Beyond the Beginning

The Zero Till Evolution

3rd in a series

Manitoba - North Dakota
Zero Tillage Farmers Association

2011

Manitoba - North Dakota Zero Tillage Farmers Association

The Manitoba-North Dakota Zero Tillage Farmers Association is run by an elected board of twelve farmers representing agricultural areas of Manitoba and North Dakota plus eight appointed advisors from government, university and industry. The Association is open to any person interested in zero tillage, not only from North Dakota and Manitoba but also from surrounding states and provinces.

The purpose of the Manitoba-North Dakota Zero Tillage Farmers Association is to:

- Facilitate the exchange of ideas
- Encourage zero tillage research
- Disseminate zero tillage information

Further, the Association pledges to "preserve our agricultural soil resource for future generations by promoting a system of crop production which drastically reduces soil erosion and builds up organic matter".

"Beyond the Beginning – The Zero Till Evolution" is a result of the continuing efforts and insights of farmers, scientists, extension and university specialists to understand the dynamics involved with zero tillage farming systems. Since the publication of "Advancing the Art", the zero tillage system has continued to evolve as we better understand soil biology and function.

Our goal was to publish information that would encourage farmers and agricultural scientists to further improve farming without tillage. We refer to zero till (or no-till) as a cropping system that leaves the soil undisturbed from harvest until seeding, except for some disturbance to apply fertilizers. We have used the terms zero till and no-till interchangeably.

The manual contains information from experienced zero / no-till farmers and researchers. It is not a specific set of production recommendations; rather it deals with what experienced producers are doing. Registered product uses and official recommendations vary between Manitoba and North Dakota. This means that information in this manual may differ from official recommendations in your area. Information in this manual supplements that of the manufacturers and the official Manitoba and North Dakota Weed Control and Crop Production publications.

ZERO T TILLAGE

www.mandakzerotill.org

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The idea of producing a third Zero Tillage Production manual came about three years ago while I was in my first year as a director on the Manitoba-North Dakota Zero Tillage Farmers Association. It is my pleasure to be able to see this project through as the current president. I give tremendous credit to the directors and advisors on the board that have been involved in putting this manual together over the last several years. They are knowledgeable on the topics and dedicated to making sure the manual was done accurately. The committee also worked hard to include the scientific background relating to the practical applications involved in modern-day zero tillage. I also have to give credit to the researchers, agricultural extension employees and the producers that have offered their experiences and knowledge enabling us to gather the information required to put the manual together.

I also note that publishing the manual was made financially possible through government funding from both the U.S. and Canada at federal, provincial and state levels. The ability to secure this funding shows the respect Manitoba-North Dakota Zero Tillage Farmers Association has built over the last 32 years. Sustainable farming practices continue to be an increasing global issue and it is apparent government recognizes the role of our organization in promoting this through zero tillage.

Our successful publication of this third manual shows the continuing passion for zero tillage farming among both our board members and the rest of the membership. I hope this manual will help grow the practice in both countries involved as well as agriculture around the world.

Darren Whetter, President
Manitoba-North Dakota Zero Tillage Farmers Association

In 1991, we published the "Zero Till Production Manual". It was a farmer driven, farmer written publication. It was, and is, a valuable guide for North American farmers as they move into zero till and other conservation cropping systems. Copies of the manual found their way throughout Canada and the United States and overseas to Africa, Australia, Europe and South America.

In 1997, we published "Advancing the Art". It was another farmer driven publication that proved to be a valuable source of information to zero till farmers around the world. It has been over 30 years since the first zero till pioneers started getting together on an annual schedule to discuss their zero till experiences. Approximately three years ago The Manitoba-North Dakota Zero Tillage Farmers Association started discussing the need for a new manual that is indeed "Beyond the Beginning" of the zero till movement.

In the years since the first two manuals were printed, ongoing farmer experiences coupled with inquiries by the scientific community have verified the soil and environmental benefits the early zero till producers spoke of. It now seems appropriate to publish a manual aimed at discussing the long-term benefits of zero tillage. These benefits are enjoyed by production agriculture as well as society in general.

This manual production has been guided by the Education Committee during the terms of four Association Presidents, Cal Thorson, Dustin Williams, Mark Jennings and Darren Whetter. Jointly, we extend our hope that it will be of value to you, whether you are a farmer, teacher, researcher, wildlife manager, environmental conservationist, government decision maker, commercial product manager, spouse sharing decisions, or whatever your walk of life. We all share in developing the future of agriculture.

Alan Ness, Executive Secretary
Manitoba-North Dakota Zero Tillage Farmers Association

Introduction

A Biological System Evolves

The risk-takers of past decades who were among the first to park plows and cultivators – believing they could plant crops into untilled stubble and still harvest good yields – may have never dreamed they'd launch a farming revolution. Yet their cumulative efforts worldwide have done just that.

"Increasing numbers of farmers are converting to no-till, making it a global phenomenon," says Jon Hanson, newly retired research director of the USDA Agricultural Research Service Northern Great Plains Research Laboratory at Mandan, North Dakota. "In South America farmers are adopting no-till in a big way, and worldwide 95 million hectares [235 million acres] are in no-till. No-till is helping to conserve soil around the globe."

Jon Hanson

The modern no-till movement on large-scale farms became possible with the invention of herbicides, such as 2,4-D and paraquat in the 1940-50's, permitting weed control without tillage. The absence of tillage results in a residue mulch covering the soil surface and requiring seeding practices or equipment designed to sow directly into mulch-covered soil.

The no-till system retains more than 90 percent of crop residue on the soil surface. By contrast, the moldboard plow retains less than 10 percent of residue; the chisel plow and disk retain between 25 and 75 percent of residue; while ridge-planting and strip-till planting systems retain 40 to 60 percent of residue.

Interest spreads

The surface residue left by no-till conserves moisture and protects soil from wind and water erosion. These benefits are of particular value to farmers of North America's Northern Plains region, where the growing season brings wind, driving rain and bouts of hot, dry weather.

In North Dakota, interest in no-till has been strongest among farmers from the western part of the state, where wind and drought make soil and water conservation critical.

This interest gains momentum from the long-term study of no-till farming practices by researchers at Mandan's Northern Great Plains Research Laboratory. Since the mid-1980s the lab's scientists have used no-till practices to implement a broad array of studies. "Don Tanaka has taken the lead in much of this work, and in the early 1980s and '90s Al Black played a big role," says Hanson. "Al was a key instigator in bringing no-till into this region."

As the potential benefits of no-till continue to unfold, the acceptance rate among farmers is bound to keep growing. "Not only is no-till a great way to reduce wind and water erosion, but it also potentially stores carbon in soil and can reduce emissions of greenhouse gases," says Hanson. "These benefits result from improvements in soil quality, which really become evident after 10 to 15 years of no-tilling."

In Canada, farmers' adoption rate of no-till suggests a growing interest in its conservation benefits. In 2006, Prairie farmers reported using no-till on 50 percent of seeded acres. The Prairie region encompasses the provinces of Alberta, Saskatchewan and Manitoba.

Jeff Thiele

"As a result of no-till we've seen a huge change in the agricultural landscape," says Jeff Thiele, soil resource specialist, Agriculture and Agri-Food Canada Agri-Environment Services Branch, Dauphin, Manitoba. "Soil erosion was a big problem 20 years ago. During a wind storm, the sky would turn gray from the blowing soil. Now, many of the farmers are direct seeding, and we see fewer erosion events."

Minnedosa, Manitoba, no-till farmer Bob McNabb was among the risk-taking farmers willing to try no-till 30 years ago. Then, the system was new to northern farmers, and no-till farming equipment was neither efficiently designed nor widely available.

Bob McNabb

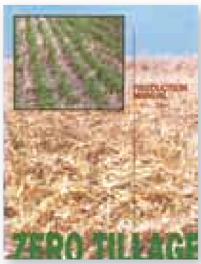
"Change brings risk, and risk brings fear," says McNabb. "In light of that, it's phenomenal to see farmers of the whole southwest area of Manitoba using no-till in a big way. In the world of agriculture, a period of 30 years is a relatively short time for farmers to adapt and make the broad-based changes needed to switch systems from tillage to no-till."

For McNabb, the decision to adopt a no-till system came at the start of his farming career, in 1978. After working in aviation, he returned to Minnedosa with his wife, Elaine, to buy and manage his parents' farm. He rented a no-till drill and experimented with direct seeding one field. The positive results fueled a lifelong commitment to zero tillage.

Farmers organize

McNabb was among the northern pioneers of no-till who in 1982 founded the Manitoba-North Dakota Zero Tillage Farmers Association, a farmer-focused information sharing organization supported by researchers and conservation agencies.

"We had like-minded people from both sides of the border, and we shared a vision," says McNabb. "As an international organization, the Association is a great vehicle for moving new ideas forward. From the start, the professional people supported the group with an acute sense of innovation and responsibility. They were willing to share information with farmers and among agencies. As a result, the Zero Tillage Association has been a guiding light helping us all move forward."



From its inception, the Manitoba-North Dakota Zero Tillage Farmers Association has served as a forum for voices of farmers and researchers alike, sharing farm-based experience alongside documented research. In 1991, the Association published its first handbook, the *Zero Tillage Production Manual*. The manual was a valuable guide for North American farmers as they moved into zero till and other conservation cropping systems. Copies of the manual found their way throughout Canada and the United States, and overseas to Africa, Australia, Europe and South America.

In 1997 came the organization's second handbook, *Advancing the Art*. This manual shared information farmers might implement in adopting advanced technology and maintaining existing no-till systems.

Now, in the words of Bob McNabb, the Association "is doing something exciting again," with the publication of its third manual, *Beyond the Beginning: The Zero-Till Evolution*. Here, farmers and researchers alike discuss today's growing need – and evolving tools – for shaping a site-specific, biological systems approach to no-till, and indeed to agriculture as a whole.

Ted Alme

"As we move into the future, no-till will continue its work of building healthy, resilient soil," says Ted Alme, state agronomist for the USDA Natural Resources Conservation Service, Bismarck, North Dakota. "It will continue to be an important means of restoring and stabilizing soils around the world – wherever soils have been damaged by destructive agricultural practices.

"Yet no-till has evolved into something more than an erosion control practice," he says. "It has transformed into a dynamic, biological systems approach to resource management."

An evolution

No-till's ongoing evolution into a biological system presents a new generation of risks and a need for new knowledge. The challenges lie in learning to let natural synergies work and in finding ways to mimic Mother Nature's rhythms for the prairie.

