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No·till On The Plains

Fix the Weak Link

by Matt Hagny

David Gillen progresses quietly, almost by stealth. For someone who's won awards for top farm management, you might expect a cagey personality with hurricane bluster. Not David. Calmly, almost serenely, he reflects on what the biggest problem is, and then gets to work researching and fixing it. Problems are to be solved, and then move on. No time for second-guessing or reviewing a catalogue of old issues. Forward!

David, who farms near White Lake, SD with his wife Carol and their children, took that same studious approach to no-till adoption back in early '90s. His interest in no-till was first piqued when he heard Dwayne Beck at a SCS meeting back in '87, who stated that you could farm successfully with a planter, sprayer, and a combine. David says it took two years for him to completely grasp that message. In the fall of '90, Gillen heard several "ecofallow" presentations, whose cautioning message was to try no-till on a "small acreage." Gillen was sufficiently intrigued that he spent the winter researching the possibility, and concluded that the right thing to do was "jump in with both feet." He sold all of his tillage equipment that spring.

Gillen had done his homework, and the move was nicely executed. "Results were well above my expectations. Planting conditions were so much better. I had more time available. And for the first time, I could pull my living expenses from grain farming instead of from the livestock . . . . No-till has been a huge success story for my farm. It allowed me to triple my acres without increasing labor. My yields are higher, and inputs reduced."

Fifteen years ago, Gillen's region in south-central South Dakota was 2/3 tame grass (pasture or hay land) and


Photo by David Gillen.

Gillen's 22-inch rows and other good agronomic practices create an incredible canopy.

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alfalfa, and Gillen's acreage was similarly split. The small amount of cropland was typically in corn and oats, and all grain was consumed locally by livestock. That has changed dramatically, with corn and soybeans dominating the landscape today, and the area exporting much grain. Gillen himself opted to get out of cattle in '96, when he lost control of much of his leased grassland, and saw little reason to maintain a herd half the original size. The move ended up working very nicely for him as he converted the remaining grassland and alfalfa to no-till crop production, reaping some very nice profits in the good growing seasons of '96 to '99.

Gillen's early results with no-till: "It just blew my mind what we were doing."

For the Long Haul

Having left the livestock behind, Gillen maintains his diversity in other ways. His rotation prior to '91 consisted of nothing more than alternating between corn and small grains (wheat, oats, and barley). With no-till, he was able to add soybeans in the early '90s, which were "very profitable" and made everything work well sequentially. "Trying to do spring wheat after corn in the '80s was a joke. Wheat does so much better after soybean." So the wheat had become quite profitable, too. And the new system offered even more benefits: "The corn in wheat stubble was doing so much better [than in tilled situations]—it doubled the yield in '91, from 30 to 60 bu/a. Then in '92, we had 127 bu/a corn, whereas before, our best yield ever up to that point was 70 bu/a. It was unheard of to have corn in this area doing over 60 to 70 bu/a. It just blew my mind what we were doing. Much of that corn had only one pound of atrazine in the fall—nothing the next year. Only three dollars an acre for herbicide." Now *that's* profitable corn production. (David cautions that such results are not exactly typical—long-term his average corn herbicide costs are running around $20/a, which includes any late-fall applications on wheat stubble, the atrazine, and whatever is needed in-crop: Accent, Callisto, Distinct, etc. He doesn't do RR corn, since he already uses glyphosate in RR soybeans and after wheat harvest.)

Gillen's rotation in the early '90s was corn >>soy >>wheat, but that posed problems for getting soybeans harvested and seeding winter wheat: "It all had to be done in about a week.

Photo by David Gillen.

"What now, Dad?"—David & Carol's son, Bryce, drilling into sod in '98.

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No·till On The Plains

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No-Till on the Plains Inc's Mission: To assist agricultural producers in implementing economically, agronomically, and environmentally sound crop production systems.

Objective: To increase the adoption of cropping systems that will enhance economic potential, soil and water quality, and quality of life while reducing crop production risks.

It was a nightmare, time-wise." Spring wheat was planted on soybean acres where the harvest was late. Eventually, he tried using winter wheat after the spring wheat, which itself followed the soybeans. This worked very well for him, and became a standard practice—"It took some risk out." Corn always follows the wheat. What happens next depends on his fields, and a number of other considerations. Sometimes a second year of corn is grown, sometimes soybean, and sometimes it's s.wht >>w.wht >>corn >>soy >>corn >>soy. "The second-year corn has been okay, but the second-year soybean really falls out of bed," referring to instances where he's done stacked soybeans and yields have disappointed. He has no explanation as to why. *(Editors' Note: Other producers and researchers indicate good results with stacked soybean, following a long break.)*

These rotations are considerably more diverse than the short, repetitive corn >>soy rotation that dominates Gillen's area currently. Prudent David always plans more than one year out. "We've been working on '04 plans all winter, but also we know what the crops will be in each field in '05. If you know what is going to happen one year out [in the rotation], you're more apt to make the right decision in the current year." David really can't understand his neighbors with only corn and soybeans in the rotation: "Their yields keep dropping, and they can't understand why. They have a lot of compaction, tight soils, and poor soil aeration. They think that they need to go out and do tillage every once in awhile to solve the problem." Gillen states that the diverse rotation and high levels of crop residues are very important for keeping his no-till soils in excellent condition.

The last four years of hot dry summers have seen the Gillens repaid handsomely for maintaining a good rotation. "Wheat has been by far our most profitable crop during the last four years, since the May and June weather has been favorable." Corn yields were averaging 111 bu/a from '96 to '99, but only 72 bu/a from 2000 to '03. Soybeans have fallen even worse, to 21 bu/a in the last four years, compared with a 42 bu/a average for the previous four. However, winter wheat yields for the last four years have averaged 61 bu/a. "Soybeans have only been break-even the last four years, but prior to that were a home run. Corn has been a loser the last four years [until he adds in LDP and disaster payments] . . . . Corn really struggles to cover any fixed costs when you have below-average rainfall and below-average prices occurring at the same time." Still, David isn't making any changes, realizing that he can't outguess the weather, and knowing the reason his wheat profits are so good is because of the rotation. "Our strategy is to continue to aim for good yields. One year of high yields and high prices will fix a lot of bad years. Drastically cutting inputs is not the road to take—it ensures that you never have the good year." But he notes that he's not incurring any significant losses, just not getting ahead much during the last four dry years.

Photo by David Gillen.

Gillen's corn in rolling south-central S. Dakota.

Despite four dry years: "Our strategy is to continue to aim for good yields. One year of high yields and high prices will fix a lot of bad years. Drastically cutting inputs is not the road to take—it ensures that you never have the good year."

Improved Agronomy

Getting those yields—both grain and profit—has meant doing top-notch agronomy while hawking over budget numbers. Changes are guided by on-farm testing, by university research, and by Gillen's agronomic consultant.

David fertilizes aggressively: he uses yield goals of 60 for spring wheat, 80 for winter wheat, and 150 for corn. "With our wheat >>wheat >>corn sequence, if you put too much N out there, you can recover it in the next crop. That's not possible with a corn >>soybean rotation." Nitrogen fertilizer needs are calculated using 1.2 units per bushel of yield goal for corn, and 2.4 units for wheat. Thorough soil testing ensures that anything left over from one crop is subtracted from the next application.

Gillen has been working more on high-management wheat in recent years, planting only the very largest seeds, targeting plant populations of 1.2 million, and using fungicides as needed. "The additional management has been paying off very well." All wheat gets 11 gallons of 10-34-0 as a pop-up at planting. For winter wheat, some dry fertilizer is applied in February, and the balance of the N requirement is applied after tillering with stream bars on his RoGator. David explains that having some N applied early guards against dry weather failing to activate the liquid streams. Although he's unsure of whether this system is the ultimate, it is by far better than applying too much too soon: "If we don't split apply, we get too much lodging."

For the corn, some fertilizer N is b'cast in early winter, and the planter applies a 55-12-0 blend (liquid) in a 2x0 placement with low-disturbance Auscherman Vantage II openers with wiper wheels. Another 3 gallons of 10-34-0 is applied in the seed furrow with Keetons. The White 6600 planter was purchased new in '98 and reconfigured to 12-row 22-inch. Being a two-bar rigid design, all row units are on the back bar, and the lift wheels are on the front bar; it's also equipped with row cleaners and spoked closing wheels.

Soybeans are planted with either the drill or planter—David emphasizes the need to keep both machines busy as much as possible, as well as the hired man. He sees no real yield difference, although seed costs are about $7/a less with the planter.

Gillen's JD 750 drill was originally a 20-foot model, purchased in '98, but rearranged to be a 22-foot model on 8-inch spacing, with a pair of wider gaps for trams. The trams were used for easy and precise spraying for several years (with a 66-foot sprayer), until GPS guidance took over. Now, with his RoGator's 90-foot boom, none of it matches anyway.

The 750 opener actually has quite a history on Gillen's farm. He bought his first one in '92. But because his cropland acreage was so much less back then, he couldn't afford both an expensive planter and a drill. So he mounted a CIH Cyclo drum on the drill, and planted corn with that for 5 years. "That drill probably made me more money than any piece of equipment I've ever owned. The depreciation per acre for those years comes to $2.30." His acreage had expanded considerably by '96, justifying two separate seeding tools—so he actually built a planter from scratch, only later trading up to the White planter. "The 750 opener was acceptable for corn planting, although we had some stand problems.

"If you have too many enterprises, the farm runs you, instead of you running the farm."

It doesn't have a parallel-link. The planter is way better."

Some aspects of Gillen's management are as much for pheasants as for agronomic reasons. "Pheasants are an important part of our operation"—and he's not simply referring to his love for the birds. Instead, they're viewed as another crop. Gillen charges hunters per day, taking two weeks in the fall to guide. Later in the fall, he contracts with an outside guide service for exclusive access to his land. Apparently it's a noteworthy source of revenue, since Gillen is very focused on cropping in a manner that is friendly toward the birds. For instance, he states that the 22-inch rows are much better habitat than 30-inch rows, and the pheasants prefer it. Blocks (not strips) of corn have their harvest delayed. Also, the wheat is harvested with a stripper-head, and the bird numbers are higher there than in adjacent fields because of the extra cover. Gillen recognizes that many of his landlords own land primarily for the hunting rights—so he squares off creeks and wetlands for even better bird habitat. Gillen sees it as win/win: "I get to grow crops on the areas best-suited to farming, and the hunters get prime

Photo by David Gillen.

Ready for action—Gillen sees the need to be on-time with his herbicides, letting him shave rates and still get good control.

hunting areas. It's sort of a voluntary set-aside. What I do for profitability often turns out to be in line with practices that are environmentally friendly."

Photos by David Gillen.

Good agronomy produces lots of grain (decent weather helps, too). No-till and astute management gave Gillen the opportunity for grain farming to be economically rewarding.

Look Ahead

Gillens have made many changes over the years, going from a livestock-centric view to a pure cropping enterprise, and then adding back diversity in the form of a pheasant harvest. But the focus has always been positioning for the future, guarding against risk, and keeping upside potential open.

David juggles plenty of other acts, too. Currently he's President of SD Corn Growers, a member of the Nat'l Corn Growers Public Policy Action Team, and a Director of the SD No-Till Association. He's also spoken at various farm seminars and hosted many visitors to his farm (including a certain pesky bus tour from Kansas). Family ranks high in his priorities: David and Carol have five children, ranging in age from 19 to a 9-month-old infant.

Keeping the farm moving forward is itself a full-time job, with 3,400 acres to plant, spray, and harvest, along with some custom spraying. The family and one full-time hired man accomplish all that, but David says his lifestyle is the best it's ever been during his career. "If you have too many enterprises, the farm runs you, instead of you running the farm. When we went straight from calving into spring planting, we didn't have the energy going into the planting season that we needed. Running hard all the time leads to management mistakes."

Always the keen manager, David is open to taking on additional cropland—but only if it pays. "If the new rented land has poor soil structure, low phos. levels, or lots of weeds, you can invest a ton of money in it. There is a good chance it won't be profitable until after three years of effort. Long-term leases are needed to get into the fifth year when the no-till benefits shine."

Gillen fully comprehends the value of knowing his costs and production trends: "A record-keeping system that compares your farm to other farms in your region is very important. If you have a history of having a high cost per unit of production, changes need to be made. . . . I see the farms of the future being more knowledge-based, rather than task-based."

For those who have seen Gillen's operation, or had the chance to discuss production challenges with him, you'll quickly understand that his methods have been carefully refined over the years. Production is quite good for his region, and costs are undeniably low. His grasp of the system is impressive—the way each piece affects every other aspect of the system. He brushes aside the compliments: "There's really nothing special about what we do. We just try to always fix the weakest link. If you fix enough weak links, the system will work."

