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VIEWPOINT

Agriculture's *no-till* revolution?

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Ever since the first organized harvests of prehistory, the plow has defined the universal symbol of agriculture. So how radical is it that America's farms are gradually abandoning the plow as a no-till revolution slowly sweeps across the American heartland? Perhaps more than any emerging green technology, this little noticed, ongoing shift in the business of farming may hold the key to feeding humanity in a post-petroleum world.

Agriculture has evolved through several so-called revolutions since some long-forgotten farmer hooked a digging stick up to a cow and invented the plow, one of the most enduring and widely adopted inventions of all time. The most recent and well known agricultural revolution, the Green Revolution of the 1960s, is widely regarded as enabling modern agriculture to keep up with global population growth through more than doubled yields of hybrid crops that thrive on fertilizer-intensive farming. But slowly over the past several decades, American agriculture has been undergoing another fundamental transformation as farmers increasingly adopt the once-heretical practice of no-till farming.

Why am I, a geologist, excited about this recent development in farming practices? Plowing the soil fundamentally alters the ratio of runoff's erosive energy to the ability of the ground surface to resist erosion, leaving the surface bare and vulnerable to dramatically increased erosion. Plowing with a conventional plow also pushes soil directly downslope. The straight, angled blade of conventional plows lifts and turns the soil over, pushing it aside and moving it downslope little by little. So over time the soil thins as it is literally eroded off of hillslopes and pushed downhill with each pass of the plow. Consequently, plowing results in what has been called the fundamental problem of agriculture—that is, conventional plowing slowly mines the soil upon which farming depends.

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Recent compilations of data on erosion rates under conventional, plow-based agriculture report rates of soil loss averaging >1 mm y^{-1} (>0.04 in yr^{-1}) (Barlowe 1979; Harlan and Barardi 1987; Uri and Lewis 1999; Montgomery 2007b). In contrast, reported rates of soil formation average <0.1 mm y^{-1} (<0.004 in yr^{-1}) (Wakatsuki and Rasyidin 1992; Troeh et al. 1999; Montgomery 2007b). Hence, conventional agricultural practices can strip a typical soil profile in less than a few thousand years. As I discuss at length elsewhere (Montgomery 2007a), this simple estimate for the life span of agricultural soils predicts remarkably well the historical longevity of major civilizations around the world, except of course for the fertile floodplains along which agriculture began.

No-till agriculture provides a way to potentially resolve this fundamental problem by shielding the ground surface beneath vegetation or vegetable matter. Instead of burying crop residue deep in the soil where it rapidly decays, no-till practices leave crop residue at the ground surface where it acts as mulch, helping to retain moisture and retard erosion. Unlike under conventional plowing, no-till farmers minimize direct disturbance of the soil by using a chisel plow to poke seeds down through crop stubble. Conservation tillage has been remarkably effective at reducing soil erosion, and no-till farming can bring soil erosion rates down close to soil production rates.

Few farmers were experimenting with chisel plows in the 1930s, when President Franklin D. Roosevelt created the Soil Conservation Service to promote soil conservation research and control erosion on American farmland. Then a new breed of agricultural researchers began to investigate alternatives to plowing, demonstrating that leaving organic matter on the soil surface sharply reduces soil erosion and gradually improves soil quality. By the 1960s the invention of new machines to plant through mulch combined with the widespread availability of chemical pesticides to control weeds set the stage for commercial adoption of conservation tillage. Conservation tillage and no-till techniques were used on one-third of Canadian farms in 1991, and on 60% of Canadian croplands by 2001. By 2004, conservation tillage was practiced on about 40% of US farmland, and no-till methods were used on almost 25%. If trends continue; no-till methods would be adopted on the majority of North American farms within a decade.

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But the rapid rise in the popularity of no-till agriculture is not simply due to less erosion. No-till methods have been adopted primarily because of economic benefits to farmers. The Food Security Acts of 1985 and 1990 required farmers to adopt soil conservation plans based on conservation tillage for highly erodible land as a condition for participating in popular USDA programs including farm subsidies. But conservation tillage has proven to be so cost effective that it also is being widely adopted on less erodible fields.

On modern mechanized farms less plowing means less consumption of increasingly expensive fuels, and no-till methods can cut fuel use by more than half. In addition, the soil better retains nitrogen and organic matter, thereby reducing the need for fertilizer. The lower cost of no-till methods is even fueling

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growing interest among large industrial farming operations. The savings from not plowing and lower fertilizer use can more than offset income lost to initially reduced crop yields, translating into higher profits. No-till practices also increase soil quality, organic matter content, and microbial activity, although stopping weed growth can take greater herbicide applications, forcing some farmers to face a hard choice between soil-conserving no-till practices and heavier herbicide use.

Incorporating organic matter back into the surface of the soil helps maintain a granular soil structure of aggregates that not only contributes to erosion resistance but also facilitates the movement of water and air down into and through the soil. In agricultural settings, higher soil organic matter helps maintain good soil structure and allows rapid entry of water into the soil, reducing runoff and making more water available to crops. Soil organic matter strongly influences soil quality and productivity. Crop yields generally increase as soil quality improves and can, over time, as much as double under no-till practices.

No-till agriculture has another major attraction; it could provide one of the few simple, profitable ways to help hold off global warming. When soil is plowed and exposed to the atmosphere, oxidation of organic matter releases carbon dioxide gas. In most settings, long-term tillage has reduced soil organic carbon levels by more than 50%. Worldwide, one-third of the total carbon dioxide buildup in the atmosphere since the industrial revolution has come from degradation of soil organic matter as hundreds of millions of acres of virgin land were plowed up in the late 19th and early 20th centuries. No-till farming can reverse this process by stirring crop residues back into the soil surface, gradually increasing soil organic matter and as much as tripling soil carbon content in less than 15 years in some studies. Adoption of no-till practices on the world's 1.5×10^9 ha (3.7×10^9 ac) of cultivated land has been estimated to be capable of absorbing more than 90% of global carbon emissions for the several decades it would take to rebuild soil organic matter. Another scenario estimates the total carbon sequestration potential for the world's cropland as roughly one-quarter of current carbon emissions. At either extreme, the opportunity for no-till methods to improve soil quality provides a win-win strategy for increasing agricultural productivity while improving the environment and partially mitigating the greenhouse effect.

Although much remains to be done to overcome key challenges to no-till farming and realize its potential on the 95% of global cropland still tilled by conventional means, the growing popularity and rapid acceptance of no-till and conservation tillage practices in the United States is expected to continue as fuel costs soar in the coming decades. If the no-till revolution manages to solve the problem of long-term soil loss, history may well record it as among the greatest of agricultural revolutions—for this quiet revolution could finally transform the relationship between humanity and the soil to address the fundamental problem of agriculture. To quibble over whether conventional farming would catastrophically deplete the world's soil in 20 or 200 years would be to miss the point. Over the long run, humanity's agricultural future depends as much on the philosophical realignment of agriculture's no-till revolution as on technical advances in agrotechnology and genetic engineering.

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