"We need to increase our knowledge and our management skills," says Thiele. "We don't understand, for instance, all the interactions in different plant communities with insects and the organisms in the soil. We must learn to work with synergies between crops. We can learn to work with Mother Nature – learn to work with what we have – rather than fighting against it."

Mimicking the prairie system means shifting away from monoculture toward cropping diversity and keeping living plants in the soil throughout the growing season. It suggests shrinking dependence on herbicides, pesticides and synthetic fertilizers, and depending instead upon the counterbalancing controls and strengths inherent in diverse communities of plants and microorganisms.

"This will require greater management by the farmer, but we should be able to decrease commercial inputs and increase economic profits as a result," says Thiele. "Yet because of changing conditions every year, I hope growers will remain flexible and keep their options open. We have to take baby steps toward a system that is sustainable for the long-term."

The sum effect will be a biological system of agriculture uniquely fitted to each individual farm. "The no-till system of the future will not be based on a one-size-fits-all formula," says Alme. "It will evolve into a dynamic, site-specific system for each farm. As such, it will reflect individual producers' personal decisions about managing farms and their resources."

– by Raylene Nickel

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Soil Biology

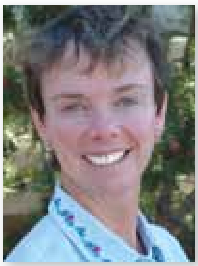
We live on the rooftops of a hidden world. Beneath the soil surface lies a land of fascination, and also of mysteries, for much of man's wonder about life itself has been connected with the soil. It is populated by strange creatures who have found ways to survive in a world without sunlight, an empire whose boundaries are fixed by the earthen walls.

– Living Earth by Peter Farb, 1959

A Web of Life in the Soil

Like most ideal human communities, healthy soils are vibrantly alive, bustling with activity. These soils team with macro- and microorganisms, and each citizen-organism provides a service critical to the healthful functioning of the broader community.

The diverse community of life in biologically active soil includes such citizens as viruses, bacteria, fungi, algae, protozoa, mites, nematodes, worms, ants, maggots and other insects. Each plays a critical role in breaking down organic matter and cycling macro- and micronutrients into forms that plants can use. The process leads to improved soil structure, tilth and productivity.



Jill Clapperton

"The diverse community below ground creates the diversity of soil services we need in order to grow healthy plants," says Jill Clapperton, a rhizosphere ecologist and consultant operating Earthspirit Land Resource Consulting, Florence, Montana. Clapperton served as the rhizosphere ecologist at the Agriculture and Agri-Food Canada (AAFC) Lethbridge (Alberta) Research Centre for 15 years.

Healthy plants naturally result in healthy food and forages, ultimately improving the health of humans and livestock. Citing just one example of this plant-food relationship, Clapperton says, "Increasing colonization by vesicular-arbuscular mycorrhizal fungi can in turn increase the mineral nutrient content of wheat, for instance."

Kris Nichols

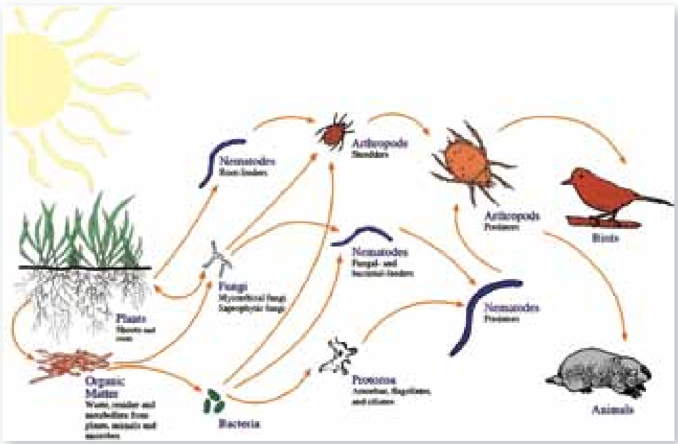
Aside from producing vigorous plants and healthful food, biologically active soils offer farmers the economic benefit of requiring reduced amounts of fertilizers and pesticides.

"Biologically active soils provide the nutrients needed by the plants, including nitrogen," says Kristine Nichols, USDA Agricultural Research Service (ARS) soil microbiologist at the Northern Great Plains Research Laboratory, Mandan, North Dakota. "Such soils also have the internal mechanisms needed to resist pests, so farmers can reduce pesticide applications. This combined with reducing the cost of fertilizers while maintaining or even increasing yields offers huge economic gain for the producer."

Management holds the key to unlocking the vibrant natural processes native to a healthy soil habitat. "It all depends on how you take care of the soil," says Nichols. "It depends on the level of tillage, the type of plants you grow, and the amount of fertilizers and pesticides you use."

The soil food web

Building a biologically active soil habitat requires management practices aimed at establishing and maintaining an elaborate soil food web. "This web is a huge interactive link of all these different organisms," says Nichols. "When you remove something from the soil food web, you can cause that web to fall apart. Imagine a spider's web. If you break the strands of a spider's web, the web will collapse. The same is true of the soil food web. If you break one of the 'strands,' the web will collapse, and the soil will lose its biological functions."



The imagery of the spider's web illustrates the importance even of disease or pest organisms, which are food for their predators, the beneficial organisms. Without the pests, the beneficial predators would have no food and would thus be starved out of the system, creating future opportunity for growth in pest or disease populations.

"The food source for the beneficial insects is often a bacterium or fungus that can cause disease," says Nichols. "These beneficial insects may be microscopic or more visible." Examples of larger beneficial insects are the spiders and ladybugs that help to control aphids.

"Disease organisms actually only cause problems when populations are allowed to get out of control," adds Nichols. "When there's a balanced community of soil life, none of the organisms are acting like disease organisms. All organisms must be present in order to have biologically active soil."

A potential downside of using pesticides is their possible disruption of this progress toward a balanced soil life. Pesticides affect soil organisms both directly and indirectly. They remove target populations, of course, but they may directly kill non-disease organisms as well and reduce their food source. This weakens their ability to continue acting as leveling agents in the soil food web.

Fertilizers, too, can disrupt the delicate balance of the soil food web. "When you apply fertilizer, you disrupt the food cycle for the plants," says Nichols. "Instead of requiring the plant to draw food from the soil, you're artificially providing the nutrients the plant needs. As a result, the plant is not contributing its part in the food web. That in turn prevents various organisms within the food web from getting the food they need, and they die, causing the soil food web to collapse."

Biology affects chemistry

The biological processes and properties of a soil unite the soil's physical and chemical properties. Illustrating this relationship, Clapperton writes: "Fungi and bacteria recycle all the carbon, nitrogen, phosphorus, sulphur and other nutrients in soil organic matter, including animal residues, into the mineral forms that can be used by plants. By breaking down the complex carbon compounds that make up organic matter, soil organisms acquire their energy."

"At the same time," she continues, "the root exudates, hyphae of the fungi, and the secretions and waste products of the bacteria are binding small soil particles and organic matter together to improve soil structure. This makes a better soil habitat that attracts more soil animals, which further increases the amount of nutrient cycling."

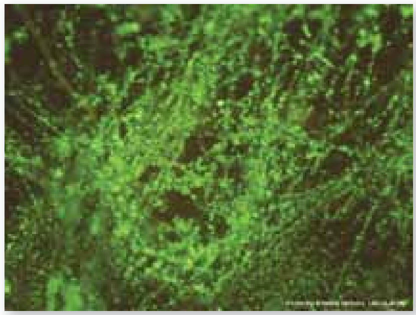
The distribution of organisms in the soil tends to concentrate along the vertical plane of plant roots. Roots are associated with organic matter, and large numbers of organisms feed on the organic matter, either directly or indirectly.

Other symbiotic relationships between roots and soil life draw the organisms to greater depths into the soil profile. "A film of water coats the roots," says Clapperton. "The bacteria will zoom down the roots on this film of water. The organisms that feed on the bacteria, like the nematodes and protozoa, will follow the food trail, penetrating the earth by as much as a meter below ground."

"When a root dies," she adds, "it creates a channel that lets arthropods go down. Most of these prefer to live nearer the surface, in the litter layer. But given a travel route, they will go down. At depth, there is often a problem with oxygen not being readily available, but the root channel aerates the soil and creates a way for arthropods to penetrate the earth." Fungi, bacteria and other organisms may colonize these root channels as well.

The role of fungi

The interconnected life shared by plants and soil organisms is best illustrated in the symbiotic relationship between roots and vesicular-arbuscular mycorrhizal (VAM) fungi. These fungi benefit nearly all plants, facilitating a process allowing plants to assimilate from the soil phosphorus and other less-available mineral nutrients such as calcium, zinc and copper.



"Getting these nutrients, which are locked in the soil, into a plant-available form requires a synergy between soil organisms and plants," says Nichols. "The fungi help to stimulate this process. They work with the bacteria and other organisms in the soil to change the chemical configuration of the nutrients."

Simply put, the VAM fungi take the sugar from the roots of the plant, and feed it to the bacteria and other microorganisms in the soil. These organisms then help convert the nutrients in the soil into a plant-available form.

When VAM fungi are not active in the soil, the nutrient phosphorus is not available to plants. Thus, producers add synthetic phosphorus fertilizers, though most soils are not deficient in phosphorus. "Because of mycorrhizal fungi present in no-till soils, many no-till farmers are using a fraction of the phosphorus they used previously," says Clapperton.

In general, when VAM fungi colonize roots, the plants have higher rates of photosynthesis, improved water-use efficiency, and are able to move more and different kinds of carbon compounds to their roots, she adds. In sum, the rhizosphere community has fewer pathogens and more plant-growth-promoting rhizobacteria.

Plants vary in their dependence upon VAM fungi as a means of accessing nutrients. *(See Table 1.)* "Highly dependent crops often have limited root systems, with thick roots and few root hairs," writes Clapperton. "Less dependent plants will have larger, fibrous root systems that are well adapted to competing for nutrients."

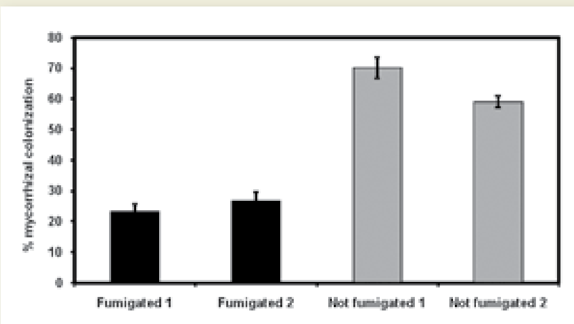
Because of its root structure and its high needs for nitrogen and phosphorus, corn is a crop exhibiting a particularly strong beneficial response to VAM fungi. When these fungi colonize the roots of corn plants, corn makes more efficient use of nutrients, meeting more of its nutritional needs from soil and requiring less synthetic fertilizers.