Photo by Matt Hagny.

David listens intently to Ray Ward describing N mobility in the corn plant, during the No-Till on the Plains bus tour '03.

History of Crop Production, With & Without Tillage

by Rolf Derpsch

PERSPECTIVE

Rolf Derpsch is a researcher and international consultant based in Asunción, Paraguay.

The following is excerpted from a paper originally presented at the 1st JIRCAS Seminar on Soybean Research while the author was working for the MAG-GTZ Soil Conservation Project, Asunción, Paraguay; reprinted and edited here with permission of the author (some statistics have been updated, and new information added, in a collaboration between the editors and the author). More is available at www.rolf-derpsch.com.

Derpsch has witnessed and played a significant part in the development of no-till in South America, with work spanning four decades. He continues to have influence in many corners of the world.

Photo by Matt Hagny.

Teotihuacán, just east of present-day Mexico City, was the sixth-largest city in the world in 600 AD, and was built entirely by hand labor. Teotihuacán was the center of a civilization sustained by an agriculture that also consisted solely of hand labor (no suitable native animals were available for domestication for pulling implements). Here, the view is from atop the Pyramid of the Moon, looking along the Avenue of the Dead with the Pyramid of the Sun on the left. The Pyramid of the Sun was the largest structure in pre-Columbian America, containing over 1 million cubic meters of material; tourists appear to be specks on the enormous structure. Much of the city remains unexcavated.

Photo by Rolf Derpsch.

Small landholder in Paraguay using a planting stick, much as the ancient peoples of the Americas did—no plowing was done.

No-tillage[1] and minimum-tillage have been used since ancient times by the so-called "primitive cultures" for the production of crops, simply because man has not the muscle force to till any significant area of land to a significant depth by hand. To think that tillage is inherent in, or synonymous with, agriculture is a more recent and erroneous idea.

The Incas in the Andes of South America, the ancient Egyptians, as well as most indigenous cultures around the world, routinely used a stick to make a hole in the ground, put seeds in the soil by hand, and covered the seeds with the foot.[2] Even today hundreds of thousands of farmers in Central and South America seed their crops using the same technology. Moreover, millions of hectares of land have been traditionally sown with a hand jab planter without tilling the soil, after burning, in the shifting agricultural system in Brazil and neighboring countries, long before the term no-tillage was introduced into the modern vocabulary. The slash mulch or "tapado" system in Central America and Mexico is another example of no-tillage developed by pre-Columbian cultures and has been used for centuries.[3] In this system, after a rain, seeds are thrown on top of the soil underneath a dense stand of Mexican Sunflower (*Thithonia diversifolia*) or other voluntary (or

[1] 'No-tillage' is defined in this paper as the planting of crops in previously undisturbed soil by opening a narrow slot, trench, or band only of sufficient width and depth to obtain proper seed coverage. No other soil preparation is performed. We also refer here to *permanent* no-tillage rather than not tilling the soil occasionally. "No-till" is the most common term used in the United States, while "direct-drilling" or "zero tillage" is used in the United Kingdom and Europe.

[2] *(Editors' Note: The "hill planting" of placing seeds in individual holes—as well as weed removal and harvesting by hand—permitted the use of mixed cultures, such as with beans, maize, and squash in the same garden or field. [from J. Harlan, 1995,* The living fields, *Cambridge Univ. Press. See also J. Diamond, 1997,* Guns, Germs, and Steel, *Norton & Co.])*

[3] H.D. Thurston, M. Smith, G. Abawi & S. Kearl, 1994, Los sistemas de siembra con cobertura, CIFAD, Cornell Univ.

seeded) vegetation. Then the plants are cut and left on top of the seeds. After a few days the vegetation dries out and the seeds germinate and take root. In this case no tillage is performed at all.

Likewise, prehistoric cropping in Europe, Asia, and Africa proceeded from simple gathering of grains from wild stands to intentional propagation, often with planting sticks. However, by 4000 BC, the first farmers in Europe (the Linearbandkeramik) were using ox-drawn ploughs to dramatically expand their cropping, as were the societies in China at that time.[4]

Power requirements for soil tillage are considerable, and the ploughing system is considered to be an inefficient use of time and energy, and causes much wear and tear to the machines.[5] In modern agriculture this may be a technical challenge or an economic problem, but formerly this meant hard long-lasting labour for a large percentage of all the people that ever lived on earth. Forces required are so great that animals were used very early to make the physical stress endurable.[6] But a small farmer ploughing his field with animal traction has to walk 30 to 40 km (19 to 25 miles) behind his plough for each hectare (2.47 acres) tilled. Therefore, the reduction of tillage to the minimum necessary to produce a crop has probably been in the minds of many farmers for a long time. But when the tractor appeared, where effort is reduced because the operator is sitting, the tendency went the other way—farmers started believing the more tillage you do, the more yield you get. Truth was: The more tillage you do, the more erosion and soil degradation you get, especially in warmer areas.

The plough of ancient times has little in common with modern ploughs of the 19th century. The ancient plough was nothing more than a branch from a tree that scratched or scarified the soil surface without much mixing of the soil layers, and in many areas of the world this type of ploughing is still used. Ploughs that inverted the soil layers and thus gave better weed control were not developed until the 17th century. Only in the 18th and 19th centuries did ploughs become more and more sophisticated. But it was not until the end of the 18th century that German, Dutch, and British developments of this tool led to the shape of the mouldboard, which turned the soil by 135° and was very efficient for weed control. It is this plough that avoided famine and death at the end of the 18th century, since it was the only tool that could effectively control quackgrass (*Agropyron repens*), a weed that had spread all over Europe and could not be controlled with ‘conventional’ tools. Because the modern plough saved Europe from famine and poverty it became a symbol of

When the tractor appeared, where effort is reduced because the operator is sitting, the tendency went the other way—farmers started believing the more tillage you do, the more yield you get. Truth was: The more tillage you do, the more erosion and soil degradation you get.

Photo by Matt Hagny.

Monte Albán, near Oaxaca, was another center of power in 600 AD, although in opposition to Teotihuacán’s. Here, the entire mountaintop was sheared off to build these temples, pyramids, and ballcourts. Again, it was built on agriculture using planting sticks—to have created the food surpluses to support such grandiose cities, the native agricultural methods were anything but primitive or ineffective.

4 Diamond, 1997. *(Editors: Some of these early cultures tended toward “broadcast” seeding, in which seeds were scattered onto a shallowly tilled seedbed and then mixed with the soil, with sizeable areas in a single crop species. Harlan, 1995.)*

5 C.W. Waydelin, 1994, Practical experience with reduced tillage farming, in Proceedings: EC Workshop II: Experience with the applicability of no-tillage crop production in the West-European countries (Silsoe, 15-17 May 1995), Wissenschaftlicher Fachverlag (Giessen, Germany).

6 H. Kuipers, 1970, Historical notes on the zero-tillage concept, *Neth. J. Agric. Sci.*, 18: 219-224. (*Editors: For this reason, plowing became widely dispersed technology in Europe, Asia, and Africa many centuries ago—large animal species were available for domestication and could be used for pulling tillage tools. In the Americas, large animals suitable for domestication and draft work were almost non-existent by the time agriculture was being developed, which was partly due to extinction by hunting. Diamond, 1997.*)

'modern' agriculture and is used as such by many agricultural research institutes, universities, agronomy schools, etc. One of these early ploughs of 1884 is displayed at the agricultural museum of the University of Hohenheim, in Stuttgart, Germany, and in a festival is taken around the city of Hohenheim each year, to commemorate the invention of this implement. By knowing the history of this tool, it becomes understandable why Europeans and especially Germans are often such fervent advocates of the plough, which has turned out to be the most frequently used symbol of agriculture worldwide.

Against this background, the European colonial powers took the modern plough to North and South America, Asia, and Africa, where it became an important tool for the development of newly cultivated land. But it took many decades to discover that the same tool that brought food and wealth to Europe (temporarily), would bring soil erosion and degradation to the warmer environments.

European colonial powers spread the culture of the plough to developing countries, while the native methods have been classified as primitive and unproductive.

Often the experts (mainly from Europe) have spread the misconception that tillage makes the soil fertile and therefore cannot be replaced. They have not understood the significance of soil erosion, as well as intensive weathering under hot, humid conditions. This has resulted in widespread erosion of soils all over the world. Economic interests and the inexperience of some of the expatriate experts (first from the colonial powers and later the aid-donor countries) have spread the culture of the plough to developing countries, while the native methods have been classified as primitive and unproductive.

Mechanised No-till is Born

In modern mechanised agriculture, no-tillage production of crops was attempted a long time ago, but it was not until the advent of modern herbicides that the technique could be put into practice. The first possibility of growing crops without tillage on large-scale farms occurred when 2,4-D, a broadleaf weed killer, was made available to farmers in the 1940s. Later, atrazine and paraquat also became available, these being the only herbicides accessible by early farmers engaged in no-tillage agriculture.

Research on "conservation" or reduced tillage, with early versions of a chisel plough, was started in the Great Plains of the United States in the 1930s to alleviate wind erosion after the occurrence of the famous "Dust Bowl." Stubble mulch farming was developed, and can be seen as a forerunner of no-tillage.

By knowing the history of this tool, it becomes understandable why Europeans and especially Germans are often such fervent advocates of the plough.

Edward Faulkner's book *Plowman's Folly*, first published in 1943, was a milestone in the history of agricultural practices—he questioned the wisdom of ploughing. Some of his statements are: "No one has ever advanced a scientific reason for plowing"; "There is simply no need for plowing in the first instance. And most of the operations that customarily follow the plowing are entirely unnecessary, if the land has not been plowed"; "There is nothing wrong with our soil, except our interference"; and, "It can be said with considerable truth that the use of the plow has actually destroyed the productiveness of our soils." The statements were questioned by both farmers and researchers, because alternatives to ploughing at that time did not allow farmers to control weeds or plant into the residues. According to *Reader's Digest*, "Probably no book on agricultural subject has ever prompted so much discussion in the United States, at the time it was written." Five editions were printed in the first year of publishing.

Photo by GTZ-Germany.

Camel and oxen plowing in northern Africa, where the operator must walk along behind the plow. Plowing for many millenia was done this way in Eurasia.

In the late 1940s, with the introduction of plant growth regulators developed during World War II, reduced tillage was becoming feasible.[7] Klingman reported on no-tillage practice in N. Carolina in the late 1940s. In 1951, K.C. Barrons, J.H. Davidson, and C.D. Fitzgerald of the Dow Chemical Co. reported on the successful application of no-tillage techniques.[8] The invention of paraquat in 1955 and its commercial release in 1961 led the Imperial Chemical Company, ICI, and others to ini-

[7] E.R. Phillips & S.H. Phillips, 1984, *No-tillage Agriculture, Principles and Practices*, Van Nostrand Reinhold Co. (New York).

[8] Also, in the 1960s M.A. Sprague, in New Jersey, reported on pasture renovation using chemicals as a substitute for tillage. (Phillips & Phillips, 1984.) L.A. Porter, in New Zealand, reported on strawberry production without tillage in the early 1960s, followed by A.E.M. Hood and R.S.L. Jeater at Jealott's Hill, England, for small grain. (Phillips & Phillips, 1984.)

tiate rigorous no-tillage research in the UK, the USA and elsewhere.[9] More intensive research on chemical seedbed preparation started in the United States in the early sixties. In 1960, experiments were begun in Virginia: killing bluegrass sod with paraquat, using atrazine for residual control and 2,4-D for post-planting cleanup. These experiments were soon repeated in Ohio, Illinois, and Kentucky.[10]

Permanent no-till is now used on 45% of cropland in Brazil, 50% in Argentina, and 60% in Paraguay, with Paraguay now leading the world in percentage of no-tillage adoption. Access to adequate herbicides and seeding machines, as well as sufficient knowledge of no-tillage methods, were necessary in each instance for widespread adoption of the system.

In 1961, demonstration trials were run on several farms in the USA. These plots led Harry Young and his brother, Lawrence, of Herndon, Kentucky, to apply the novel technology on their farm in 1962, and they became one of the first mechanised farms in the world to use no-tillage crop production. A metal plate at the site remembers the event: "First practice of no-tillage crop production in Kentucky occurred on this farm in 1962. Harry and Lawrence Young of Christian County were among first in nation to experiment with no-tillage techniques which use herbicides in providing seed bed in residue stubble. Conserves soil and water, saves time, labor, fuel and often produces higher crop yields."

