to adopt a new farming practice if the risk of failure is greater than in conventional practice. Because no-till is a radical departure from other farming practices, growers making the switch to no-till experience a steep learning curve. In addition to the demands of different field practices, the conversion has profound impacts on farm soils and fields. Different pest species can arise with the shift from tillage-based agriculture to no-till, for instance. And the kinds of weeds and crop diseases can change. For example, the elevated moisture levels associated with no-till can promote soil-borne fungal diseases that tillage previously kept in check. Indeed, the discovery of new crop diseases has sometimes accompanied the shift to no-till.

Some of the changes that follow from no-till can take years or even decades to unfold, and farmers need to remain vigilant and adaptable to new, sometimes unexpected, situations, such as those that arise from shifts in soil and residue conditions or fertilizer management. During this transition, there is a real risk of reduced yields and even failed crops. In the Palouse, for example, some farmers who attempted no-till in the 1980s are no longer in business. Consequently, farmers looking to switch to no-till should initially limit the converted acreage to 10 to 15 percent of their total farm.

Farmers who are new to no-till techniques often visit successful operations and form local or regional support groups, where they share experiences and discuss specific problems. But the advice they receive in areas with limited no-till adoption can be incomplete or contradictory,

TWO SIDES OF NO-TILL

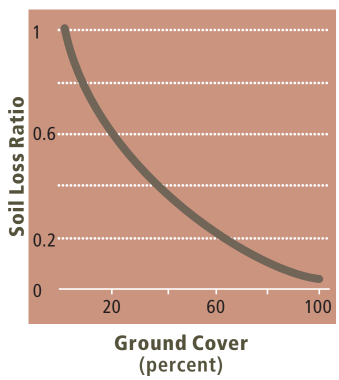
PAYOFFS

- Reduces soil erosion
- Conserves water
- Improves soil health
- Reduces fuel and labor costs
- Reduces sediment and fertilizer pollution of lakes and streams
- Sequesters carbon

TRADE-OFFS

- Transition from conventional farming to no-till is difficult
- Necessary equipment is costly
- Heavier reliance on herbicides
- Prevalence of weeds, disease and other pests may shift in unexpected ways
- May initially require more nitrogen fertilizer
- Can slow germination and reduce yields

SOIL SAVER



LEAVING 30 PERCENT of the soil surface covered with residue reduces erosion by half as compared with bare, fallow soil. And leaving 50 to 100 percent of the surface covered throughout the year, as no-till does, reduces soil erosion dramatically.

DANIELA NAOMI MOLNAR

and gaps in knowledge, experience or technology can have potentially disastrous outcomes. If the perception that no-till is riskier than conventional techniques develops in a farming community, banks may not underwrite a no-till farmer's loan. Alternatively, growers who are leasing land may find that the owners are opposed to no-till because of fears that they will not get paid as much. Improving the quality of information exchange among farmers, universities, agribusinesses and government agencies will no doubt go a long way toward overcoming these obstacles.

Yet even in the hands of a seasoned no-till farmer, the system has drawbacks. No-till crop production on fine-textured, poorly drained soils can be particularly problematic, often resulting in decreased yields. Yields of no-till corn, for instance, are often reduced by 5 to 10

[A CASE FOR NO-TILL]

PAY DIRT

The slow pace at which soil rebuilds makes its conservation essential **By David R. Montgomery**

A fundamental drawback of conventional farming is that it fosters topsoil erosion, especially on sloping land. Tillage leaves the ground surface bare and vulnerable to runoff, and each pass of the plow pushes soil downhill. As a result, the soil thins over time. How long this process takes depends not only on how fast plowing pushes soil downhill—and wind or runoff carries it away—but also on how fast the underlying rocks break down to form new soil.

In the 1950s, when the Soil Conservation Service (now known as the Natural Resources Conservation Service) began defining tolerable rates of soil erosion from agricultural land, hardly any data on rates of soil production were available. The agency thus determined the so-called soil loss tolerance values, or T values, on the basis of what farmers could do to reduce erosion without "undue economic impact" using conventional farming equipment. These T values correspond to as much as an inch of erosion in 25 years. But recent research has shown that erosion rate to be far faster than the rate at which soil rebuilds.