Photo by Kristine Nichols, USDA-ARS

"Because of their high demand for phosphorus, legumes like soybeans and peas also have a strong response to VAM fungi," says Nichols. "These plants use the phosphorus to feed the bacteria which fix atmospheric nitrogen into plant-available nitrogen in the soil."

What would corn production look like if Arbuscular Mycorrhizal fungi, a beneficial fungi, was partially or completely eliminated from the soil? Corn plants would likely appear phosphorous deficient and stunted even when soil phosphorous levels were more than adequate (27 ppm P Olsen) and 30 pounds of P_2O_5 was banded near the seed. In this demonstration conducted on the Ryan Kadrmas Farm near Dickinson, North Dakota, a soil fumigant was applied in the September 2002, was seeded to corn in May 2004, and the result can be seen below. Yield was substantially reduced in the area devoid of mychorrhizal fungi. Analysis of corn roots by Kris Nichols, ARS Scientist, Mandan, ND, showed a significant reduction in mycorrhizal fungi colonization on corn roots grown in the fumigated soil compared to the natural soil. Though deficiencies may be overcome with additional fertilizer, applying additional fertilizer to overcome a soil health issue can be expensive reducing the producer's net return. Further information on this demonstration can be found at www.ag.ndsu.nodak.edu/dickinso/

Corn plants in a field where the soil was fumigated (three rows in the center) or not fumigated (outer rows) (A) showed signs of phosphorus deficiency (B) which may be linked to the level of mycorrhizal colonization.



Percentage root colonization by arbuscular mycorrhizal fungi measured in corn grown in soil that was fumigated or not fumigated. Bars (means ±SE) with different letters are significantly different ($P \le 0.01$).]

Soil cleansing

In addition to providing for the nutrient needs of plants, the life in the soil has internal cleansing mechanisms that help remove soil contaminants. "In biologically active soils the organisms produce enzymes, or chemicals, that help to break down pesticides," says Nichols. "These enzymes help to remove the contaminants from the soil so that there is less carry-over of pesticides and less leaching off site."

Older pesticides now taken off the market may be exceptions. These may continue to have a residual effect on some soils. "There's also some potential that fungicides, even the newer chemicals, may have some carry-over effects that cannot be contained by soil organisms," says Nichols.

Thus, the healthful functioning of the soil community requires the critical services of each citizen-organism. The more diverse the community, the more extensive will be its services. "By priming the biodiversity, every plant can thrive, and that's our ultimate goal," says Clapperton.

– by Raylene Nickel

Table 1.
The relationship between some crop species and VAM fungi

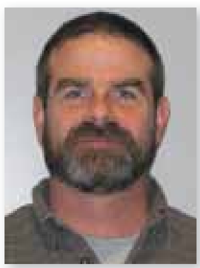
High dependency	Low dependency	Non-hosts
Peas, beans and other legumes	Wheat and other cereals	Canola, mustard and other brassicas
Flax		Lupins
Sunflowers		
Maize and other warm-season cereals		

Source: Jill Clapperton, Earthspirit Land Resource Consulting

Citizens of the Soil

Examining a mere cross section of the soil populace and those services each citizen provides its community gives but a glimpse of a mysterious underworld and its workings.

Along with fungi, bacteria are among the most numerous and critical of soil residents. These vital organisms are so microscopic that half-teaspoon of soil contains a billion of them.



Mike Lehman

Bacteria play key roles in the processes of residue decomposition and the recycling of carbon, nitrogen, phosphorus and other nutrients. "We would all die if it weren't for the bacteria in the soil," says microbiologist Michael Lehman, USDA-ARS North Central Agricultural Research Laboratory, Brookings, South Dakota.

The presence of living roots in the soil attracts and stimulates bacteria, increasing the scope of their beneficial work.

Some species of bacteria do not require oxygen, but many soil bacteria do. Because of this need for oxygen, many species of bacteria become less active in excessively wet or flooded soils, where they are starved for oxygen. Under these conditions, organic matter is resistant to degradation, slowing the release of nutrients.

Tillage, on the other hand, rapidly aerates the soil, encouraging a burst of respiration by bacteria. Following tillage, populations can grow quickly, increasing the rate of residue decomposition and nutrient release. "However, these periods of rapid respiration cause large losses of soil carbon, production of greenhouse gases, and release of soluble nutrients that may migrate away before they can all be taken up by plants," says Lehman.

"Moderate aeration with fewer enormous peaks of activity preserves soil carbon and releases nutrients gradually so they can be taken up by plants," he adds. "Well-tended no-till fields with good soil structure, roots and root channels promote moderate aeration without the episodic events associated with tillage."

The impact of pesticide applications on bacteria populations varies, depending upon the bacteria species. Pesticides inhibit some species, while other species actually clean pesticides from the soil. "Some types of bacteria consume pesticides for carbon and energy," says Lehman.

Pesticides that the bacteria cannot degrade are those tending to persist in soil. "Persistent pesticides can accumulate in some soil organisms and be magnified as animals are consumed in the food chain," he says.

Mites and others

In the soil food web, the bacteria are a food source for soil mites, which also feed upon fungi. In the absence of tillage, populations of mites tend to increase.

"Under no tillage, litter or residue is primarily decomposed by fungi that accumulate nitrogen in their hyphae," writes rhizosphere ecologist Jill Clapperton. "In response, the population of fungal-feeding mites increases rapidly. The mites use some of the nitrogen from the fungi and release the remainder into the soil to be used by plants and other organisms."

Other soil life, the soil algae, are partners in the nitrogen-fixing process. These help to take nitrogen from the atmosphere and supply it to the soil in a plant-available form.

A species of bacteria called actinomycetes also participate in a process of drawing nitrogen from the air and fixing it in the soil. "Actinomycetes look like fungi, growing in thread-like configurations," says soil microbiologist Kristine Nichols. "Tillage breaks up their threads, and so reducing tillage, of course, benefits these organisms."

Good and bad nematodes

Populations of larger soil life, such as nematodes, also thrive in the absence of tillage. Nematodes are roundworms smaller than earthworms. Nematode populations include species that are beneficial as well as those that are detrimental. The harmful species act as plant parasites, such as the root worm nematode that feeds on potato crops or soybeans, preventing plants from taking up nutrients.

Sharon Weyers

"Nematodes exist in a complex food web feeding primarily on bacteria and fungi," says soil scientist Sharon Weyers, USDA-ARS North Central Soil Conservation Research Lab, Morris, Minnesota. "But as a community all are involved in some way in the process of residue decomposition and nutrient cycling."

Pesticide applications tend to reduce populations of harmful as well as beneficial species of nematodes. Given adequate food and soil moisture, however, populations can "come back up within the season," says Weyers. A season-to-season rotation of crops and pesticide applications helps beneficial populations of nematodes recover more fully from pesticides.

Eroded soils tend to support reduced nematode populations. "The more eroded a soil becomes through tillage, the less organic matter it may hold, and the fewer nematodes it may support," says Weyers. "Nematode populations respond to the quantity as well as quality of organic matter. A soil with a high level of organic matter as a resource base is likely to support a larger and more complex community of nematodes and other soil organisms, compared to a soil with less organic matter."

Soil engineers

Like nematodes, earthworms suffer under tillage. Their absence takes a toll on soil life because of the broad scope of their benefits. Earthworm tunnels provide a slime-coated channel that stimulates microbial activity.

"Earthworms are ecological engineers because of the dramatic changes they have on soil structure," says Clapperton. "They increase water infiltration, improve aeration and stimulate microbial activity in the soil."

Reducing soil disturbance is an effective way to increase earthworms. "You can further increase earthworm populations by adding oilseed crops and retaining legumes in rotations under no tillage," she writes. "Research has shown that there are more and bigger earthworms under no tillage after oilseed crops – particularly flax and canola – and legume crops compared with cereals."

– by Raylene Nickel

Building a Soil Habitat

As is true with our human communities, the diversity and robustness of the soil community depend directly upon the conditions of its home and the quality of its food, the poorer the food and the more stressful the living conditions, the less functional the life.

The good news for farmers is that soil organisms are resilient, and their communities can grow and thrive even from harsh beginnings. In the case of these organisms, there's truth in the popular saying "Build it and they will come."

This is possible because some of the soil life has the ability to wait out the hard times by existing in a subsistence state. Given adverse environmental conditions, soil organisms like bacteria, nematodes and arthropods exist in a sort of hibernation. They wait in this resting phase for improving conditions in their home and diet.

Stop disturbing soil

Stirring them to life requires taking steps to provide the habit they need to thrive. "Decreasing the disturbance of the soil is an important way to stimulate the microorganisms," says soil microbiologist Kristine Nichols. "The lower the level of the soil disturbance the more the organisms will thrive. It doesn't mean they will be absent with some disturbance of the soil. But the more you repeat the soil disturbance, the harder you make it for them to thrive."

Research at the Agriculture and Agri-Food Canada Lethbridge (Alberta) Research Centre illustrates the effect of tillage on populations of earthworms, for instance. Long-term studies of dryland tillage systems showed that earthworms in no-till fields numbered as many as 300 worms per square meter, while no earthworms were found in conventional-till fields.

Provide diverse food

Providing abundant sources of diverse food for soil life may have a mitigating effect on the disruptive consequences of tillage. "If you're growing a lot of cover crops and adding green manures to the soils, you're feeding the soil food web," says Nichols. "You may compensate a bit for the level of tillage by the diversity of the plants you grow. Tillage will destroy the habitat, but by increasing the amount of food for the organisms, you can compensate for destroying the 'house' – not entirely, but it can help."

Providing the soil organisms with abundant and diverse food sources helps them rebound from other potential setbacks they might experience, such as synthetic fertilizers or pesticides.

"When we can get organic matter with a 20 to 30:1 carbon-to-nitrogen ratio, we're feeding the organisms a better-balanced diet," says rhizosphere ecologist Jill Clapperton.

In the case of vesicular-arbuscular mycorrhizal (VAM) fungi, populations can be strengthened by planting perennial crops and legumes, and by including in the rotation crops highly dependent upon VAM fungi, such as corn, sorghum, flax and sunflower.

In general, growing multi-crop rotations including cover crops is an important way to prime the diverse food supply soil organisms need in order to maintain their natural resiliency. "We know that native prairie soils had a lot of plant diversity, especially when grazing was right and there was a fire response," says Clapperton. "Biodiversity drives soil health. By using cover crops, diverse crop rotations and proper sequence of crops in the rotation we can move toward the original productivity and soil conditions of native prairie."