Soon thousands of visitors were traveling to the farm to learn about the new technology,[11] and other farmers in the region began testing no-tillage corn production. At this time machinery manufacturers started developing adequate equipment, and in 1966 Allis-Chalmers introduced the fluted coulter no-tillage planter. As no-tillage enabled the farmer to sow seeds immediately after harvest, soybeans produced by the no-tillage method started to be double-cropped after wheat in 1967.[12]

Shirley Phillips wanted to prove that no-tillage was not suitable for adequate crop production. But after seeing the results, he became one of the pioneer researchers of no-tillage (most of his work was at the University of Kentucky), as well as becoming one of the strongest advocates and most successful propagators of no-tillage, not only in the United States, but abroad as well. Because of his commitment to the system, and his scientific, extension, and lecture work, Shirley Phillips can be regarded today as the father of no-tillage technology for mechanised agriculture. In 1973, Phillips and Young published the book *No-Tillage Farming*, the first of its kind in the world. It has been translated into other languages and had widespread impact.

Coming of Age

The area under no-tillage in the United States experienced a steady growth from 2.2 million hectares in 1973, to 4.8 million ha in 1983, to 22 million ha in 2003. Despite the impressive increase of no-tillage in the USA, the expansion has been much slower than anticipated. In 1975, USDA predicted that in the year 2000 about 82% of the cropland in the United States could be under conservation tillage and 45% under no-tillage.[13] This predic-

Photo by John Griebel.

Erosion unleashed by tillage. Erosion is not an unavoidable process.

[9] Among the earliest research publications on no-tillage crop production we can cite J.E. Moody, G.M. Shear & J.N. Jones, Jr., 1961, Growing corn without tillage, *Soil Sci. Soc. Am. Proc.* 25: 516-517; G.R. Free, S.N. Fertig & C.E. Bay, 1963, Zero tillage for corn following sod, *Agron. J.* 55: 207-208; G.B. Triplett, Jr., W.H. Johnson & D.M. Van Doren, Jr., 1963, Performance of two experimental planters for no-tillage corn culture, *Agron. J.* 55: 408-409; J.H. Lillard & J.N. Jones, Jr., 1964, Planting and seed-environment problems with corn in killed-sod seedbeds, *Trans. Am. Soc. Agr. Eng.* 7: 204-208; and, R.S.L. Jeater & H.C. Mcilvenny, 1965, Direct drilling of cereals after use of paraquat, *Weed Res.* 5: 311-318. A report on a six-year comparison of no-tillage was published by Shear and Moshler in 1969.

[10] G.W. Thomas & R.L. Blevins, 1996, The development and importance of no-tillage crop production in Kentucky, Agronomy Research Report: 1996, *Kentucky Agric. Exp. Sta. Progress Report* 385: 5-6. R.L. Blevins, R. Lal, J.W. Doran, G.W. Langdale & W.W. Frye, 1998, Conservation tillage for erosion control and soil quality, in *Advances in Soil and Water Conservation*, Ann Arbor Press.

[11] S.H. Phillips & H.M. Young, 1973, *No-Tillage Farming*, Reiman Assoc. (Milwaukee, WI).

[12] Phillips & Young, 1973.

[13] USDA, 1975, Minimum tillage: A preliminary technology assessment, Office of Planning and Evaluation. USDA, 1985, Conservation tillage: Things to consider, *Agriculture Information Bulletin No. 46*.


Photo by Keith Thompson.

No-till is routine in much of Brazil, such as shown here in the state of Paraná.

tion did not become reality; by 2000 only about 17% of the total cropland area in the USA was under no-tillage. Further, the 17% figure is overstated, since a large portion of those hectares is not considered to be in continuous or permanent no-tillage.

In South America, the first no-tillage experimentation began in Brazil in 1971, and the technology is now being applied to 45% of cropland in Brazil, 50% in Argentina, and 60% in Paraguay, with Paraguay now being the leading country in the world in terms of percentage of no-tillage adoption. Access to adequate herbicides and seeding machines, as well as sufficient knowledge of no-tillage methods, were necessary in each instance for widespread adoption of the system. As more, better, and cheaper herbicides appeared on the market in the 1990s, no-tillage became easier to manage and this, together with the development of better no-tillage seeding machines by manufacturers in Brazil and Argentina, has had a tremendous impact on adoption rates by mechanised farmers in South America.

Compared to the Americas, no-tillage practice is adopted very little in Europe, Africa, and Asia, and in many countries this soil-conserving sustainable production system is virtually unknown. For instance, despite a wealth of research information generated at IITA, Nigeria since the '70s, the total area under no-tillage in Africa is still very small. Probably about 85% of the practical application of no-tillage by farmers worldwide takes place in the Americas.

In North America, despite decades of research and experience, the no-tillage system is still not well understood, nor accepted. This is most unfortunate, and demands our attention, since: "No technique yet devised by mankind has been anywhere near as effective at halting soil erosion and making food production truly sustainable as no-tillage."[14]

The author gratefully acknowledges the help of many colleagues, friends, and farmers in the preparation of this portion of the paper, especially Grant Thomas, Univ. of Kentucky, USA; Friedrich Tebrügge, Justus-Liebig Univ., Giessen, Germany; and, Kurt Steiner, GTZ, Eschborn, Germany.

Derpsch further notes, "It is very difficult to be always fair to all who have contributed over the years to the history and development of no-tillage farming over the world. Therefore I would like to apologize to those not mentioned in this paper."

[14] C.J. Baker, K.E. Saxton & W.R. Ritchie, 1996, *No-tillage Seeding, Science and Practice*, CAB Int'l Publishing (Wallingford, Oxon, UK).

An Ecological Approach to Weed Management:

Crop Competitiveness

by Randy Anderson

SCIENCE

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The following is excerpted from an article in Advances in Agronomy, *volume 80, reprinted and edited here with permission of the author.*

With ecologically based management, emphasis is placed on 1) lowering weed community density, and 2) increasing crop competitiveness with weeds. Diversifying rotations with crops of different life cycles is one tactic for lowering weed community density, whereas any production practice that helps crops access resources earlier than weeds improves a crop's competitiveness. With the ecological approach, herbicides supplement other agronomic practices, rather than serve as the sole tactic for weed control.

Crop interaction with weeds varies with crop, weed species, and environmental conditions, but consistently, any plant, whether a crop or a weed, that captures resources first gains a competitive advantage over neighboring plants.[1] For example, some varieties of winter wheat are more tolerant of downy brome interference.[2] Tolerant varieties are usually taller and intercept more solar radiation; less light within the crop canopy reduces downy brome growth.

A second example is planting winter wheat at higher seeding rates with narrower row spacing, which leads to earlier canopy closure. This strategy improves winter wheat's competitiveness with cheat (*Bromus secalinus*) by 10 to 25% compared to standard practices, reducing yield loss as well as cheat seed production.[3] Another strategy favorable for crops is fertilizer placement. Scientists found that placing N fertilizer in a band below the crop seed reduced jointed goatgrass biomass in winter wheat by 15 to 20% because the winter wheat can then access N earlier than jointed goatgrass.[4]

Summer annual weed density in corn differed among varieties of the previous winter wheat crop.

Production practices can be devised that help the crop capture resources such as nutrients or solar radiation before weeds. To improve competitiveness of winter wheat, corn, sunflower, and proso millet, we evaluated agronomic practices such as nitrogen fertilizer placement, narrow row spacing, higher plant densities, or delayed planting, either alone or in combinations, to determine their impact on weed growth and crop yields.

Strengthen the Wheat Canopy

At Akron, CO, a series of agronomic systems was evaluated to determine if seed production of weedy winter annual grasses could be reduced, comprised of various practices such as higher seeding rates, tall varieties, and banding N fertilizer with the seed.[5] *(Editors' Note: High rates of N with or near the seed may be damaging, even for wheat. Also, sim-*

Photo by Matt Hagny.

It's a fierce struggle between individual plants, and a high-stakes game for the competitors. Here, a patch of henbit established before the wheat, and got the upper hand.

[1] A.M. Mortimer, 1984, Population ecology and weed science, in *Perspective on plant population ecology,* ed. R. Dirzo & J. Sarukhan, Sinauer Assoc. (Sunderland, MS).

[2] Challaiah, O.C. Burnside, G.A. Wicks & V.A. Johnson, 1986, Competition between winter wheat (*Triticum aestivum*) cultivars and downy brome (*Bromus tectorum*), *Weed Sci*. 34: 689-693.

[3] J.A. Koscelny, T.F. Peeper, J.B. Solie & S.G. Solomon, Jr., 1991, Seeding date, seeding rate, and row spacing affect wheat (*Triticum aestivum*) and cheat (*Bromus secalinus*), *Weed Technol*. 5: 707-712.

[4] A.O. Mesbah & S.D. Miller, 1999, Fertilizer placement affects jointed goatgrass (*Aegilops cylindrica*) competition in winter wheat (*Triticum aestivum*), *Weed Technol*. 13: 374-377.

[5] R.L. Anderson, 1997, Cultural systems can reduce reproductive potential of winter annual grasses, *Weed Technol*. 11: 608-613.

ilar results may be obtained with various locations for the fertilizer N placement, so long as the wheat plants have preferential access to it over the weeds. In some climates, delaying N topdressing may provide similar benefits, assuming some fertilizer placement with the seed at planting.) We compared these competition-enhancing practices to the typical methods of producers in the area (seeding rate of 45 kg/ha, semi-dwarf varieties, and N fertilizer applied broadcast early).

Seed production of both feral rye and jointed goatgrass was reduced 40 to 45% by the most effective system—a seeding rate of 67 kg/ha, tall variety, and N banded with the seed at planting. When only one or two competition-enhancing practices were used, weed seed production was reduced less than 20%. In another study, seed production of downy brome was reduced more than 40% by strengthening winter wheat's canopy with similar practices.[6]

Producers may accrue additional benefits for weed management with this strategy, as strengthening the canopy of winter wheat can reduce weeds in other crops in the rotation. Researchers in western Nebraska observed that summer annual weed density in corn differed among varieties of the previous winter wheat crop.[7] They attributed this to two factors: more competitive wheat canopies, and higher crop residue levels after harvest. Any agronomic practice that improved resource capture by winter wheat (such as increased seeding rate, narrow row spacing, or N and P placement) reduced weed density and seed production.[8] Less seed production by weeds in winter wheat led to lower weed density in corn or sorghum.

In corn, foxtail biomass was reduced 60% when three competition-enhancing practices were used. In contrast, weed biomass was reduced 10% or less if only one practice was used, whereas combining any two practices reduced biomass 10 - 25%. Synergism among practices occurred.

The second component involved with winter wheat's suppression of future weed density was residue production. Studies have found that suppression of weed emergence and establishment was related to quantity of crop residue on the soil surface.[9] Weed density was reduced approximately 30% by 3500 kg/ha of crop residue and 60% by residue levels of 8000 kg/ha.

Photo by Doug Palen.

Fertilizer placed with or near the seed (in appropriate amounts) is another tactic with measurable effects on crop competitiveness. Done properly, yield advantages may also be had.

Producers can improve management of winter annual grasses in winter wheat with agronomic practices that help wheat capture resources before weeds. In addition, this strategy may provide an ancillary benefit by reducing the density of summer annual weeds in following crops such as corn or sunflower.

Corn

Corn is rapidly increasing in the northwestern Great Plains region because of its favorable performance when planted after winter wheat. Corn is not strongly competitive with weeds because it is typically grown in wide rows (76 cm, or 30 inch), with low target populations (30,000 to 38,000 plants/ha, or 12,000 to 15,000 plants/acre), and N fertilizer applied broadcast (preplant or wintertime). Consequently, current production practices often rely on high herbicide inputs to manage weeds.

To strengthen corn's competitiveness, we evaluated three agronomic practices: 1) banding N near the seed; 2) higher corn density (47,000 plants/ha); and, 3) narrow row spacing (38 cm).[10] All possible combinations of these practices were evaluated, with the study established in a no-till system. The standard system (common practices) was included for comparison, and treatments were split into weed-free and weed-infested subplots (residual herbicides plus weekly hand-removal of escapes created the weed-free sub-

[6] R.L. Anderson, 1996, Enhancing winter wheat tolerance to downy brome, *West. Soc. Weed Sci. Res. Rpt*.

[7] G.A. Wicks, R.E. Ramsel, P.T. Nordquist, J.W. Schmidt & Challaiah, 1986, Impact of wheat cultivars on establishment and suppression of summer annual weeds, *Agron. J.* 78: 59-62.