Over the past several decades, scientists have determined that measuring the soil concentrations of certain isotopes that form at a known rate permits direct quantification of soil production rates. Applying this technique to soils in temperate regions in coastal California and southeastern Australia, geologist Arjun Heimsath of Arizona State University and his colleagues found soil production rates ranging from 0.00118 to 0.00315 inch a year. As such, it takes 300 to 850 years to form an inch of soil in these places. My own recent global compilation of data from soil production studies, published last year in the *Proceedings of the National Academy of Sciences USA,* revealed an average rate of 0.00067 to 0.00142 inch a year—equivalent to 700 to 1,500 years to form an inch of soil.

The soil on undisturbed hillsides in temperate and tropical latitudes is generally one to three feet thick. With natural soil production rates of centuries to millennia per inch and soil erosion rates of inches per century under plow-based agriculture, it would take just several hundred to a couple of thousand years to plow through the soil in these regions. This simple estimate predicts remarkably well the life span of major agricultural civilizations around the world. With the exception of the fertile river valleys along which agriculture began, civilizations generally lasted 800 to 2,000 years, and geoarchaeological studies have now shown a connection between soil erosion and the decline of many ancient cultures.

Clearly, then, if we are to conserve resources for future generations, we need alternatives to conventional farming practices. No-till systems simultaneously reduce the erosive force of runoff and increase the ability of the ground to hold onto soil, making these methods remarkably effective at curbing erosion. In a study published in 1993, researchers at the University of Kentucky found that no-till methods decreased soil erosion by a whopping 98 percent. More recently, investigators at the University of Tennessee reported that no-till tobacco farming reduced soil erosion by more than 90 percent over conventional tobacco cultivation. Although the effect of no-till on erosion rates depends on a number of local factors, such as the type of soil and the crop, it can bring soil erosion rates down close to soil production rates.

WIND EROSION in the Southern Plains of the U.S. during the Dust Bowl era revealed the perils of plow-based farming.

In the mid-1990s Cornell University researchers estimated that undoing damage caused by soil erosion would cost the U.S. $44 billion a year, and that it would take an annual investment of about $6 billion to bring erosion rates on U.S. cropland in line with soil production. They also estimated that each dollar invested in soil conservation would save society more than $5. Because it is prohibitively expensive to put soil back on the fields once it leaves, the best, most cost-effective strategy for society at large is to keep it on the fields in the first place.

David R. Montgomery is a professor of geomorphology at the University of Washington and author of Dirt: The Erosion of Civilizations.

GETTY IMAGES

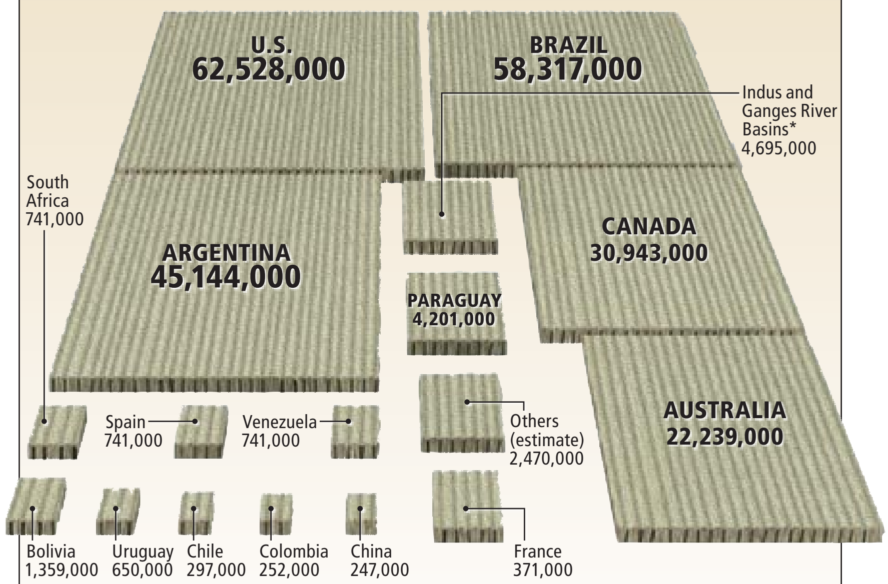
percent on these kinds of soils, compared with yields with conventional tillage, particularly in northern regions. And because the crop residue blocks the sun's rays from warming the earth to the same degree as occurs with conventional tillage, soil temperatures are colder in the spring, which can slow seed germination and curtail the early growth of warm-season crops, such as corn, in northern latitudes.