Just one season of growing a diverse cover crop, for instance, creates a robust microbial community improving soil health for a period spanning four to five years.

"There is definitely a connection between plant diversity and soil biological activity, a connection between how cover crops grow and the health of subsequent crops," says Clapperton. "This is certainly not new research, but we're just beginning to understand it."

Releasing minerals

Plant diversity also influences soil chemistry. Plant species differ in the way they take up nutrients from the soil. As the plants mature and their residues decompose, this process of decomposition releases nutrients for the formation of organic matter. The mix of mineral and trace mineral nutrients released into the organic matter will vary according to plant species.

"Buckwheat, for example, is an accumulator of calcium, phosphorus, boron and zinc," says Clapperton. "It preferentially takes up these nutrients. So when we include buckwheat in a crop mix, we put more of those nutrients into the organic matter in the root zone and at the soil surface."

Plant diversity yields maximum benefits to soil chemistry and biological activity when root structure and rooting depth guide the choice of plants to include in cover crops or long-term rotations.

"To create ideal soil structure and health, fill the vertical profile of soil with root material," says Clapperton. "Create a root canopy in the ground in the same way that you create plant canopy above ground. Use both deep- and shallow-rooted plants to fill the soil profile. We need to think of cover crops as filling the root profile. The roots become organic matter, and this diversity of organic matter feeds the diversity of life below ground."

Roots of deep-rooted plants in particular provide additional services. These pull up and recycle the nutrients, like nitrogen, accumulating at lower depths. "If you leave those nutrients down there, they're prone to leaching into the ground water," says Clapperton.

Deep-rooted plants also benefit saline soils. "In areas where salinity causes problems, it's an indicator that the plants are not using water in an appropriate way," she says. "This used to be less of a problem with native range because of the deep roots of plants like sagebrush. In range soils, some roots are shallow, and some are deep. They're all tangled together and adapted to exploiting nutrients at different depths."

Deep roots create channels for water and oxygen to get into the soil. Oxygen may also be released from deeper roots, providing an aerobic environment in the rhizosphere.

While building a secure habitat for soil life may take three to five years to accomplish, it eventually pays off in thriving crops. Says Clapperton, "We can work with the plant community to create a microbial community in the soil that is very promoting of plant growth."

– by Raylene Nickel

Producer Profile

Fields Full of Good Insects

A growing population of beneficial insects tells Wayne and Dustin Williams their no-till fields are increasing in biological diversity.

Dustin and Wayne Williams

Farming near Souris, Manitoba, the father-son partners have practiced no-till since the mid-1990s. Wayne began a transition to reduced tillage much earlier than that, adapting conservation-till methods as early as the 1960s.

"As a result of no-till and rotation, our beneficial bugs have increased, and our problem insects have decreased," says Dustin. "We find lacewings and ladybugs, and our soil is teaming with earthworms. We also see a lot of 'undertaker' bugs, those scavenger insects that break down residues. When you look down at the ground in our fields, you always see a lot of insects. Because of that, we rarely have to control problem insects by using insecticides. Except in sunflowers fields, our need now for insecticide has decreased mainly to emergency use only."

Even grasshoppers may be checked by this robust diversity of soil life. It's too early to tell, but Wayne theorizes that a growing population of crickets may suppress grasshoppers that sometimes thrive in the surface litter of no-till fields.

"This past year we had a minor outbreak of grasshoppers, but we also had more crickets than I've ever seen before," he says. "The crickets will likely control the grasshoppers because they burrow into the litter and eat the grasshopper eggs."

Soil quality

Yet another indicator of vigorous biological activity in their soil is rapid breakdown of surface residue. "In spring, before seeding, we do a medium-tine field harrowing to level the surface residue," says Dustin. "Behind that operation, we have complete breakdown of cereal straw by the end of year one."

Their soils are sandy loam and clay loam soils, and fields have flat to rolling topography.

"Our main limiting factor is rainfall," says Dustin. "Zero till has really benefited us because we've seen the water-holding ability of the soil increase. Because of that, year in and year out our yields have remained consistent despite fluctuations in rainfall."

Steady increases in organic matter contribute to improved moisture retention as well. Organic matter in their soils ranges from 4 to 5 percent, and continues to increase.

Yet another long-term improvement in soil quality is a balancing of the soil pH. Historically, their soils have tended to be acidic but are now shifting toward a more alkaline makeup, testing in the high 6s and low 7s.

A reduced need for fertilizer is another result of the Williamses' long-term no-till practices. "Because of the improved health of our soil profile, we're applying half the amount of fertilizer we used to apply," says Dustin. "We're into our third year of using less fertilizer, and we haven't seen a loss in yields." Dustin noted that captured engine exhaust supplies nearly 30 percent of their nitrogen inputs.

Rotation

They grow a four-year rotation of crops including spring wheat, oats, flax and peas, alternating between sunflowers and canola in the fourth year to break disease and pest cycles affecting sunflowers. They grow peas as a soil-building crop, using it to fix nitrogen and improve soil structure.

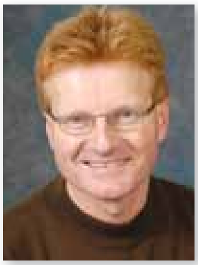
"Peas create a mellow, loamy soil," says Dustin. "Because flax and canola tend to harden soils, we try to bring peas

Continued on page 21 ▸▸

Role of Crops, Cover and Cover Crops

The Synergy Between Soil and Plants

Plants and soils are entwined in shared life; the health of one depends upon the health of the other. In the natural prairie ecosystems these life forms evolved mutually sustaining rhythms surviving the passage of time and ravages of weather. Mimicking these holistic rhythms ensures an enduring future for agriculture.



Martin Entz

"Soils are formed by plants, and plants are critical to keeping the living part of the soil alive," says plant scientist Martin Entz, University of Manitoba, Winnipeg. "It's essential for plants to be a part of any process intended to improve soil health. Healthy soils lead to healthy plants and, in turn, healthy people."

Maintaining this shared cycle of health over the long term is the time-old challenge of agricultural systems across the globe. For the Northern Plains, the challenge is made particularly difficult by a short growing season marked by frequent bouts of hot, dry weather.

Managing moisture

Maintaining sufficient moisture is critical to plant-soil synergy. "Moisture dictates how much biomass plants produce," says Entz. "The volume of biomass is important because from that storehouse of material comes the soil's potential to make organic matter. The carbon in the biomass is the carbon source for the soil, and the amount of root material contributes to this carbon. The soils in the wetter region of the Red River Valley have more carbon than the soils of the drier regions of the Prairies, for instance, because the plants of the Red River Valley have the moisture to produce more biomass."

Thus, on the Northern Plains, the conservation of moisture is an overriding aim of sustainable agriculture, and it is a particular strength of no-till systems. "Because there's no tillage, the loss of moisture through evaporation from the soil surface is reduced," says Entz. "The surface residue conserves the moisture, making it available for plants."

Stubble left standing in fall by many no-till farmers also traps snow, and the snow melt contributes to soil-moisture reserves. This process is critical on the Northern Plains, since "30 percent of our moisture falls as snow," says Entz.

Spring often brings early spells of hot, dry weather. Heat bakes moisture and life from soil not sheltered by residue or living plants. "Where the soil is bare, temperatures in spring can easily exceed 100 degrees Fahrenheit (37 degrees C) in that top half-inch of soil," says Ted Alme, state agronomist for the USDA Natural Resources Conservation Service, Bismarck, North Dakota. "Temperatures in that range will kill soil microbes, and most of the biological activity in the soil then ceases." High heat also causes heat canker and slows, reduces or stops germination of crop seed.

"It's a devastating loss to the total productivity of the soil if we lose the microbes in the upper layer," he says. "A tremendous amount of biological activity occurs in that top inch of soil because much of the organic matter is located there. It's critical to keep the soil biologically active by keeping it covered with residue from the previous crop or by growing a cover crop."

Keeping the soil alive is the catalyst for the ongoing breakdown of decomposing plant residue from previous years' crops. In long-term and stabilized no-till systems this breakdown of residue by microorganisms recycles nutrients, making them available for subsequent years' crops.

Growing diverse plant communities aids residue decomposition because plant diversity above ground stimulates diversity of life below ground. The more diverse the population of soil microorganisms, the more diversified and efficient will be their cycling of residue.

Don Tanaka

"Every crop has a unique set of organisms associated with it, and the organisms gravitate to that crop," says soil scientist Don Tanaka, USDA Agricultural Research Service (ARS) Northern Great Plains Research Laboratory, Mandan, North Dakota. "The best way to develop a diversity of organisms in the soil is to grow a diversity of crops."

Managing rotations

Rotations most efficient in building diverse soil life and most effective in interrupting cycles of weeds, pests and diseases are those comprising crops from five plant families: cool-and warm-season grasses, cool- and warm-season broad-leaved crops, and legumes.

Within these families, however, are crops that are either synergistic or antagonistic to a subsequent year's crop. In other words, a previous year's crop can either help or hinder the crop in the following year.

"If you sequence crops appropriately, you can get a synergism creating an exponential response," says Tanaka. "We define synergism as the greater effect of two components than would be expected from summing the effect of each component alone."

"The crops might start out slow, for instance, but all of a sudden they'll just take off," he says. "Flax, for instance, is synergistic with wheat. When you grow wheat behind flax, you get a boost in yield in the wheat that can't be explained by added fertility. The yield increase is not associated with reduced plant disease, either. That certainly accounts for part of the yield increase, but not all of it. The synergy seems to cause a lot of little things to work together to increase yield."

In long-term studies, the Mandan ARS researchers evaluated the synergistic and antagonistic effects of more than 100 sequences of 16 crops under no-till management. One report states, "In a year with about average growing-season precipitation, it became apparent that sunflower, safflower or flax as the previous crop synergizes the seed yield of canola, crambe, dry bean, flax, safflower, spring wheat and barley."

Conversely, canola and crambe had negative effects on subsequent crops. As brassicas, canola and crambe are non-mycorrhizal crops. Growing these crops may negatively impact mycorrhizal fungi in the soil, consequently affecting subsequent mycorrhizal crops.

The Mandan ARS researchers developed a Crop Sequence Calculator to help producers design rotations capitalizing on synergism between crops. The Calculator includes information on 16 crops adapted to regions receiving 18 inches or less of annual precipitation.

The Calculator provides information about the effect of individual crop sequences on seed yield, soil-coverage residue, soil-water use, surface-soil properties and plant diseases. "The Calculator helps farmers develop crop rotations that fit their individual farm and management style," says Tanaka.