[8] P.B. Vander Vorst, G.A. Wicks & O.C. Burnside, 1983, Weed control in a winter wheat-corn-ecofarming rotation, *Agron. J.* 75: 507-511. S.A. Valenti & G.A. Wicks, 1992, Influence of nitrogen rates and wheat (*Triticum aestivum*) cultivars on weed control, *Weed Sci*. 40: 115-121.

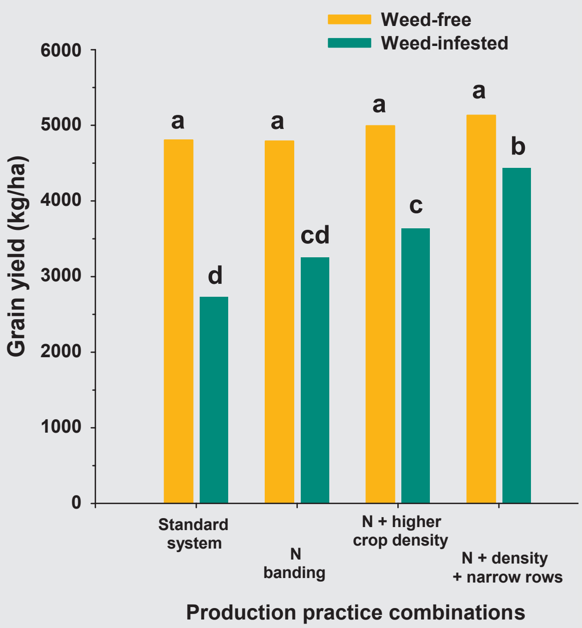
[9] D.A. Crutchfield, G.A. Wicks & O.C. Burnside, 1986, Effect of winter wheat (*Triticum aestivum*) straw mulch level on weed control, *Weed Sci*. 34: 110-114.

[10] R.L. Anderson, 2000, Cultural systems to aid weed management in semiarid corn (*Zea mays*), *Weed Technol*. 14: 630-634.

plots). We found foxtail (*Setaria* spp.) biomass was reduced 60% when three competition-enhancing practices were combined in one system. In contrast, weed biomass was reduced 10% or less if only one practice was used, whereas combining any two practices reduced biomass only 10% to 25%. Synergism among practices occurred; impact on weed biomass was six-fold greater when three competition-enhancing practices were combined as compared to any one practice alone.

Corn yield did not differ among treatments in weed-free conditions, but the competition-enhancing practices improved corn tolerance to weeds. Yield loss due to grass interference was 43% with the standard system, a three-fold difference compared to 13% yield loss with the system using all three enhanced-competition practices (see graph). If only one or two practices were used, yield loss due to weed interference was still reduced, but not to the extent of combining all practices together.

Producers have a multitude of options to favor corn over weeds; competitive canopies in both winter wheat and corn will help weed control by reducing weed density and interference in corn.

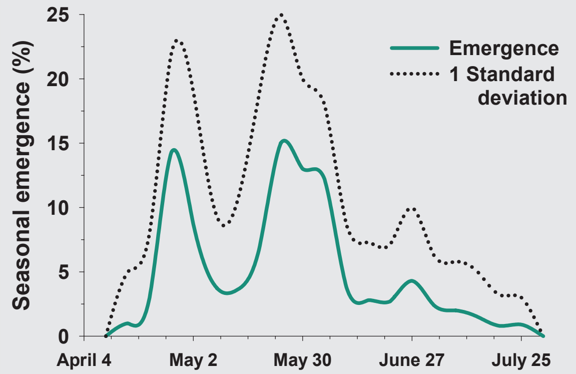


Corn grain yield in weed-free and weed-infested conditions as affected by production practice combinations. Standard system was 37,000 plants/ha at a row spacing of 76 cm, with N fertilizer broadcast at planting. Enhanced-competition practices were banding N near the seed, increasing crop density to 47,000 plants/ha, and reducing row spacing to 38 cm. Weed-free plots with acetamide + atrazine pre-plant, plus hand-weeding on a weekly basis. Data averaged across three years; bars with the same letter are not significantly different based on Fisher's LSD (0.05). (Adapted from Anderson, 2000.)

Sunflower

Sunflower is commonly grown in rotation, often following corn. However, sunflower has a life cycle similar to corn; thus, similar weeds infest both crops. Furthermore, like corn, sunflower is grown in wide rows at low plant densities; consequently, sunflower is not competitive with weeds.

Yet, growing sunflower after corn still offers producers ecological opportunities for weed management. Sunflower is normally planted in early June in northeast Colorado, 3 to 4 weeks later than corn. Planting sunflower later enables producers to reduce potential weed density, as weed emergence declines during the summer. This trend was shown in a long-term study that monitored weed emergence between April 1 and September 1.[11] Averaged across seven years, weed emergence showed two peaks, the first between April 25 and May 9, and the second between May 23 and June 6. The first peak was comprised of cool-season species, whereas warm-season species were dominant in the second peak. Emergence after June 1 was only

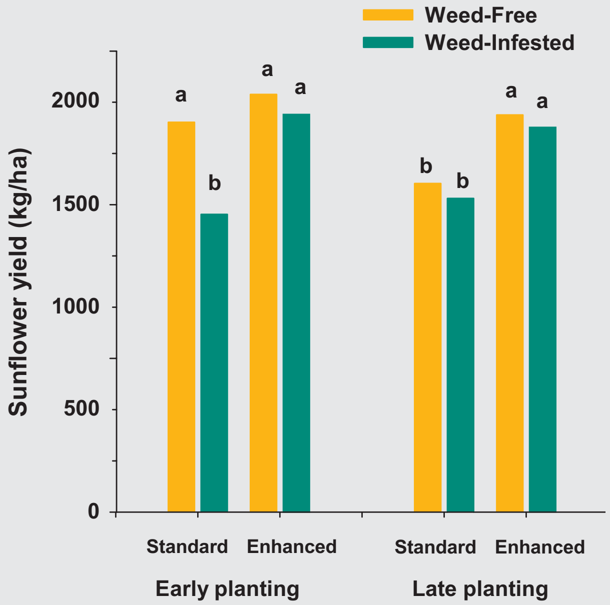


Emergence pattern for a weed community in the central Great Plains. Data collected from two tillage treatments, no-till and tillage with a sweep plow, and averaged across 7 years. Dotted line represents one standard deviation. (Adapted from Anderson, 1994a.)

Photo by Matt Hagny.

A dense thatch of wheat stubble works wonders for suppressing weeds, and has an effect for several years. Many details go into growing and preserving maximum amounts of residues.

[11] R.L. Anderson, 1994a, Characterizing weed community seedling emergence for a semiarid site in Colorado, *Weed Technol*. 8: 245-249.



Grain yield of sunflower grown in two production systems; the competition-enhancing system eliminated yield loss due to weed interference. The standard system was comprised of 76-cm row spacing, crop population of 39,000 plants/ha, and N fertilizer applied broadcast. The competition-enhancing system included row spacing of 50 cm, crop population of 47,000 plants/ha, and N fertilizer applied in a band near the seed at planting. Planting dates differed by two weeks. No in-crop herbicides. Data averaged across 2 years; bars with the same letter are not significantly different based on Fisher's LSD (0.05). (Adapted from Anderson, 1999b; Tanaka & Anderson, 2000.)

30% of the total seasonal emergence; thus, planting sunflower later reduces potential weed emergence in the crop 35 to 40% compared to corn.

To further improve weed management, we evaluated production practices to strengthen sunflower competitiveness.[12] Common production practices for sunflower in this region include plant populations of 35,000 to 39,000 plants/ha in 76-cm rows, with N fertilizer applied broadcast (referred to as the standard system). To improve canopy development, we grew sunflower in narrow rows (50 cm wide), increased plant population (47,000 plants/ha), and banded N fertilizer adjacent to the seed row (referred to as the enhanced system). We compared these systems at two planting dates: early June, and two weeks later. Treatments were split into weed-free and weed-infested subplots.

With early planting, weed biomass was reduced approximately 65% by the enhanced system compared to the standard system. When planting was delayed two weeks, the enhanced system reduced weed biomass 85% compared to the standard system. Within the standard system, weed biomass was 50% less with later planting versus early. Later planting provided an additional two weeks to control weeds.

The competition-enhancing system eliminated yield loss due to weed interference at both planting dates (see graph). In contrast, with the standard system, weeds reduced yield 24% at the early planting date but did not affect yield when planting was delayed. Sunflower usually yields less when planted late—comparing the standard systems in weed-free conditions, later planting reduced yield 17%. Surprisingly, delayed planting did not reduce yield with the enhanced system. We speculate that this system improved growth efficiency of sunflower, thus minimizing the detrimental effect of late planting. *(Editors: Repeated usage of delayed planting methods may cause weed species or biotype shifts toward more late-emerging weeds.)*

With early planted sunflower, weed biomass was reduced 65% by the enhanced system.

Proso Millet

Proso millet, a summer annual grass, is being included in many planned rotations in the region. As with sunflower, proso millet is usually planted in early June in northeast Colorado, with optimum planting dates in no-till systems being June 1 to June 10.[13]

Proso millet is competitive with weeds because it is planted in narrow rows (20 to 30 cm) and at high plant populations (2 million seeds/ha); weed biomass in proso millet is commonly a fraction of that found in corn or sunflower.[14] Because proso millet is highly competitive, we hypothesized that production systems could be designed to eliminate the need for herbicides in proso millet. Not only would this tactic help producers reduce input costs, but would avoid herbicide injury to proso millet, which can reduce yield by 20%.[15]

Again, production practices were evaluated. The competition-enhancing system strengthened proso canopy by increasing the seeding rate 50% and banding N fertilizer near the seed; also, planting was delayed two weeks compared to the standard system.

[12] R.L. Anderson, 1999b, Improving weed control in corn and sunflowers with narrow rows, in Proceedings: 11th Annual Meeting, Colorado Conservation Tillage Association (Sterling CO), Colo. Conserv. Tillage Assoc. D.L. Tanaka & R.L. Anderson, 2000, Integrated approach to weed control in sunflowers, in Proceedings: 22d National Sunflower Association Research Workshop (Fargo ND), Natl. Sunflower Assoc.

[13] R.L. Anderson, 1994b, Planting date effect on no-till proso millet, *J. Prod. Agric*. 7: 454-458.

[14] by a factor of three as compared to sunflower, and a factor of 10 compared to corn. R.L. Anderson, 1999a, Cultural strategies reduce weed densities in summer annual crops, *Weed Technol*. 13: 314-319.

[15] D.J. Lyon & S.D. Miller, 1999, Herbicide injury in proso and foxtail millets, in Proceedings: Western Soc. Weed Sci. Annual Meeting 52: 24.

We also evaluated two tillage treatments, no-till versus tillage with the sweep plow, on weed dynamics in each production system. The weed community was primarily redroot pigweed (*Amaranthus retroflexus*). Each plot was split into weed-free and weed-infested subplots.

The competition-enhancing system eliminated yield loss due to redroot pigweed interference. With tillage, weeds reduced grain yield 29% in the standard system, but yield loss was only 2% with the enhanced system (see table). In no-till, yield loss decreased from 4% in the standard system to 0% with the enhanced system. Yield differences reflect production system impact on redroot pigweed density and biomass. With tillage, only 8 plants/m^2 infested the enhanced system whereas 42 plants/m^2 established in the standard system, a five-fold increase. Further, the more competitive system reduced weed *biomass* by a factor of nine. Similar trends occurred in no-till; the enhanced system reduced redroot pigweed density by a factor of 6, and biomass by a factor of 10.

In proso millet, the more competitive system reduced weed biomass by 90%.

Grain yield in weed-free conditions did not differ between systems within a tillage treatment. But, yield was 25% greater in no-till, which was attributed to improved water relations.

Tolerable Weed Levels?

Producers are concerned that seed production of isolated weeds in the crop will rapidly increase weed density in future years. Weeds produce a considerable number of seeds per plant.[16] Yet research has shown that weed density *in rotations* remains relatively stable if control efficacy of either weed seed production[17] or biomass[18] approaches 85 to 90%. (*Editors: Weed population stability is highly dependent upon species, climate, amount of soil disturbance, residue levels, rotation, etc. Also, control in a 3-year rotation of 100% >>100% >>55% probably behaves very differently from 85% every year, even though the averages are the same.*)

In our proso millet study, biomass of redroot pigweed was reduced almost 90% with the competition-enhancing system in both tillage treatments (see table). Furthermore, seed production/m^2 by redroot pigweed was reduced by factors of 10 to 16 by the enhanced system. With no-till, one plant in the enhanced system produced 600 seeds; in contrast, six plants in the standard system produced 9,700 seeds, or approximately 1,600 seeds/plant. A similar trend occurred between agronomic systems in the tilled treatment; seed production/m^2 was reduced by a factor of 10 with the enhanced system.