In the first four to six years, no-till demands the use of extra nitrogen fertilizer to meet the nutritional requirements of some crops, too—up to 20 percent more than is used in conventional tillage systems—because increasing organic matter at the surface immobilizes nutrients, including nitrogen. And in the absence of tillage, farmers depend more heavily on herbicides to keep weeds at bay. Herbicide-resistant weeds are already becoming more common on no-till farms. The continued practice of no-till is therefore highly dependent on the development of new herbicide formulations and other weed management options. Cost aside, greater reliance on agrichemicals may adversely affect nontarget species or contaminate air, water and soil.

[WHERE IT IS USED]

NO-TILL ACREAGE

Less than 7 percent of the world's cropland is farmed using no-till methods. Of these 236 million acres, about 85 percent are in North and South America.



*Encompasses much of India, Pakistan and Bangladesh.

SOURCE: United Nations Food and Agriculture Organization. Data from 2004.

Integrating No-Till

No-till has the potential to deliver a host of benefits that are increasingly desirable in a world facing population growth, environmental degradation, rising energy costs and climate change, among other daunting challenges. But no-till is not a cure-all; such a thing does not exist in agriculture. Rather it is part of a larger, evolving vision of sustainable agriculture, in which a diversity of farming methods from no-till to organic—and combinations thereof—is considered healthy. We think that ultimately all farmers should integrate conservation tillage, and no-till if feasible, on their farms.

Future no-till farming will need to employ more diverse pest and weed management strategies, including biological, physical and chemical measures to lessen the threat of pesticide resistance. Practices from successful organic farming systems may be instructive in that regard. One such technique, crop rotation—in which farmers grow a series of different crops in the same space in sequential seasons—is already helping no-till's war on pests and weeds by helping to break up the weed, pest and disease cycles that arise when one species is continuously grown.

To that end, the capacity to grow a diverse selection of economically viable crops would advance no-till farming and make it more appealing to farmers. But the current emphasis on corn to produce ethanol in the Midwestern Corn Belt, for instance, is promoting monoculture—in which a single crop, such as corn, is grown over a wide area and replanted every year—and will likely make no-till farming more difficult in this region. Experts continue to debate the merits of growing fuel on farmland, but if we decide to proceed with biofuel crops, we will need to consider using no-till with crop rotation to produce them sustainably. Development of alternative crops for bioenergy production on marginal lands, including perennials such as switchgrass, could complement and promote no-till farming, as would perennial grain food crops currently under development [see "Future Farming: A Return to Roots?" by Jerry D. Glover, Cindy M. Cox and John P. Reganold; Scientific American, August 2007].

Today, three decades after first attempting no-till on his Palouse farm, John Aeschliman uses the system on 100 percent of his land. His adoption of no-till has followed a gradual, cautious path that has helped minimize his risk of reduced yields and net returns. Consequently, he is one of many farmers, large and small, who is reaping the rewards of no-till farming and helping agriculture evolve toward sustainability. ■

➡ MORE TO EXPLORE

Corn-Soybean Sequence and Tillage Effects on Soil Carbon Dynamics and Storage. David R. Huggins, Raymond R. Allmaras, Charles E. Clapp, John A. Lamb and Gyles W. Randall in *Soil Science Society of America Journal,* Vol. 71, No. 1, pages 145–154; January/February 2007.

Constraints to Adopting No-Till Farming in Developing Countries. Rattan Lal in *Soil & Tillage Research,* Vol. 94, No. 1, pages 1–3; May 2007.

Dirt: The Erosion of Civilizations. David R. Montgomery. University of California Press, 2007.

No-Tillage Seeding in Conservation Agriculture. Second edition. C. John Baker et al. CABI Publishing, 2007.

More information about conservation agriculture from the United Nations Food and Agriculture Organization is available at **www.fao.org/ag/ca**

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