Visit www.mandan.ars.usda.gov to order the Crop Sequence Calculator free of charge.

Besides improving health of soil and plants, growing diverse crops also benefits soil moisture, especially when rotations include deep-rooted crops. Decaying roots create pore spaces serving as channels for water to enter the soil profile.

"Roots aerate the soil and improve water infiltration," says Tanaka. "Deep-rooted plants like alfalfa help to get water deeper into the soil profile, where there's a better chance of moisture being retained."

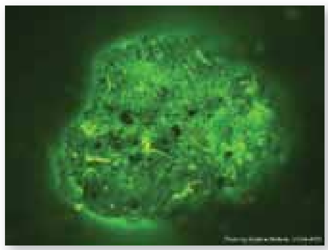
Alfalfa roots will penetrate to depths of 12 feet. By comparison, sunflower roots will penetrate 6 feet; corn and sweet clover, 5 feet; and the roots of peas will penetrate 3 feet into the ground.

The apparent synergistic effects in crop rotation and/or sequencing where crops planted into the residues of the previous crop have lead producers and researchers to examine methods for enhancing these effects. These methods include the addition of perennial crops into an annual crop rotation, cover crops following a cash crop within the same year, or creating a system including annual crops, perennial crops, cover crops, and/or livestock may capitalize upon the synergies between crops and boost yields and soil and water conservation even further or faster than rotation alone. It is also important to note that crop rotation is the foundation to getting these advanced methods to work most appropriately.

Living roots

The symbiotic relationship between plants and soils functions at its best when living roots populate the soil profile. "This is how the prairies were formed, and yet we as scientists did not fully recognize until relatively recently the importance of keeping the soil biologically alive by keeping living plants on the land," says Entz. "Living roots leak carbon all the time and keep the mycorrhizal fungi alive. These fungi cannot live on dead plant material."

The fungi produce a glue-like substance called glomalin, which stabilizes carbon in the soil. "Glomalin is known to be one of the most important factors allowing soil to form aggregates," says Entz.



Adding perennials and cover crops to a rotation of annual crops extends the growing season for living plants. The perennials most closely mirror the native prairie ecosystem. Thus, they are best adapted to the particularly short growing season of the Canadian Prairie and the northern Great Plains of the U.S., and their extensive roots draw water from deep in the soil profile during seasons of drought.

"Perennials put carbon into the soil all day, every day from the end of April through the end of October," says Entz. "They produce a significant amount of glomalin. As additional rewards, farmers can get a boost in grain production as many as seven years following alfalfa, for instance."

But without livestock as part of the enterprise mix on a farm or within a community, the short-term economic rewards often don't warrant including perennials in a rotation. Over the long term, developing enterprise systems for forage-based milk and beef production could build profitability for perennial crops, says Entz.

Perennial grains offer another futuristic possibility for including perennial crops in rotations. "These crops are 10 to 15 years away from commercial availability," says Entz. "They will be particularly well adapted to saline and erodible soils, and will complement no-till production of annual crops." Perennial grains have roots penetrating to depths of 6 feet.

One management scenario might be to intercrop perennial grains with legumes to supply nitrogen. The crop aftermath would provide feed for livestock.

Cover crops

Besides growing perennial forages, planting cover crops after harvesting regular-season crops provides an opportunity to bank living roots in the soil and accomplish other services. *(See accompanying article "Cover Crops at Work.")*

"Adding cover crops to a rotation of annual crops mimics a perennial system and benefits soil quality and carbon over the long term," says Entz. "Producing just 4 or 5 inches of top growth is all that's needed to keep the mycorrhizal fungi active and stabilize carbon in the soil, reducing the loss of carbon through respiration."

The volume of biomass produced by cover crops depends upon moisture and remaining growing days. In the midsection of southern Manitoba, for instance, the shortness of the post-harvest growing season often limits the amount of biomass cover crops produce.

"When you look at long-term weather records for the region along the border between Canada and the United States, you'll find evidence of years when cover crops would have been possible," says Entz. "But you'll also find years when weather conditions caused the harvest to be very, very late. In those years cover crops won't grow a lot of biomass."

The availability of soil moisture is another factor determining the amount of cover crop biomass. "Our research shows that a cover crop producing 1,500 pounds per acre of dry matter could use up to 2 inches of water," says Entz. "In the Red River Valley, that amount of water use is wonderful. It helps to reduce producers' problems with excess soil moisture."

Cover crops' use of late-season moisture in drier regions may limit the availability of moisture for the subsequent crop.

However, Tanaka notes: "From previous research at the Northern Great Plains Research Laboratory at Mandan, North Dakota, we have found that storing soil water during the fall or late summer is inefficient. Therefore, trying to store late-summer and fall precipitation results in little gain in soil water. Converting the evaporation in evapotranspiration to transpiration by plants could result in increased dry matter production, some N and almost the same soil-water content the next spring."

Services and types

A side benefit of cover crops is their ability to scavenge and store excess nutrients. Since moisture and temperature affect the timing of nutrient cycling from decomposing residue and mineralization of soil organic matter, nitrogen may be released after the main crop stops taking up nutrients. The cover crop can consume these nutrients, storing them in plant tissue, thereby making them less vulnerable to leaching or other vehicles of nutrient loss. Eventual decomposition of the cover crop residue releases stored nutrients for use by subsequent crops.

Yet another side benefit of cover crops is their ability to germinate seeds of weeds or volunteer plants from that season's crop. The cover crop canopy produces a more humid environment that conserves surface moisture needed to germinate seeds in fall, exposing seedlings to winterkill.

For the Red River Valley region of Manitoba, Entz recommends cover crop species tolerating wet soil conditions, such as red clover, faba beans and soybeans.

"Peas, lentils and hairy vetch are more drought tolerant," he says. "Forage radishes are particularly good for late-season planting because they are cold tolerant and have penetrating bulbous roots. Though we are only starting to research cover crops for our region, we expect the 'cocktail' mixes of covers to be most beneficial."

Because cover crops of the brassica family are non-hosts for mycorrhizal fungi, they suppress the beneficial activities of these microorganisms. “That’s a good reason to grow the brassicas in cocktail mixes including crops dependent upon mycorrhizal fungi,” says Entz.

Weeds and volunteer crops growing after harvest offer cover crop benefits as well. “We have underestimated the value of weeds,” says Entz. “A diverse community of weeds has mycorrhizal activity in the root zone. I suggest rethinking fall weed control and letting Mother Nature look after weeds with winterkill.”

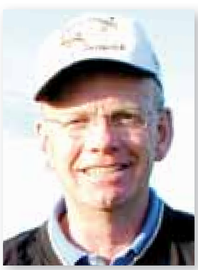
Winter crops

Including winter crops in a crop rotation can make the growing of cover crops more viable. Planting short-season cover crops after a spring-seeded-crop harvest often deprives the cover crops of the time needed to grow well before winter sets in. Planting cover crops behind winter crops that are harvested 10 to 14 days earlier, on the other hand, gives them a longer time to grow in late summer and early fall.

The Conservation Cropping Systems Project (CCSP) research farm in southeastern North Dakota, near Forman, has had good success no-till seeding cover crops after winter crops such as winter wheat. “Cover crops should work equally as well following winter rye and triticale,” says agronomist Blake Vander Vorst of Ducks Unlimited, an organization contributing to the farm’s research.

“Winter cereals are crops that can be harvested one or two weeks earlier than spring-seeded small grain crops,” he says. “This early harvest gives more time to establish a cover crop and gives the cover crop more time for fall growth.” Because of early maturity, pea is a spring-seeded crop providing a similar post-harvest window of opportunity to start cover crops earlier.

At the CCSP farm, the winter wheat is typically harvested in the latter part of July, and the cover crops are planted soon after. A cocktail mix of cover crops has shown good growth well into the fall.



Blake Vander Vorst

“Winter wheat leaves a lot of residue on the soil surface after harvest, which is beneficial to conserving soil moisture near the surface to enhance cover crop germination and sustain seedling growth,” says Vander Vorst.

Winter wheat and the other winter crops also provide attractive cover for spring and early-summer waterfowl nesting. Studies by Ducks Unlimited indicate there are 24 times more nests hatched in winter wheat fields than in fields of spring-seeded crops.

Future research at the CCSP farm will look at the impact of winter wheat and cover crops on soil erosion and soil quality. This work will potentially add to the growing storehouse of knowledge suggesting the many ways living plants benefit soil and a living earth.

– by Raylene Nickel

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Cover Crops at Work

Researchers at several locations are documenting the multiple ways cover crops benefit soil and cropping rotations.

A no-till trial at Cronin Farm, Gettysburg, South Dakota, measured the effects of eight cover crop combinations on soil and yields of a subsequent corn crop. The cover crops stored nitrogen (N) and fostered competitive corn yields with no synthetic fertilizer.

Researchers from the USDA Agricultural Research Service (ARS) North Central Agricultural Research Laboratory, Brookings, South Dakota, conducted the year-long trial in cooperation with farm manager Dan Forgey. The farm site is located in the north central part of the state, where dry growing conditions are common. Average annual precipitation is 18 inches.

After harvesting winter wheat in August 2007, Forgey planted eight cover crop treatments: lentils, canola, cowpea, canola/lentils, canola/cowpea, canola/cowpea/lentils, radish/cowpea/lentils and turnip/cowpea/lentils. No cover crop was planted on a control treatment. Winterkill terminated the cover crops.

On May 13 the following spring he planted corn into the cover crop residue, splitting the treatments into fertilized and unfertilized plots. The fertilized plots received 108 pounds/acre of total N.

Rainfall for the 2008 growing season was slightly above average.

Trial results

Researchers measured cover crop biomass at the end of October 2007. Dry matter ranged from a low of about 580 pounds/acre for radish/cowpea/lentil to a high of about 960 pounds/acre for canola. The second-highest yielder was canola/cowpea, producing about 920 pounds/acre.

Nitrogen in the biomass ranged from a high of 26 pounds/acre for lentil to a low of 8 pounds/acre for turnip/cowpea/lentil. Canola had the second-highest N, and radish/cowpea/lentil had the second lowest.

Lentil, canola/lentil, radish/cowpea/lentil and turnip/cowpea/lentil showed the greatest reductions in fall soil nitrate. In October these plots had 21 to 23 pounds/acre of soil nitrate, compared to 47 to 58 pounds/acre in August. In the control plot with no cover crop soil nitrate dropped from 54 pounds/acre to 30 pounds/acre.

“Fall cover crops will scavenge residual N from the soil and prevent it from leaching,” says Shannon Osborne, a research agronomist at the Brookings ARS laboratory. “The N is stored in the crop biomass, and as this begins decomposing the following spring, the N becomes available to the following crop. The amount of N depends upon the biomass of the cover crop and its carbon-to-nitrogen ratio.”