This suggests that ecologically based weed management could play a major role in preventing weed population growth, as seed production is severely reduced with more competitive proso millet. We suggest that a similar result with weed seed pro-

	Redroot Pigweed			Proso Millet
	Density (plants/m^2)	Biomass (g/m^2)	Seed production (seeds/m^2)	Yield loss (%)
Tilled				
Standard	42 a	475 a	88,400 a	29 a
Enhanced	8 b	56 b	8,100 b	2 bc
No-Till				
Standard	6 b	72 b	9,700 b	4 b
Enhanced	1 c	7 c	600 c	0 c

Effect of production systems on redroot pigweed growth and interference in proso millet. Data averaged across three years. Tillage was performed with a sweep plow. Standard system was comprised of a seeding rate of 11 kg/ha, N broadcast, and early planting; competition-enhancing system was proso millet planted at 17 kg/ha, N banded near the seed, and planting delayed two weeks. Means within columns followed by the same letter do not differ as determined with Fisher's LSD (0.05). (Adapted from Anderson, 2000.)

[16] R.L. Anderson, 1998, Designing rotations for a semiarid region, in Proceedings: 10th Annual Meeting, Colorado Conservation Tillage Association (Sterling CO), Colo. Conserv. Tillage Assoc.

[17] L.G. Firbank & A.R. Watkinson, 1986, Modelling the population dynamics of an arable weed and its effects upon crop yield, *J. Appl. Ecol*. 23: 147-159. R. Cousens, S.R. Moss, G.W. Cussans & B.J. Wilson, 1987, Modeling weed populations in cereals, in *Reviews of Weed Science* 3: 93-112, Weed Science Society of America.

[18] A.C. Bosnic & C.J. Swanton, 1997, Economic decision rules for postemergence herbicide control of barnyardgrass (*Echinochloa crus-galli*) in corn (*Zea mays*), *Weed Sci*. 45: 557-563. Our interest in the rate of weed population increase was stimulated by producer experiences with weeds in corn. Seeking to reduce jointed goatgrass in winter wheat, producers grew corn three years in a row to deplete the goatgrass seed bank. However, this strategy led to a dramatic proliferation of summer annual grasses in corn. To understand this trend, we quantified the following parameters that influence population growth of green foxtail. (Anderson, 1998.) First, green foxtail growing in corn produces approximately 2,300 seeds per plant, and secondly, 8% of green foxtail seeds in soil emerge each year. We also noted that weed control in corn generally eliminates 90% of green foxtail plants. Based on these parameters, one green foxtail plant establishing during the first year of corn will lead to 18 plants in the second year of corn and 324 plants in the third year—a rate of increase of 18-fold per year. Exponential growth by green foxtail led to the severe infestation after three years of continuous corn. We also have observed a similar rate of increase for downy brome infesting winter wheat. These trends with green foxtail and downy brome indicate that growing crops with similar life cycles more than two years in a row favors exponential growth in weed density. If rotations are comprised only of crops with similar life cycles, producers will have to compensate for the natural rate of increase in weed population with herbicides or other weed control tactics.

Rotation	Downy Brome Density (plants/m²) 1999	2001
w.wht >>fallow	3	54
w.wht >>green fallow[1]	50	115
w.wht >>chickpea	44	102
w.wht >>flax[2]	78	
w.wht >>corn >>fallow	1	1
w.wht >>corn >>flax[2]	5	
w.wht >>corn >>(field) pea	1	1
w.wht >>corn >>chickpea	1	3
s.wht >>w.wht >>corn >>soy	10	0
s.wht >>w.wht >>soy >>corn	13	0
w.wht >>corn >>soy >>pea	1	0
w.wht >> soy >>flax[2]	13	

All rotations long-term no-till, at Dakota Lakes W. River site; rotations had been in place for 9 years by '99, in a very good winter wheat production year (good crop canopy). Measurements by Dakota Lakes staff ('99) and Randy Anderson ('01).

Surprisingly, the 2-yr wheat >>fallow rotation wasn't as badly overrun with d. brome as one might expect for that 'rotation' being in place for that long, under no-till. Over the course of the study, the production practices on the wheat have been superb in terms of seeding rates, seed placement, fertilizer placement, etc., which has afforded excellent competitiveness. Now compare the rotations with the same interval, but with broadleaf crops seeded in the non-wheat year—in those, the 'cheatgrass' numbers really exploded. Beck explains: "The secrets included not applying N until after [wheat] canopy, low-disturbance, and the stripper header . . . The heavy wheat stubble was a barrier to the weeds, and if we broke it by seeding a crop, then the weeds could go."

However, the situation played out entirely differently in longer rotations—breaking the barrier to plant a crop was okay because the downy brome was then trying to establish during a couple years when it was met with herbicides (little or no seed production). After 2 or 3 years, when those plots went into w.wht again, very little viable downy brome seed remained. It is clear from these results that very heavy residue and the absolute least disturbance possible have a profound effect on weed seed viability and/or ability to establish.

[1] The high weed numbers for this rotation partly reflect what Dwayne Beck (the site manager) describes as poor methods for doing green fallow—not choosing the right cover crop, planting at the wrong time, etc. It was exacerbated by the fact that the site was a 45-mile roadtrip from the main farm, which didn't lend itself to doing lots of extra or uniquely timed passes with the seeder or sprayer.

[2] Canola was substituted for flax in the last years of the study.

duction may occur with competition-enhancing systems in sunflower, as weed biomass can be reduced 85%.[19] (Seed production by weeds is related to their biomass; generally, larger plants produce more seeds.) With both proso millet and sunflower, systems enhancing crop competitiveness may enable producers to eliminate in-crop herbicide use, consequently reducing input costs as well as minimizing selection pressure for resistant weed species. However, corn still required the use of in-crop herbicides to maintain adequate weed control.

In our proso millet study, tillage had a startling impact on weed dynamics. Redroot pigweed density and biomass was at least six-fold greater with tillage compared to no-till (see table). Tilling with the sweep plow apparently placed redroot pigweed seed in more favorable germination sites in the soil. A second outcome was that proso millet yielded less with tillage. These trends were similar to results found with corn where tillage increased weed density but decreased grain yield.

Implications

An opportunity exists for the agricultural community to develop production systems guided by ecological principles. Along with appropriate crop sequencing and rotational design, producers who integrate strategies for strengthening crop competition can greatly reduce weed populations and interference.

No-till systems have changed cropping practices in the central Great Plains because of beneficial impacts on water relations and soil health.[20] Some scientists have suggested that no-till systems have initiated a spiral of soil regeneration in this region, where interactions among more favorable water relations, residue production, and crop yield are continually improving soil health and, consequently, future crop performance.[21]

Producers are struggling with this paradox: Tools (herbicides) needed for more intensive cropping are being rendered ineffective by resistant weeds; yet intensive cropping is less feasible in tilled systems. For weed management in crops, the ecological approach expands producer options to control weeds and avoid herbicide resistance.

For a detailed discussion on reducing weed density with rotations, and the effects of soil disturbance on weed seed banks, see the December '03 Leading Edge.

[19] Anderson, 1999b. Tanaka & Anderson, 2000.

[20] G.A. Peterson, A.J. Schlegel, D.L. Tanaka & O.R. Jones, 1996, Precipitation use efficiency as affected by cropping and tillage systems, *J. Prod. Agric.* 9: 180-186. R.A. Bowman, M.F. Vigil, D.C. Nielsen & R.L. Anderson, 1999, Soil organic matter changes in intensively cropped dryland systems, *Soil Sci. Soc. Am. J.* 63: 186-191.

[21] G.A. Peterson, D.G. Westfall & C.V. Cole, 1993, Agroecosystem approach to soil and crop management research, *Soil Sci. Soc. Am. J.* 57: 1354-1360.

A year ago, *Leading Edge* reported some studies comparing strip-till to low-disturbance no-till, with appropriate rates and sources of pop-up fertilizer applied with the seed. 2003 provided another look. Once again, we can conclude that the use of pop-up fertilizer eliminates any 'advantage' to strip-till. (Unfortunately, the vast majority of studies do not include the use of pop-up fertilizers to approximate the effect of fertilizer placement with strip-till, which biases the study from the outset and makes the results deceptive. Other flaws in many of those studies include the failure to equip the planter for successful no-till, with proper row cleaning, seed firming, and furrow closing capabilities.)

If you apply the economics, it looks even worse for strip-till—and that's just accounting for the extra pass (and/or hp) and costs associated with the strip-till machine. It gets much worse when you start figuring weed control differences (see Anderson's data in Dec. '03 *Leading Edge*—just a little disturbance has major impacts, all of which benefit the weeds), and realize that now you've got two very different emergence timings and growth rates for weeds in the field.

Paul Jasa, Extension Ag Engineer at Univ. Neb.-Lincoln, offers additional insights: "The key to making no-till work is *continuous* no-till and allowing soil structure to build. . . . Moisture conservation and soil structure are the two main reasons I'm not a strip-till promoter . . . . Thus I always ask producers considering strip-till: 'Why do they think they need it or what are they trying to accomplish?' . . . nutrient placement can be done with far less soil disturbance."

	'03 Corn bu/a
Fall strip-till with fert. placement	data not shown*
Fall strip-till, no P_2O_5 in fall	151.3
No-till	150.9
LSD (P=0.05)	not significant

* Slow emergence and a significantly reduced stand resulted in lower yields; no comparisons could be made, according to the researchers.

Location: farm near Sinai, SD. Soil test: 5 ppm Olsen P. Previous crop: wheat. Long-term no-till.

All treatments had 46 lbs. P_2O_5 applied in the seed furrow at planting, except the fall strip-till with fert. placement which had 46 lbs. P_2O_5 applied with the strip-till rig ~ 7 inches below the surface.

N fertilizer was broadcast, except on fall strip-till with fert. placement; rates were equal. Planter with row cleaners.

Conducted by SDSU (A. Bly, R. Gelderman, J. Gerwing & D. Winther). 4 replications, randomized.

	Row Cleaner	Row Coulter	Nitrogen	Phosphorus	'03 Corn bu/a
Strip-till	yes	no	Fall	Fall	95.3
Strip-till	yes	no	Spring	Fall	95.6
Strip-till	yes	no	Spring	Seed Furrow	94.1
Strip-till	yes	no	Spring	None	96.7
No-till	yes	yes	Spring	Seed Furrow	103.5
No-till	yes	no	Spring	Seed Furrow	101.3
No-till (slot)	no	yes	Spring	Seed Furrow	97.9
No-till (slot)	no	no	Spring	Seed Furrow	102.6
Deep-till	yes	no	Spring	With DT	100.0
Deep-till	yes	no	Spring	None	95.3
LSD(P=0.05)					ns

Location: farm near Brookings, SD. Previous crop: soybean. Soil test: 11 ppm Olsen P. Long-term no-till.

All treatments had 30 lbs. P_2O_5 applied in the seed furrow at planting, except the fall strip-till with phos. placement (which had 30 lbs. P_2O_5 placed ~ 7 inches deep in the fall), and the deep-till with phos. placement (which had 90 lbs. P_2O_5 applied ~ 7 inches below the surface). Deep-till was ~ 21 inches with ripper.

N fertilizer was broadcast, except on fall strip-till with N fert. placement; rates were equal.

Conducted by SDSU (A. Bly, R. Gelderman, J. Gerwing & D. Winther). 3 replications, randomized.

'03 Corn Yield bu/a

	Soybean Stubble	Wheat Stubble
Fall strip-till with P_2O_5 fert. placement	143	154
Fall strip-till, no P_2O_5 in fall	149	160
No-till	141	158
LSD (P=0.05)	not significant	not significant

Location: SDSU research farm near Beresford, SD. Soil test: 10 ppm Olsen P. Long-term no-till.

All treatments had 46 lbs. P_2O_5 applied in the seed furrow at planting, except the fall strip-till with fert. placement which had 46 lbs. P_2O_5 applied with the strip-till rig ~ 7 inches below the surface.

N fertilizer was side-dressed on all plots. Planter with row cleaners.

Conducted by SDSU (A. Bly, R. Gelderman, J. Gerwing & B. Berg). 4 replications, randomized.