Cover crops such as legumes not only fix additional N in the soil through roots, they also release more N to the following crop because of the low carbon-to-nitrogen (C:N) ratio of their biomass.

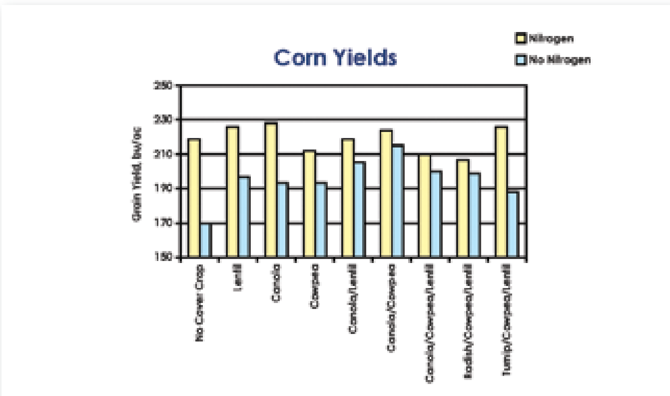
Shannon Osborne

"Residue from cover crops with a low carbon-to-nitrogen ratio decomposes more quickly than does residue from cover crops with a high ratio," says Osborne. Because residue of cover crops with a high C:N ratio decomposes more slowly, it is more effective at building soil carbon. In the Cronin Farm trial, measurements of soil moisture in the top 3 feet of the profile in October of the cover crop year showed little difference in soil moisture between the no cover crop plot and the cover crop plots.

Corn yield

Yields of the subsequent corn crop were significantly higher for unfertilized plots following cover crop mixtures than for the unfertilized control plot where no cover had been grown. *(See Figure 1.)* Corn in the unfertilized control plot yielded 170 bushels/acre, while unfertilized corn in the canola/cowpea cover plot yielded 215 bushels/acre, the highest yield of the unfertilized cover crop treatments. Plots were hand-harvested.

Figure 1



Except for the turnip/cowpea/lentil plot, unfertilized corn grown in plots previously producing combinations of cover crops out-yielded unfertilized corn from plots previously producing single-species covers – even lentil, which had produced the most plant nitrogen of all cover crop treatments.

"Combination cover crops seem to have more value, and the following crop seems to do better," says Osborne. "I can't say why that happens because there are too many possibilities."

Cover crop of choice

While Dan Forgey is experimenting with a range of cover crops in his rotation, canola/lentil is a combination he favors. In the ARS trial, this combination yielded only slightly less than canola/cowpea in the unfertilized plots. "I'm leaning more toward lentils than cowpeas because cowpeas freeze off so early in the fall," he says. "But lentils don't mind the early cold weather."

Like the canola/cowpea combination, the canola/lentil cover crop combination significantly increased the protein of the corn, testing 8.8 and 8.4 percent respectively. The corn protein on the unfertilized plot growing no cover crop tested 7.7 percent. "Improving the protein in the corn by growing cover crops creates added value for livestock producers," says Forgey.

Additional value could result from reducing fertilizer applications in corn crops following cover crops. To accomplish this, Forgey plans a site-specific strategy requiring the measuring and drying of biomass samples from cover crops. "I want to find out how much N these cover crops are actually contributing each year," he says. "If there are nitrogen credits available, I'll decrease N application rates by that much."

Wet soil conditions

Measuring cover crops' effect on no-till spring-planting conditions in the higher-moisture region of eastern South Dakota is the focus of a study jointly undertaken by the Brookings USDA-ARS and South Dakota State University. The first-year results showed that cover crops increased the weight-bearing capacity of no-till soil in spring and resulted in corn yields comparable to yields in fields not previously producing cover crops.

"Producers here in eastern South Dakota resist no-till because we get a lot of rain in the spring, after the frost is out of the ground but before planting," says Osborne. "Many producers believe that no-till delays planting, and they tend to till to dry out the ground."

Researchers designed a no-till study to find out whether or not a fall-planted cover crop would use up spring soil moisture and provide a stable weight-bearing surface for no-till spring seeding.

They seeded a variety of cover crops after harvesting a crop of small grains, either spring wheat or oats harvested for hay or as a cash crop. "We planted 14 cover crops and cover crop mixtures," says Osborne. "The mixtures included grains and grasses such as ryegrass, slender wheatgrass and switchgrass. In some cover crop mixes, we included legumes and grasses that would come back in spring and use up some moisture."

Surviving cover crops are killed with herbicide prior to planting corn the following spring. Cover crop species surviving the winter included hairy vetch, red clover, sweet clover, Alsike clover, slender wheatgrass and winter ryegrass. These species increased soil strength and reduced soil moisture relative to conventional-till and no cover crop treatments.

Spring soil-surface temperatures in cover crop treatments were less variable than control plots growing no cover crops. "Average temperatures were not significantly cooler than where there was no cover crop," says Osborne.

Three years of data showed that germination of spring-seeded crops no-tilled into cover crop residue was delayed an average of three to four days compared to germination date of spring crops conventionally seeded into plots not growing cover crops. "Despite the delay in germination there was no difference in yield between treatments," says Osborne.

Cover crops and cattle

Researchers at the USDA-ARS Northern Great Plains Research Laboratory, Mandan, North Dakota, are integrating no-till cover crops with a livestock enterprise. The system yields a grazing resource as well as increased soil fertility for a subsequent corn crop.

In the first year of the three-year crop rotation they spring-plant oats was underseeded with a mix of hairy vetch, alfalfa and red clover. They swath the oats at the dough stage in mid-August. "Swathing opens up the canopy, and the cover crops take advantage of sunlight and moisture to produce fall growth," says ARS soil scientist Don Tanaka. "From mid-September through mid-October cow-calf pairs graze the swaths and legume growth."

An electric wire provides the cross-fencing needed to graze the field in strips. The wire permits the calves to creep-graze the legumes ahead of cows.

The cover crops overwinter and regrow in spring. Ten days before seeding sorghum-sudan in June, researchers apply an herbicide to terminate the legumes. "We seed sweet clover and red clover with the sorghum-sudan," says Tanaka.

The sorghum-sudan is swathed after the first killing frost, leaving stubble about a foot in height. The tall stubble elevates the swath above the ground, making it more accessible for cattle to graze after snow falls.

In the third year of the sequence, researchers no-till corn into the sorghum stubble in spring. "We let the corn come up, and in the process of controlling weeds with a herbicide we also control the legume cover crops that have overwintered," says Tanaka. They harvest the corn for grain, leaving the residue in swaths.

The three sequences of the cropping system are staggered among fields so that each year cattle graze forages from all three sequences, with grazing periods timed to provide forage well into winter.

After grazing the oats swaths and legume regrowth, the calves are weaned and cows graze swaths of corn residue. In mid-December cows start grazing sorghum-sudan, which is particularly well suited to swath-grazing after snow starts to accumulate, because of the fluffy swaths supported by tall stubble. If weather permits, grazing continues into February.

System benefits

The legume cover crops combined with livestock manure provide fertility for the corn crop. "The nitrogen supplied by the system tends to be much greater than the N inputs from fertilizer," says Tanaka.

As the system has evolved, N application rates have decreased. "We had been applying 60 pounds/acre of nitrogen for every crop in the system," he says. "Now, we apply 60 pounds/acre only to corn and have decreased the rate to 30 pounds/acre of nitrogen for the oats crop and for the sorghum-sudan."

Corn yields range from 70 to 120 bushels/acre. The oats and sorghum-sudan crops yield 5,500 pounds of dry matter per acre. The area's annual precipitation averages 16 to 17 inches.

Varying rooting depths of the legumes help counteract the potential for compaction from cattle traffic. "Alfalfa tends to break up a hardpan, and the roots of the other legumes along with the surface residue keep compaction down," says Tanaka. "Wherever you have a growing plant using water, your chances of compaction are much less.

"We think the livestock have a positive impact on soil and water resources," he adds. "Manure stays in the field, and hoof action seems to incorporate some residues. That's especially helpful in years when there is a large quantity of residue because the hoof action helps with decomposition."

– by Raylene Nickel

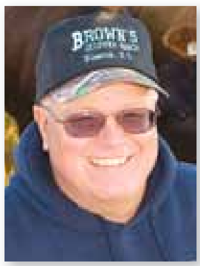
Producer Profile

Crop Diversity Builds Fertility

Growing cover crops in combination with livestock grazing has improved soil health and reduced commercial inputs on Gabe Brown's crop and cattle operation near Bismarck, North Dakota.

The farm's cash crops include corn, hard red spring wheat, winter triticale, sunflowers and alfalfa. Fields of corn receiving no synthetic fertilizers yield 120 to 130 bushels/acre, while unfertilized spring wheat has averaged as high as 72 bushels/acre. Average annual precipitation is 15 to 16 inches.

"We're increasing soil fertility because we're improving the health of the soil," says Brown. "In any given year, half of our cropland receives no commercial fertilizers. We do fertilize fields we've just rented or fields we're not yet able to graze with cattle."



Gabe Brown

Since 1991, soil organic matter in some fields of Williams loam soils has doubled, increasing from 1.7 and 1.9 percent to 4.2 and 4.4 percent.

"By improving soil health and increasing organic matter we've improved infiltration and increased the water-holding capacity of the soil," says Brown. "The organic matter is food for the macro- and microorganisms, which provide nutrients for the plants. The microorganisms feed off the variety of root types and provide nutrients for the following year's crops. When you focus on improving soil health, it's amazing how soils are then able to provide the nutrients needed for the growing crop."

The cropping system

The evolution of Brown's present management system began in 1993, when he started no-tilling fields. In 1996 he began diversifying his cropping sequence by planting combination crops, growing red clover with barley, for instance, and hairy vetch with triticale. In 2006 he added cocktail cover crops to the cropping mix.

The late-season cover crops are a good match for winter triticale. The triticale provides a good opportunity for planting the cover crops because its late-June to mid-July harvest gives the cover crop plenty of time to grow before winter. Brown may also plant cover crops behind spring wheat if the harvest is early enough to permit growing time for the cover.

"We put a lot of planning into our choice of cover crops," he says. "We decide what mix of cover crops to plant based on what improvements we want to make to the soil. If we want to improve organic matter, for instance, we'll include millet because of its fibrous roots. Depending on what else we want the cover to do, we might add to the mix crops like soybean, hairy vetch, radishes and turnips."