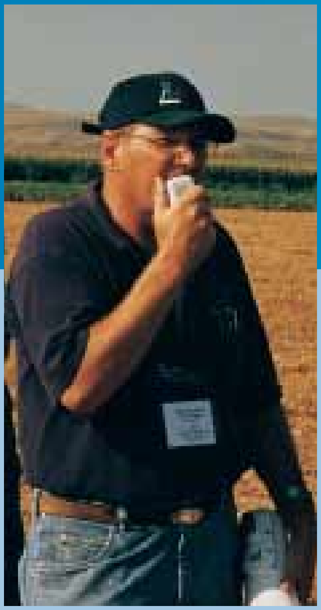


Photo by Matt Hagny.

An Emphasis on Rotations

by Dwayne Beck

TECHNIQUE

Dwayne Beck is manager of Dakota Lakes Research Farm at Pierre, SD.

The following was included in the proceedings for the SD No-Till Association's "No-Till Under Cover" conf. (Feb. '03), and also No-Till on the Plains' Winter Conference 2003. Edited here.

Yes, it's worth reading again.

Determining what to grow as rotational crop(s) and how they will be sequenced can be a complex process. There are however some general guidelines that can be extremely helpful in beginning the process. Consider this to be 'Beck's Top 10 List.' The order they appear does not denote their importance.

1. Reduced- and no-till systems favor the inclusion of more diverse crops. Tilled systems may not.
2. A two-season interval between growing a given crop or crop type is preferred. Some broadleaf crops require more time.
3. Chemical fallow is generally not as effective at breaking weed, disease, and insect cycles as are black fallow, green fallow, or production of a properly chosen crop (or cover crop).
4. Rotations should be sequenced to make it easy to prevent volunteer plants of the previous crop from becoming a weed problem.
5. Producers with livestock enterprises find it less difficult to introduce diversity into rotations. (Use of forage or flexible forage/grain crops and green fallow enhance the ability to tailor rotational intensity.)
6. Crops destined for direct human food-use pose the highest risk and offer the highest potential returns.
7. The desire to increase diversity and intensity needs to be balanced with profitability.
8. Soil moisture storage is affected by surface residue amounts, inter-crop period, ability of stubble to catch snow, rooting depth characteristics, soil characteristics, precipitation patterns, and other factors.
9. Seedbed conditions at the desired seeding time can be controlled through the choice of the previous crop(s), with differing characteristics in regard to residue color, amount, distribution, and architecture.
10. Rotations that are not consistent in either crop sequence or crop interval guard against pest species shifts and minimize the probability of developing resistant, tolerant, or adapted pest species.

Classification of Rotation Types

It is sometimes easier to discuss concepts if they are placed into categories of some sort.

We have developed the following scheme with this in mind. This classification is totally arbitrary and is meant to serve only as a tool to help understand rotation planning.

Simple Rotations: Rotations with only one crop of each crop type used in a set sequence, using only a single-year of each type. This is the most common rotation.

Examples: 1) Winter Wheat >>Corn >>Fallow; 2) Wheat >>Canola; 3) Spring Wheat >>Corn >>Soybean;

Photo by Matt Hagny.

Whatever your rotation, both sequence and interval are critical. In some climates, soybeans provide an excellent transition from the summer grass crops (corn & milo) into wheat.

4) Corn >>Soybean; and 5) W. Wheat >>Corn >>Pea

Advantages: Simplicity; limited number of crops to manage and market.

Disadvantages: Limited number of crop sequence and interval combinations. For example, all corn is sequenced behind wheat or all wheat goes into broadleaf stubble. In other words, this style is consistent in both sequence and interval. Conditions for each crop are the same on all of the acreage, which increases risk that any production problems encountered would affect all the acres of that crop.

Simple Rotations with Perennial Sequences: Simple rotations that are diversified by adding a sequence of numerous years of a perennial crop.

Example: Corn >>Soybean >>C >>Sb >>C >>Sb >>Alfalfa >>Alf >>Alf >>Alf

(many others exist)

Advantages: Simple. Limited number of annual crops to manage and market. The perennial crop is an excellent place to spread manure. Perennial crops probably can produce more soil structure than annual crops. This is especially true when grass or grass mixtures are the perennial crop. Biomass crops and use of grazing systems have potential.

Disadvantages: It is difficult to manage a sufficient percentage of the farming enterprise as a perennial crop without grazing. Harvesting 40% of the farmland as forage is tough. Using less than 40% perennial crop minimizes its impact.

Humans tend to operate in a different time frame than other species. Days, hours, and years have a totally different meaning to a bacterium or fungus than they do to a tree.

Marketing Perennial Crops is an Issue. For instance: If the producer could only harvest 400 acres of alfalfa in a timely manner with the machinery and labor resources available, he would be limited to having 300 acres each of corn and soybeans in the above rotation. If he expanded his corn and soybean acreage more than this, the rotational benefit of the alfalfa sequence would be negated on the extra acreage. If he had 400 acres of alfalfa and 1000 acres each of both corn and soybeans (leaving the alfalfa for 4 years), alfalfa would be placed on any given field only one time in a 24-year period. He would in essence have 6 years of corn >>soybean in a perennial sequence rotation and 14 years of corn >>soybeans in a simple rotation.


Photo by Doug Palen.

Doing significant acres of alfalfa poses workload problems, although perennials can improve rotations.

Perennial sequence rotations have substantial benefit when used on fields close to the farmstead or feedlot. A producer could allocate 1,000 acres in proximity to where the forage would be used to a perennial sequence rotation. His remaining acreage could be managed in a more diverse rotation that did not involve perennials.

Another option for obtaining a larger percentage of annual crop acres is to combine a more diverse type of rotation and a perennial sequence.

The main reason agriculture faces issues with resistant weed and insect biotypes is that cropping programs create conditions that favor certain individuals amongst the pest population and keep these conditions in place long enough, frequently enough, and/or predictably enough to allow that biotype to become the predominate population.

Compound Rotations: Combination of two or more simple rotations in series to create a longer, more diverse system.

Example: S.Wheat >>Corn >>Soybean >>Corn >>Soybean.

(This results from a combination of the S.Wheat >>Corn >>Soybean, and a Corn >>Soy rotation)

Advantages: There are still a limited number of crops to manage and market. This approach creates more than one sequence for some crop types. In the example, there is diversity in both sequence and crop environment for corn (but not soybean or wheat). Diversity exists in interval for all crops except wheat.

Disadvantages: There is a limited ability to spread workload since 2/5 of the acreage is in corn and 2/5 in soybeans.

Complex Rotations: Rotations where crops within the same crop type vary.

Examples: 1) S.Wheat >>Corn >>Sunflower >>Sorghum >>Soybean; and 2) Barley >>Canola >>Wheat >>Pea.

The first example is similar to the one cited for compound rotations. Sorghum has been substituted for one of the corn crops, and sunflowers for one soybean. In the other example, a barley has been substituted for a wheat crop, and pea for a canola.

Advantage: This type of approach is capable of creating a wide array of crop type by sequence combinations. If the crops are chosen wisely there is substantial ability to spread workload. This approach is effective at combating many crop-specific pest problems such as cyst nematode in soybeans, blackleg in canola, or corn rootworm in corn. (*Editors: However, if a biotype of corn rootworm arises that lays eggs in wheat stubble or growing wheat, this approach has no effect—corn always follows wheat in the example.*) Pests such as white mold that have multiple hosts respond similarly to the way they behave in compound rotations.

> **Stacking should not be unfamiliar because it is the way plants sequence in nature. A species predominates a space for a period of time and is succeeded by another species. Eventually, after many such successions, the original species will again occupy the space.**

Disadvantages: The larger number of crops requires substantial crop management and marketing skill.

Stacked Rotations: One of the lesser-known approaches we call a 'stacked' rotation. This includes rotations where annual crops are grown in succession (normally twice) followed by a long break.

Example: Wheat >>Wheat >>Corn >>Corn >>Sb >>Sb

(The example is a 'pure' stack, where the same crop species is used in the second year; a variation uses a different species of the same crop type in the second year, such as sorghum following corn, which captures some but not all of the advantages of stacking. Also, the above example is 'fully' stacked in that every crop is grown two years in succession.)

Stacked Rotation Concepts: This should not be an unfamiliar concept because it is the way that plants sequence in nature. A species predominates a space for a period of time and is succeeded by another species. Eventually (after many such successions) the original species will again occupy the space. The time frame for these 'rotations' is much longer than the one usually considered in annual crop production but the principles are the same. Humans tend to operate in a different time frame than other species. Days, hours, and years have a totally different meaning to a bacterium or fungus than they do to a tree. Some species populations have very fast growth curves, once they are given the opportunity, while others take a long time to build population. Each species has a 'survival strategy' to increase the chances that it will continue to exist. Humans learned to build shelters, grow food, etc. because we were not the best-adapted species at enduring the elements and hunting or gathering. Many annual weeds produce huge numbers of seeds, increasing the probability that at least one will survive. Other weeds have seeds with longer ranges of dormancy, allowing them to fit into environments where all years are not good years. Many disease organisms produce resting bodies that require favorable conditions to exist before they attempt to grow.

> **Rotations containing only one crop sequence or one interval will eventually select for a species (or a biotype within a species) that is suited to the particular conditions. Stacking greatly reduces the selection pressure for any certain biotype.**

The universal survival strategy for all species is genetic diversity. This allows some of them to survive in conditions that eliminate the rest of the population. Some of the offspring of these survivors have this same survival advantage. Consequently, individuals with this trait will increase as long as the conditions that favor them continue. They may not have an advantage if conditions change. The main reason agriculture faces issues with resistant weed and insect biotypes is that cropping programs create conditions that favor specific individuals amongst the population and keep these conditions in place long enough, frequently enough, and/or predictably enough to allow that biotype to become the predominate population.

The concept behind stacked rotations (as with some of the other types of rotations as well) is to keep both crop sequence and crop interval diverse. Part of the strategy recognizes the fact that rotations containing only one crop sequence or one interval will eventually select for a species (or a biotype within a species) that is suited to the particular conditions. In the case of a species biotype, the population will continue to grow and purify as long as the conditions remain the same.

It is probably best to provide a few examples (even though these examples pertain to corn insects, similar mechanisms for pest biotype shifts could occur in any crop). In the Corn Belt and in irrigated areas on the plains in the U.S., it was at one time common for many growers to produce corn on the same land every year. When this was done, an insect known as the corn rootworm beetle (there are several species with similar habits) would feed on the corn silks and lay eggs at the base of the corn plant. Most of these eggs would hatch the next spring. If corn or other suitable hosts were present, the larvae would feed on the corn roots and cause significant losses. This required use of insecticides on land devoted to continuous corn production. When corn was seeded following soybeans this insect was initially not a problem. Interestingly enough, following a long history of corn >>soybean rotation in parts of the Corn Belt, the corn rootworm beetles have 'devised' two known survival strategies. In western areas an "extended-diapause" biotype has become common and in some cases predominate. The majority of the eggs laid by this biotype do not hatch the next spring (when soybeans are seeded), waiting instead for corn to predictably return the second year. In reality, eggs laid by some individuals always had a higher proportion with this tendency. They now predominate the population in some regions because the persistent and widespread use of the corn >>soybean rotation was consistent in the interval between successive corn crops. This gave this biotype competitive advantage.

Shifts in characteristics do not always occur quickly. Species with only one generation per year may take a decade or two for a biotype with a suitable survival strategy to develop into predominance. During this period the producer becomes convinced he has developed the ultimate cropping program. Then, almost without warning, the system fails.

The second example comes from more eastern areas. This adaptation involves the gravid females migrating to *soybean* fields to lay their eggs. When these hatch the next spring, corn will most likely be there. In this case the biotype was given an advantage because the corn >>soybean rotation is consistent in *sequence*. A similar adaptation would probably occur if the majority of corn in an area is seeded following wheat for many years.

In the fully stacked wheat >>wheat >>corn >>corn >>soybean >>soybean example, the sequence for corn and the interval between corn crops is unpredictable in the time frame of an insect. (It looks very predictable to humans.) This greatly reduces the selection pressure for any certain biotype, and creates selection pressures that push in opposite directions. Just as importantly, some of the population with normal habits (feeding on corn, laying eggs in corn, eggs hatching the next spring) have been kept alive due to the corn >>corn stack. This will dilute the population of those with aberrant behavior.


Photo by Dwayne Beck.

Canola can have a fit in some rotations. In dry regions, it is a good seedbed for wheat.

The examples given dealt with insects. Examples can just as easily be found using weeds or diseases. The important point to remember is that these shifts in characteristics do not always occur quickly. Species with only one generation per year may take a decade or two for a biotype with a suitable survival strategy to develop into predominance. During this period the producer becomes convinced that he has developed the ultimate crop rotation, found the perfect chemical, etc. for his operation (it has worked for 7 years in a row). Then, almost without warning, the system fails. Everyone with resistant weed biotypes has witnessed this phenomenon.

The second part of the stacked concept is to have a long break (crop-to-crop interval) in the rotation. From a diversity standpoint it is better to have a mixture of intervals. To provide maximum protection against pests, one of the intervals must be sufficiently long to allow populations of certain diseases or weeds to drop to low levels. Careful study of growth and decay curves demonstrates that 'first-year' (new) crops on a given piece of land experience few crop-specific pest problems. If the crop is planted a second time in succession on this 'virgin' site, it does as well or maybe even better. It is only during the third year (or more) that problems begin to appear. These problems often grow very quickly once they establish. The reason this happens is that growth and decay curves for biological systems follow geometric patterns. (Examples: 2, 4, 8, 16, 32, 64; or 1, 10, 100, 1000). Since decay works the same as growth in reverse, a short break is not enough to decrease some problems sufficiently. This is especially true if they have survival mechanisms like seed dormancy. The power behind a perennial sequence is the long break. The theory behind stacked rotations is to provide a long break somewhere in the system.

In "the old days" it was common to have a perennial sequence followed by several years of the same crop. When the homesteaders came, that is why they were initially so successful (and the fact that they had a huge no-till history preceding them). In Argentina, it is still common to rotate 7 years of pasture with 7 years of cropping. On rented land this may be 7 years (or less if disease strikes) of continuous soybeans.

Populations may grow quickly once they establish. The reason: growth and decay curves for biological systems follow geometric patterns. (Examples: 2, 4, 8, 16, 32, 64; or 1, 10, 100, 1000). Since decay works the same as growth in reverse, a short break is not enough to decrease some problems sufficiently.

Plants develop associated positive biology just as they develop associated negative biology. These associated species can sometimes benefit crops when they are planted in the same field in subsequent years. The most commonly cited example is VAM, the mycorrhizal fungi that help crops like corn and sunflowers obtain moisture and nutrients from the soil. It is thought that these organisms might be the reason for corn-on-corn and sunflower-on-corn sequences performing better than expected. Another example is the N-fixing *Rhizobia* bacteria associated with legume crops. Soybeans grown following soybeans are capable of fixing more N because higher populations of the proper *Rhizobium* exist in the soil. The soil is also lower in mineral nitrogen sources since the previous year's legume crop scavenged these prior to beginning the fixation process. Part of the theory of stacked rotations involves taking advantage of these positive associations before negative associations can build to harmful levels. There probably are positive associations involving predatory insects as well, but this has not been studied much.

Still another concept in stacked rotations involves allowing the use of more diverse herbicide programs, specifically those utilizing long-residual compounds. Relatively high rates of atrazine can be used in the first-year corn (or sorghum or millet) of a stack since another tolerant crop will follow. This provides the time necessary for the herbicide to degrade before sensitive crops are grown. Similarly, products like Command or Scepter can be used in first-year soybeans in areas where these products could not be used in other rotations. A typical herbicide program at Dakota Lakes Research Farm for an irrigated rotation of s.wheat >>w.wheat /double-crop forage sorghum >>corn >>corn >>soybean >>soybean would be as follows. Year One: spring wheat—no herbicides at planting, followed by Bronate (Buctril M). Year Two: winter wheat would have a 'burndown' between spring wheat harvest and winter wheat seeding. No herbicide is normally required in the winter wheat. Two pounds of atrazine would be applied either to the double-crop forage sorghum or after it is harvested in the fall. This is dependent on the weeds present. The first-year corn usually does not need a burndown but normally receives an early post-emergence application of dicamba. Second-year corn receives a traditional program. A herbicide-tolerant technology like LibertyLink or Clearfield could be used. We do not use Roundup Ready in this slot at Dakota Lakes. First-year soybeans receive a long residual program like Scepter plus Command. Second-year soybeans are Roundup Ready. With this program, we have used ALS chemistry once (maybe twice) in 6 years, triazines once in 6 years, Roundup Ready once in 6 years (and perhaps a burndown between wheat crops also, but this could be paraquat), etc. It is obvious that weeds (viewed from their perspective of time) will find it difficult to develop resistance or tolerance to any of the modes of action employed.

Photo by Matt Hagny.

In Argentina, several years of pasture commonly break up rotations with grain crops. Here, soybeans are emerging from killed sod in western Buenos Aires province.

It would be possible to fill several more pages with stacked rotation concepts. We will conclude with a final example. Recently, I saw an agronomist give what he thought was a negative example of a producer's rotational planning. He stated that the gentleman would seed a particular field to wheat every year until jointed goatgrass pressure became sufficient to preclude wheat.

Chickpeas (garbanzos) are a human-edible grain commanding significant premiums if the quality is good, and are therefore more risky than other crops. Some western South Dakota producers have had very good success with chickpeas in some rotations. Chickpeas blur the distinction between cool-season and warm-season broadleaf crops.

He would then seed it continuously to sorghum until shattercane overwhelmed him. At that point he would seed sunflowers in successive years until diseases became a major problem. At that point he began again with the wheat program. My response was that the producer was at least responding to the natural cycles observed in his field. It might be better if he anticipated these occurring so that the switch could be made in advance. However, he probably was doing a better job than someone who blindly planted a corn >>soybean, wheat >>canola >>wheat >>pea, or wheat >>corn >>soybean rotation and was surprised when he had to keep changing technology to deal with “new” problems.

Advantages: Stacked rotations attempt to keep pest populations diverse (confused) through diversity in the sequences and intervals used. Diversity is gained while keeping the number of crops smaller. They allow a mix of long and short residual herbicide programs. This approach can reduce costs and minimizes the chance of tolerance, resistance, and biotype changes.

Disadvantages: Not well tested. Some crop sequences may not be ideal. Fewer crops means less workload spreading.

Partially Stacked Rotations: This approach is a hybrid between stacked rotations and the other types. The idea is to use stacks for the crop species where it provides the most advantage while avoiding it for other crops. This may be the most powerful rotation type. The key with this and other rotational planning is to understand how natural cycles work and to use sequences and intervals to create the type of environments that favor the crops while preventing problems.

Examples: 1) Canola >>W.Wheat >>Soybean >>Corn >>Corn; and 2) S.Wheat >>W.Wheat >>Pea >>Corn >>Millet >>Sunflower.

Advantages: Depending on the rotation, either a large or smaller number of crops can be used. It provides many of the advantages of the stacked rotations but can be designed to avoid some potential problems. The spring wheat to winter wheat stack is especially powerful in areas where winter hardiness is an issue.

Disadvantages: There are few disadvantages if the rotations are well designed.

The power of this approach can be demonstrated best by using the examples given. The s.wht >>w.wht >>pea >>corn >>millet >>sunflower rotation is designed for cool and dry regions. The two cool-season grasses in a row follow a 4-year break for that type. The two wheat crops build deep soil moisture and surface residue. Winter hardiness of the w.wht is less of a concern than with other sequences. Peas and other large-seeded, cool-season legumes perform well in heavy residues. They turn this cool environment to their advantage and transform it into a warm environment for the subsequent corn crop. Peas make this transformation without using the deep moisture needed for the corn. Atrazine can be safely used in the corn year because millet (or second-year corn or forage sorghum) tolerates the carryover. Millet is a low intensity crop that again allows excess moisture to recharge the subsoil. Sunflower is now seeded into a nice environment that has deep moisture most years. Any volunteer millet can be easily controlled. Broadleaf weeds should have been controlled easily in the corn and millet crops. The warm and dry environment left by the sunflowers allows early seeding of the spring wheat crop. Herbicides with longer residual can be used in the spring wheat going to winter wheat than if a broadleaf were to be used the next year. If a producer feels it would be too risky to try to grow spring wheat after sunflower, he can use a less intense broadleaf (flax for instance) or include a green fallow year following the sunflowers.

Part of the theory of stacked rotations involves taking advantage of positive plant associations before negative associations can build to harmful levels.

The above discussion is meant to be an overview of some strategies that will allow producers and those working with them to better understand the ‘art’ of rotational planning.

Further Notes Concerning Rotations

- I have no better chance of designing the best rotation for you than I have of choosing the best spouse for you. There are things in life that you have to do on your own. I can only point out some factors you should consider when choosing a rotation.
- There is no ‘best’ rotation. No one can design a rotation that will work every year under every circumstance. It is a probability game. There are bad rota-

tions that work well for a while. There are good rotations that fail at times due to weather or other uncontrollable factors. Poor gamblers make money at times; good gamblers lose money at times. The difference is in the long-term outcome.

- Rotations can be designed that work well in dry years but fail to take advantage of good years. Or even worse, they fail badly in good to wetter-than-normal years.

The spring wheat to winter wheat stack is especially powerful in areas where winter hardiness is an issue.

- Producers with more risk tolerance (financially and psychologically) will be more comfortable with riskier rotations. Properly designed 'risky' rotations can make more money in the long run but can result in substantial losses over the short term.
- The best approach to spreading risks is to use more than one rotation (preferably sequentially to make an even longer rotation).
- Rotations used may differ depending on the soils involved. In other words, some of your land may require a different rotational approach than other land you farm. Some of the reasons for this include inherent soil characteristics, past history, weed spectrum, distance from the farmstead, landlord, etc.
- Most farmers are good at designing rotations once they start trying.
- The rotations used may have to change as market, soil, climate, and enterprise conditions change. That is to be expected. When designing a rotation, be thinking of ways you could change it.
- Don't be afraid to ask for advice, but accept no recipes from others. *Do your own cooking!*

Crop Characteristics Important in Rotation Planning

Crop	Type	Water Use
Winter Wheat	Grass (Cool-season)	Low
Spring Wheat	Grass (Cool)	Low
Oats	Grass (Cool)	Low
Barley	Grass (Cool)	Low
Corn	Grass (Warm)	High
Sorghum	Grass (Warm)	High
Millet, Proso	Grass (Warm)	Low
Millet, Pearl	Grass (Warm)	Mod/High
Soybean	Broadleaf (Warm)	High
Sunflower	Broadleaf (Warm)	High
Field Beans	Broadleaf (Warm)	Mod/High
Cotton	Broadleaf (Warm)	High
Cowpea	Broadleaf (Warm)	High
Mung bean	Broadleaf (Warm)	High
Chickpea	Broadleaf (Cool*)	Mod
Safflower	Broadleaf (Warm*)	High
Flax	Broadleaf (Cool)	Low/Mod
Canola	Broadleaf (Cool)	Low/Mod
Field Pea	Broadleaf (Cool)	Low
Lentil	Broadleaf (Cool)	Low
Lupin	Broadleaf (Cool*)	Mod
Alfalfa	Broadleaf (Warm)	Very High

*blur the distinction between cool- & warm-season habits.

Subject: Keep up the good work!

To: Editors of Leading Edge . . .

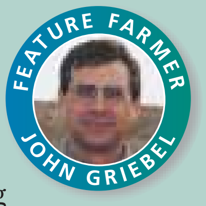
You guys are doing an absolutely fantastic job with your Leading Edge publication and I really look forward to receiving it. I especially like how you bring in upcoming academic journal articles. Clearly, you have taken the high road throughout, with science the centerpiece. But, being somewhat philosophical myself, I have also greatly enjoyed your past articles that may have been a little more historical/philosophical. All in all, besides being genuinely interesting, your publication is providing a tremendous service to those making decisions around no-till technologies—especially in the Great Plains. So, keep up the good work.

Terry Kastens
Extension Ag Economist
Kansas State University

—via e-mail

The Junior Scientist

by Roger Long



Spending time on the Griebel farm west of Stockton, KS is a little like stepping into a college farm management textbook. Their decisions are never based upon one simple variable, but instead reflect numerous aspects of agronomy and economics available to everyone, although seldom put to full use. For Griebels, that's only where it starts to get interesting. They derive real advantages from lessons learned with on-farm research—from detailed records capturing the data, to skilled analysis to sleuth out the nuances and implications.

The Griebels rely upon personally collected electronic data to guide the next year's game plan. They routinely practice what so many college professors, economists, and farm magazines preach—and Griebels do it all with 21st-century technology. Ask a question, and you will never get a single answer; everything revolves around multiple variables. Fill in the variables—the soil type, the fertility report, the previous crop and its yield—and now, after consulting the data and doing the calculations, John Griebel, Jr. is ready with a reliable response. His Palm Pilot is always at the ready, tracking every operation, application, and input purchase. A database John built allows quick and consistent data entry into the Palm, which is easily and routinely downloaded to his desktop—data that don't simply disappear into a black hole, but data that are readily retrieved for analysis to guide the next decision.