In addition to including these late-season cover crops in the rotation, some years Brown plants a full-season cover crop in a field in place of a cash crop. With a goal of further improving soil health, he plants a diverse mix in a single planting, including as many as 11 crop species planted anytime from mid-May through early June.

The multi-species cover crop grows undisturbed throughout the growing season. Cattle graze the mature crop in early winter, trampling much of it onto the soil surface. Their fecal material adds nitrogen and phosphorus to the soil.

Before grazing, the full-season cover crop may grow as tall as 3 to 5 feet and may produce as much as 11 tons of dry matter per acre. More typical yields are 4 to 5 tons of dry matter per acre.

The following spring Brown no-tills corn into the mat of surface residue. "In 2009, by July 1, the residue from a large cover crop had almost disappeared," says Brown. "All the residue was being consumed by the earthworms and macro- and microorganisms. It actually becomes a challenge growing enough residue to feed all those soil organisms that keep increasing."

Brown's efforts to diversify crops don't stop with short- or full-season covers. He diversifies cornfields, too, by including a companion crop, most often a legume like hairy vetch. "The legume will help supply nitrogen to the corn," he says.

Inputs reduced

Besides supplying its own fertility, the diversified cropping system reduces the need for herbicides and pesticides. "The litter on the soil surface keeps weeds from germinating, so we've cut back our herbicide use by about 75%," he says. "Where we grow companion crops we can't use a herbicide anyway because it'll kill the companion crop."

Brown seldom uses pesticides except to control occasional outbreaks of seed weevils in sunflowers. "We have found that the healthier the soil becomes, the fewer problems we have with diseases and pests," he says.

Production costs have decreased as a result of applying fewer inputs of fertilizers, herbicides and pesticides. In 2008 Brown's production cost for corn was $1.19/bushel. This cost did not include the cost of establishing the companion crop.

Brown cautions that cover crops are not a cure-all for all cropping situations and may not be able to replace commercial inputs in all soil conditions or production systems. He points out, too, that his livestock lend added benefits to his operation because of their fertilizer inputs and use of crop biomass.

"On the Northern Plains, the soils were formed by large numbers of animals grazing across the prairie," he says. "We're trying to move away from using massive amounts of fertilizers and chemicals on the soil and mimic what Mother Nature did thousands of years ago."

– by Raylene Nickel

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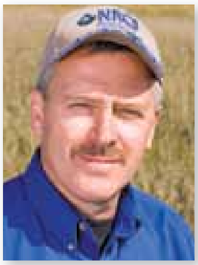
Selecting Cover Crops to Improve Soil Health



Jay Fuhrer

"Before you start planting cover crops, set a goal identifying what you want the cover crop to accomplish," says Jay Fuhrer, district conservationist with the USDA Natural Resources Conservation Service, Bismarck, North Dakota. "My ultimate goal for Burleigh County is to improve soil health."

Start by identifying your natural resource concerns and pinpoint areas needing improvement. When Fuhrer walks no-till producers through this process in the field, he finds that some of the more common resource concerns are: adequate soil armor, expanding crop diversity, enhancing soil organic matter, improving infiltration, and increasing nutrient cycling.

Soil armor (surface residue) is needed to control wind and water erosion, reduce evaporation rates, and manage soil temperatures. Adequate soil armor is required to get cover crops off to a good start, when seeding after an early harvested crop.

Where diversity is lacking in the rotation of primary crops, cover crops can fill the gap. The most ideal primary rotations include crops from the four major crop types: cool season grass, cool season broadleaf, warm season grass, and warm season broadleaf. Growing cover crops representing whatever crop type is missing from the primary rotation helps restore balance to the system by providing an improved diet for soil biology.

If building soil organic matter is a goal, adding additional roots to the soil profile along with reducing soil disturbance with no-till seeding will help move the soil organic matter in an upward direction. Cover crops with fibrous roots are effective at increasing soil organic matter. Good candidates include rye, triticale, oat, millet, and sudangrass.

"Improving water infiltration is important for all farmers and is an area that commonly doesn't get addressed," says Fuhrer. It can be particularly challenging when you consider the big picture, since many North Dakota cropland fields have undergone 100+ years of tillage. The aggregates have been diminished creating a soil profile which now holds a smaller amount of water. For example, the western half of North Dakota tills because they perceive themselves as too dry; the more they till the more soil aggregates are destroyed resulting in a soil profile which holds less and less water and oxygen. The eastern half of North Dakota tills because they perceive themselves as too wet; the more they till the more soil aggregates are destroyed resulting in a soil profile which holds less and less water and oxygen. "Producers considering a switch to a no-till seeding system should first improve infiltration and compactions issues," he adds. "No-till producers who have been continuously growing small grains or other shallow-rooted crops will find their infiltration improving very slowly. However, infiltration can be improved more rapidly by adding taproot cover crops, such as radish, turnip, and sunflower."

Improving nutrient cycling is another common need Fuhrer sees among no-till producers. "You need adequate surface residue to protect and feed the soil, however fields with multiple years of residue is excessive and delays the release of nutrients," says Fuhrer. "Planting low carbon cover crops will accelerate biological time so that nutrients start cycling and become available to a subsequent crop." "Such cover crops include any of the legumes and brassicas, like turnip," says Fuhrer. "These decompose quickly." Planting low carbon cover crops in mixtures with high carbon cover crops contributes to a balance in the carbon nitrogen ratio by allowing for a gradual release of nutrients and still maintaining adequate surface residue.

Planning a cover crop strategy may require expanding the primary rotation in order to provide a window of opportunity for early seeding; which in turn permits the cover crop sufficient growing time in late summer and fall. The early seeded cover crop can then harvest more sunlight; this energy is what drives the system. Some of the greatest soil health gains made on cropping and grazing systems in Burleigh County comes from the fact that we no longer terminate sunlight harvest at "harvest time." The value of the early fall seeded cover crop is its ability to capture this energy and ultimately transform it into carbon. Using a no-till seeding approach for the annual crop and cover crop enhances the soils ability to sequester the carbon and start to reclaim a degraded soil. A simple corn-soybean rotation, for instance, may be too "tight" to work in a cover crop effectively. Expanding the rotation to include a small grain provides additional diversity and the needed window of opportunity for seeding a cover crop. Adding cover crops into your existing rotation will help your cropping system more closely mimic native rangeland. "The benefits from growing cover crops don't occur all in one year," says Fuhrer. They're spread over a period of years.

When choosing cover crop mixes, consider including species of flowering crops that will attract pollinators and beneficial insects. According to The Xerces Society for Invertebrate Conservation "There are approximately 4000 species of native bees in North America, hundreds of which contribute significantly to the pollination of farm crops." We can increase their populations by providing them a habitat with minimum soil disturbance and flowering cover crops such as: alfalfa, canola, squash and sunflower.

Adding livestock further diversifies a cover crop strategy. The cover crops allow us to take the livestock off the native rangeland earlier in the fall, allowing for a longer grass recovery period, and a higher livestock nutritional diet. We try to graze the cover crops with a large number of head for a short period of time. A reasonable goal is to graze approximately 40 to 50 percent of the forage. "Let the rest of the cover crop residue be the "armor" for the soil and food for the soil biology; you've got to feed both," says Fuhrer.

"Cover crops, like no-till seeding, are one more tool we can use to strengthen the foundation blocks of soil health. Resulting in reduced fossil fuel inputs and improved soil health, as we move toward the bigger picture of Soil Health – Food Health – People Health," says Fuhrer.

– by Jay Fuhrer, District Conservationist
Natural Resources Conservation Service,
Bismarck, North Dakota

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back in after these crops." In the future, they plan to include cover crops in the rotation and hope to find ways to work with neighboring livestock producers in the recycling of cover crop nutrients.

To control quack grass and thistle, they fall-apply glyphosate. In spring, they apply glyphosate as needed to control weeds. "If we can get the crop off to a good start and get a good crop canopy, we reduce the need for some of the more expensive chemicals," says Wayne. "We have had cases where we haven't had to spray at all during the growing season."

Their 10-year average yields run 35 to 38 bushels/acre for wheat, 80 bushels/acre for oats, 32 bushels/acre for flax and 1,500 pounds/acre for sunflowers.

The Williamses have found that no-till's benefits to biological activity in sandy, previously tilled soil takes time to evolve and depends, of course, on previous management. "It takes about three years to get organic matter cycling and to get some tilth in the soil," says Wayne. "After three years we start to see better water retention."

The benefits of no-till to their farming operation have been dramatic, improving the sustainability of their soil resource and risk-proofing crops by improving their ability to handle adverse growing conditions.

"Zero till has a lot of benefits," says Wayne, "but it also has problems we have yet to address, including weeds, diseases and input costs. We have to go to the next step, and find ways to cut back on chemicals and find more natural ways to control weeds and diseases."

– by Raylene Nickel

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Organic No-till

Exploring Site-Specific Synergies

While organic no-till remains a production system of the future, it's very much at the forefront of some researchers' study of ways to let natural synergies between soil and plants both eliminate tillage and replace inputs such as pesticides, herbicides and synthetic fertilizers.

Pat Carr

"It's exciting to think that we could develop a viable system of organic no-till for our region," says agronomist Pat Carr, North Dakota State University Dickinson Research Extension Center. "It could potentially offer much to producers. We know that no-till offers advantages in conserving moisture, and this is particularly helpful to organic producers in drier regions."

Carr's study of organic no-till systems adapted to the dry growing conditions of western North Dakota is in its infancy. Research of similar systems at Pennsylvania's Rodale Institute provides guidance, but the warmer, more humid climate of Pennsylvania presents growing conditions more favorable to the development of organic no-till. Researchers of the Northern Plains must pioneer systems better able to withstand drought and radical swings in temperature.

Surface mulch

Ecological no-till must evolve as a site-specific production system fitted to the unique growing conditions of each region. "The design of an organic no-till system will depend on how much cover crop can be grown in a specific place," says plant scientist Martin Entz, University of Manitoba, Winnipeg. "The cover crop produces the mulch needed to suppress weeds."

Entz is developing an organic no-till cropping system on plots of sandy soil at Carman, Manitoba, where average annual precipitation is 19.7 inches (500 millimeters).

Five-year average yields are 22 bushels/acre for flax and 48 bushels/acre for hard red spring wheat.

The rotation sequence begins with a full-season cover crop grown to produce a green manure mulch on the soil surface. Entz spring plants a cereal-legume combination

such as peas and oats, or hairy vetch and barley. He terminates the cover crop in July by rolling it with a heavy drum fitted with blunt blades.

"We let the crop rest for the remainder of the season," says Entz. "Some weeds come up through the mulch, but if we can grow a cover crop producing 5,000 pounds per acre of dry matter, it will suppress weeds effectively. It appears from our work that a 2-inch mulch suppresses most weeds. Anything less than that is less likely to provide weed control."