Those data and decisions flow through a father/son team who've come to relish their no-till; where fields with dense residue are prized, and sparsely covered fields are built to a new plan. John Griebel, Sr. returned to the established family farm in 1967, after being away for a few years. John Griebel, Jr. also gained experience off the farm—his in the banking industry at 1st Interstate Bank (now Wells Fargo) in Denver. John Senior's dad, an early conservationist, was one of the first in the area to buy an undercutter, in 1961. Leap ahead 43 years and John, Jr. is now in his 9th year of continuous no-till. Senior still keeps a watchful eye over the workings and lends moral and physical support, but Junior is now the CEO with ideas churning about where to head next.

John, Jr. and his father point to no-till meetings and the success of other no-tillers that led them to convert to no-till. Be assured, an old 486 desktop spit out countless "what ifs" before any purchases took place. Along with economics, the Griebels saw the need to be good stewards: "We wanted to leave these fields in better condition than when we took them over." No doubt a plan for the next generation of Griebels!

With facts in hand, the switch began in 1995 when Griebels bought a Great Plains drill and no-till planted their wheat that fall. They haven't done any tillage since. In 1999 they replaced the Great Plains with their current Flexi-coil air drill with Barton openers and continue to use that drill today. John points out that they've made some minor alterations such as removing the scrapers on the fertilizer openers, and fabricating some holders for the fertilizer delivery tubes. John has been eyeing some other makes of air drills, but is postponing that expenditure until the drought breaks.

Economics wasn't the only factor pushing Griebels toward no-till: "We wanted to leave these fields in better condition than when we took them over."

Griebel's rotation has evolved into a wheat >>wheat >>milo >>milo >>soybean rotation, sometimes with corn replacing the first milo.

Photo by John Griebel.

Griebels' milo. Note the alternating hybrid strips—the yield maps tell the tale. Extensive on-farm testing gives Griebel an advantage.

Photo by Roger Long.

Griebel's wheat in late winter of '04.

"The three- or four-crop rotation is really key to making no-till work." He began with a simple wheat >>milo >>summerfallow rotation, then tried a corn >>wheat rotation through some of the wet '90s, and added soybeans in the late '90s (after the corn and before the wheat). Some large swings occurred from year to year, taking advantage of opportunities, but he's now settled into a more definite rotation and acreage split. Griebel also recognizes the importance of the 'stacks' within his rotation: "You really need the stacks to lengthen the interval before you come back to a particular crop. The interval is what takes care of weeds and various other problems." Griebel has been letting his stubble lay idle but has been considering planting some Group 4 or 5 soybeans and using them as a cover crop after the second wheat; but he is quick to point out that if the '04 summer is the same as the '03 and '02 summers, " . . . it won't matter much because nothing is going to grow." He sprayed his stubble twice this past year but both those applications came in the late fall—severe drought was all the 'herbicide' needed during the summer.

Observation & Analysis

While all sincere no-tillers know that residue has value as expressed in subsequent crops, John, Jr. can supply some actual numbers in dollars per acre. During milo harvest this past year, he noticed 24-foot-wide strips throughout the field where milo had heads and 6-foot-wide strips of barren plants. The pattern wasn't from planting, or a past spray pattern, or a fertilizer goof, but rather from the previous wheat harvest. Griebel uses a 30-foot header on his 8820 John Deere combine but the straw spreader only distributes over a 24-foot swath. The extra moisture retained by the mulch of the wheat straw in the 24-foot swath was enough to produce 50 bu/a sorghum, while the streaks with only standing stubble produced nothing—a $100/a return to the cut straw (40 bu/a field avg. x (30 feet total swath / 24 feet width of production) x $2/bu = $100). Griebel's mental wheels no doubt revolve on the question of how to produce and preserve even more wheat residue; and yes, getting it evenly spread with the combine is also the center of attention. Wherever there is an observation, there are numbers to be collected and utilized.

"You really need the stacks to lengthen the interval before you come back to a particular crop. The interval is what takes care of weeds and various other problems."

Few owners of yield monitors get the value from them that Griebel does. Every year John (v.2) conducts several on-farm trials including population and fertility rate studies. Connecting the link between the GPS-based planting notes and the yield maps, Griebel is able to produce meaningful data and analyses that translate into bottom-line economics. In fact, it was the yield mapping in 1996 that showed their highest yields were coming on the end rows where corn was double planted, which prompted a studied look at planting populations. Few farmers in Rooks County would tell you that the optimum dryland corn population is 28,000 plants per acre, but thanks to multiple years of field-length, replicated trials, Griebel can say with confidence that, "If we get enough rain to grow any crop at all, 28,000 gives us the best chance of optimum returns."[1] Changes during field operations are marked with GPS and then yield maps are eventually overlayed; costs versus return are calculated, and a new standard is born. John notes a large gross profit difference between 16,000 and 28,000 plants per acre. A keen eye in the field (ground-truthing) throughout the year helped make sense of it all: "The higher populations gave better ground cover, more shading, and had a lot fewer stalks

Photo by Roger Long.

Wheat stubble awaiting '04 milo installation.

[1] Griebel's corn population studies were conducted during the years of '97, '98, and '99. Populations in '97 were 16K, 20K, and 24K; in '98—20K, 24K, 28K; and in '99—24K, 28K, 32K. The highest yield in both '97 and '98 was the highest population planted; the highest yield in '99 was 28K.

putting energy into a second ear." All very plausible, but not every techno-wizard would have the discipline and savvy to correlate the raw output with growing-season conditions to find a real explanation.

Griebel extensively soil tests and relies heavily upon the data generated. Maybe his confidence in those analyses derives from knowing the process used to obtain the data is so well-defined: John uses a GPS handheld unit to test the same spots within the field year after year. He then has a standard in which to compare one year's results against another.

This 'details man' notices things happening on his farm, and doesn't just espouse whatever he's read in the latest farm magazine. For instance, Griebel has observed that frequently his best corn and sorghum yields are on sidehills in the driest of years. John theorizes the yield boost comes from moisture seeping out on the sidehill.

The influence of research at Dakota Lakes: "It gives us ideas about what works and what doesn't. From there, we can fine-tune it."

Not every trial works out like he expects. Griebel notes a past idea that seemed logical, but ended in the ditch—literally. Needing to get N placed properly with minimal soil and residue disturbance, John decided to use his Flexicoil/Barton drill to apply 46-0-0 in a field that would later be planted to corn with his 12-row 7200 JD. The Flexicoil did a fine job of cutting through the existing wheat stubble and placing the N where it needed to be, but what John had not counted on was the fact that the tractor wheels and drill carrier tires were breaking much of the wheat stubble at its base. Within minutes after pulling out of the field, strong northwesterly winds (gusts in excess of 65 mph) blew all the detached stubble from the wheel traffic areas over into the more upright and intact strips of stubble—and into the ditch, the neighboring fields, and the next county (well, maybe not quite that far). Remembering the value of residue in its proper place, John notes the risk is greater than the reward. He instead plans to utilize the starter tanks on his planter a little more.

Photo by John Griebel.

Griebel's milo has proven quite responsive to the extra moisture available under a heavy thatch of wheat stubble. Griebel is scheming on how to grow and preserve even greater quantities of wheat residue.

Griebel eagerly anticipates acquiring technology that will let him do even more: "I'll be glad when we have auto-steer in the tractor and RoGator—I can hardly keep up with everything that is going on in the cab, and it would be nice to not have to worry about the steering wheel." When you can use technology to take care of something as mundane as steering (and the technology does it better anyway), and you can then manipulate and manage more important variables, why not?

Photo by Roger Long.

Griebel's stacked wheat nestled amongst last year's stubble, emerging from its winter nap.

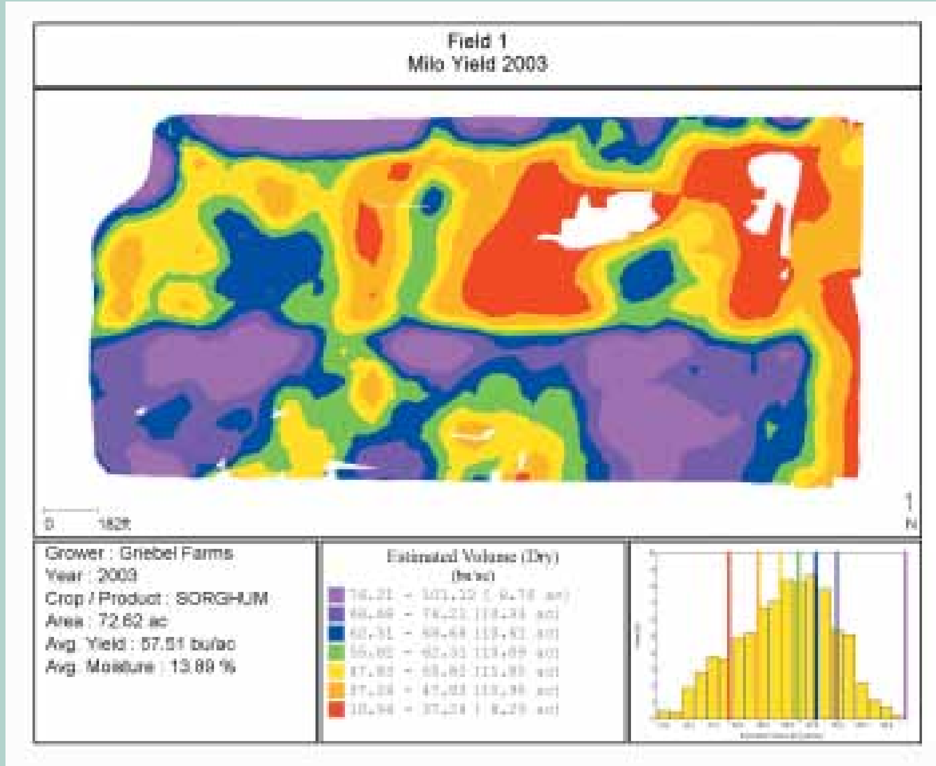
Stronger Production Facilities

A '97 RoGator allows Griebel to cover the acres rather quickly and to occasionally provide contract spraying for an area retailer; it's on these custom jobs that Griebel is reminded of the excellent condition of his own fields. "Some of those conventionally tilled fields are so hard they just beat a guy to death. I have a newfound respect for professional rig drivers that travel those fields day-in and day-out. . . . Even walking on tilled soils is so much different—they just don't have the structure that a no-till soil has." Meaning, it takes more effort to get foot traction in the looseness, or your bones jar when it bakes hard, not to mention that it's always either dusty or muddy.

When supporting wheeled traffic, it seems almost too good to be true that no-till soils are firmer than tilled soils, and yet John talks about being able to " . . . stick my fingers in the ground and pull up a handful of earth [easily] . . . that's just loaded with earthworms!" The drought may have John a little pessimistic about things to come, but he takes comfort in knowing that his soils—his production facilities—are in prime condition to optimize inputs when the weather turns favorable again.

As with so many good no-tillers, Griebel's weed problems—while they still exist—are not a major concern: "We really don't have big weed problems." Some cockleburs here (in newly acquired fields), a fading bindweed patch there, and sparsely scattered windmillgrass plants spark amusement rather than fear or wrath. Diversified rotations, dense crop canopies, and timely herbicide applications keep weeds at bay. With a chuckle, "I've heard people talk about using 64 ounces of glyphosate to kill windmillgrass." John just doesn't see the need for such drastic measures.

Contemplating his current understanding of no-till, Griebel notes the influence of the research done at Dakota Lakes and what it has meant to his operation. "It gives us ideas about what works and what doesn't. From there, we can fine-tune it." Like all good researchers, for Griebel the production theory will be contemplated, applied to existing conditions, data gathered, results heavily scrutinized, and then—and only then—a new rule will be adopted as a basis for the next departure in theory.



More data. The upper half of the map shows where a different milo hybrid was planted, with major yield effects. But John, Jr. will caution against drawing hasty conclusions quicker than you can say, "software upgrade"—data is <u>not</u> the same as knowledge, he reminds us.

Reflecting back upon the times leading up to his conversion to no-till, John quips, "It just made economic sense . . . a person wonders why we didn't do it sooner!" Only no-till allows a western Kansas farmer to grow the diversity and intensity of crops produced by the Griebel farm. "You just can't grow the crops with the yields we do without no-till." And when faced with overwhelming evidence for greater profitability, how else *would* you expect a number-cruncher like Griebel to farm?

No·till On The Plains

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