The decomposition rate of the mulch contributes to its weed-suppressing ability. Dry conditions slow down decomposition, while wet conditions speed it up.

Decomposition rate also varies by cover crop species. The rate increases with legumes, which have a low carbon-to-nitrogen ratio, and slows down with cereal crops, which have a high carbon-to-nitrogen ratio. "In our environment we need to include a cereal in the cover crop to slow down decomposition of the mulch," says Entz. "We include oats in mixture with peas, and barley in mixture with hairy vetch in order to slow the rate of mulch decomposition. The choice of cover crop species must be site specific."

The first of September Entz sometimes direct-seeds a brassica like rapeseed into the cover crop mulch. Because the roots of the mulched crop remain anchored in the soil, a no-till disk seeder penetrates the mulch without dragging residue. "The cover crop helps tie up any nitrate-N released by the mulch, thereby reducing N losses," says Entz.

"In an organic system, there's never just one crop growing," he adds. "I tell organic growers that for every time a more conventional no-till grower takes a sprayer to the field, the organic producer needs to pull out a drill, to make sure something green is growing on the land as much as possible."

Rotation and weeds

The following spring Entz direct-seeds flax or spring wheat into the mulch. These crops are harvested later in the season as cash crops.

He direct-seeds fall rye after harvesting the cash crops. "Rye is a weed killing crop, and because there is a lot of nitrogen in the system, it grows extremely well," says Entz.

After harvesting the rye for grain the following July, several management options are possible, and Entz continues to experiment with these. One alternative is to simply leave the rye stubble alone after harvesting the grain. Other possibilities include planting into the stubble field peas or Indian Head lentil as fall cover crops.

The following spring, the rotation begins again with the planting of a full-season cover crop.

While the heavy surface mulch from the cover crop year and the planting of weed-fighting rye do indeed suppress weeds, they continue to pressure the system.

"There are always weeds in an organic system," says Entz. "But if you don't disturb the mulch, you tend to have weed populations a little like those in a conventional no-till system. The small-seeded annual weeds don't do as well, while the perennial weeds are the ones we have the most trouble with."

Adding livestock to the system could provide an alternative way to control perennials. "We have a herd of sheep at our research site, and we plan to research the possibility of using grazing animals to control weeds. Adding a perennial forage to the rotation could help as well."

Tillage option

Incorporating a tillage year into the rotation to control weeds is another possibility. "We may have to till one year out of four," says Carr. "We know that tillage is very disruptive to some microbial populations and to arbuscular mycorrhizal fungi. But controlling perennial weeds in an organic system is a huge challenge without using tillage."

While incorporating a tillage sequence into a long-term organic no-till rotation may indeed set back some populations of soil microorganisms, the saving grace of an organic system is its diverse rotation of crops. The diversity stimulates microbial and fungal activity. "There is research showing that some organic systems involving tillage have soil properties indicating greater health than similar measurements taken in some no-till systems," says Carr.

Entz theorizes that a tillage aftershock on soil microorganisms could be mitigated by immediately following the tillage treatment with the planting of a mycorrhizal-dependent cover crop. This could support rapid recovery of some soil life.

Future research

Carr's organic no-till research at Dickinson, where average annual precipitation amounts to 16 inches, has looked at producing buckwheat, pinto beans, navy beans and corn. So far, dry seedbed and dry growing conditions have prevented the harvesting of significant yields.

Mulch producing cover crops he has evaluated include fall-seeded winter rye, hairy vetch and winter wheat, grown alone and in combination. "We have found that if we get a year with good growing conditions, the rye in particular will produce 7,000 kilograms per hectare [or 6,200 pounds/acre] of biomass," says Carr. "That amount will suppress weeds in our environment."

However, terminating either rye or hairy vetch by rolling has proved troublesome in his system.

Future research at Dickinson will expand the cover crop sequence and look at 10 species of cover crops, some spring planted and terminated in fall. Carr's goal is to develop an organic no-till system uniquely fitted to dry regions of the Northern Plains.

As in the Manitoba system, success with organic no-till, says Entz, boils down to "creating a weed-suppressing mulch and growing very competitive crops."

Whether transitioning from long-term no-till to organic (fewer or no synthetic inputs) no-till or from organic conventional tillage to organic no-till, organic no-till may be the next evolution in sustainable no-till farming. Although this system is in its infancy and will require hard work and many modifications to perfect, particularly in lower rainfall and colder environments, organic no-till offers the integration of soil health and biology with crop and livestock production which will provide for food, feed, and fiber needs while maintaining environmental and economic sustainability.

– by Raylene Nickel

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Fertility Issues

Match N Supply to Crop Demand

Getting the most efficient use from fertilizer inputs boils down to a simple formula: Apply fertilizers from the right source, at the right place, at the right time and at the right rate. Determining the most efficient application rate presents the greatest challenge for nitrogen (N) fertilizers.

Cynthia Grant

"A critical production and environmental issue relating to soil fertility is matching nitrogen availability to crop demand to avoid excess N being in the system when the crop cannot use it, such as after crop growth ceases in the fall or before crops are actively growing in the spring," says soil scientist Cynthia Grant, Agriculture and Agri-Food Canada (AAFC) Brandon (Manitoba) Research Centre. "Nitrogen that's out of sync with crop uptake can be lost to the air and water, causing environmental problems.

"Nitrogen fertilization should make up the difference between the demands of the plant and the supply from the soil," she says. "This requires accurately predicting nutrient supply before applying fertilizer. The nutrient supply includes both inorganic nutrient in the soil and the ability of the soil to supply nutrients to the growing crop through mineralization of organic matter. I think that this is the 'Holy Grail' of nutrient management, but it may not be totally achievable."

Variables at work

The difficulty in predicting the difference between the plants' N demand and the soil's N supply lies in the unpredictable factors of weather and the behavior of soil biology. Moisture and warm weather speed up the cycling of both applied nitrogen and N released through the growing season from microorganisms breaking down residue, speeding up plant growth and nutrient uptake. Drought or cold weather delay these processes.

Varying amounts of mineralizable nitrogen in the soil play a role, too. "With reduced tillage, organic matter tends to accumulate and release of nutrients from organic matter decomposition is decreased," writes Grant. "The balance between nutrient release and tie-up will depend on the environment, and whether temperature and moisture conditions are limiting to microbial activity. Generally, at least in the initial years of a reduced- tillage system, tie-up of N in the soil organic matter increases, and the N available for crop growth declines.

"While the increase in organic matter is beneficial in terms of increased soil aggregation, improved water-holding capacity, improved tilth, and enhanced resistance to wind and water erosion, the amount of nutrients available for crop growth from the soil may be lessened, at least in the initial years of a reduced tillage system. Therefore, until the soil organic matter under a no-till system is no longer increasing, it may be necessary to compensate by increasing fertilizer rate or improving the efficiency of fertilizer management.

"Eventually, in theory, a new equilibrium organic matter concentration should be reached under no-till," she adds, "and the increased organic matter content of the no-till soil may result in increased mineralizable N available for crop growth."

Upon reaching this equilibrium in soil organic matter, producers may reduce fertilization rates. Determining the size of the reduction may be a site-specific process of discovery.

Reduced rates

Research at North Dakota State University shows that fields in continuous no-till for more than five years require 50 pounds/acre less supplemental nitrogen than conventional-till fields to maintain yield and a wheat protein level of 15 percent. The research is based upon data gathered from multiple sites in North Dakota.

At Indian Head, Saskatchewan, AAFC trials showed where fields were zero tilled for 22 years, nitrogen mineralization rates are 50 to 63 pounds/acre greater than on an adjacent conventional-till fields under crop-fallow cropping systems with very little fertilizer added over the years.

The AAFC trials examined varying rates of nitrogen. The results showed similar yields and higher grain protein in wheat on long-term no-till fields with 27 pounds/acre less nitrogen fertilizer applied than was used on the short-term no-till fields. In 2009, applying 50 pounds/acre of N instead of 80 pounds/acre supported optimum yields on fields in no-till for 30 years. The soils at this site are loam and sandy soils. *(See accompanying article "Managing Mineralization.")*

Experimenting with on-farm check strips is a way for producers to discover the reduction in fertilizer rates their fields can support. Grant suggests using strips to do side-by-side yield comparisons of two application rates. In addition to the normal rate applied by the producer, two additional application rates, one representing half and one double the amount of the field's normal fertilizer application rate can be applied in a side-by-side yield comparison. "This is a way for farmers to see what their soil is doing for them," she says.

Reducing application rates below the threshold supported by the annual recycling of soil nutrients risks mining the organic matter. "If you remove more nutrients than you are supplying or returning to the soil through crop residue, the soil will be mined over time, and organic matter will be depleted," says Grant. "The fertilizer N rate should be enough to make up the difference between the crop requirement and the soil supply, keeping in mind that N losses will occur from both the soil and the added fertilizer." Losses can result from volatilization, immobilization, leaching and denitrification.

Estimating rate

Estimating crop demand for nitrogen based on yield potential is the first step in determining application rate. "As a rule of thumb, a wheat crop needs about 2 to 3 pounds of N to produce a bushel of wheat," writes Grant. "Nitrogen requirements for the crop can be estimated after selecting a reasonable target yield."

The next step is estimating soil supply of nitrogen. Soil testing reveals the amount of nitrogen available in the soil, and this measurement can be fine tuned with estimates of input and removal of nitrogen from the soil system.

"Each bushel of wheat at 15 percent protein removes about 1.5 pounds of N from the system in the grain," writes Grant. "With high crop yields in the preceding year, crop removal will likely have depleted reserves of soil N, leading to a reduced supply of available N for the current crop. This is particularly true if the crop also contained high-protein content, which will increase N removal."

Over the long term, decomposing crop residues contribute to the soil supply of nitrogen. Crops vary widely in the amount of nitrogen they'll return through residue decomposition. The amount of N depends upon the volume of residue and its nitrogen concentration. If the N concentration is low, the decomposing residues may tie up nitrogen rather than release it.

"Straw from a well fertilized wheat crop will decompose more rapidly and release more N to the following crop than will straw from an N-deficient crop," writes Grant. "Therefore, species and nutrient management of the preceding crop will influence its nutrient content and the amount of nutrient it will release to the subsequent crop."

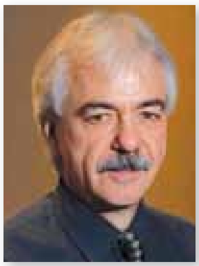
Including annual legumes in the rotation increases the amount of N available to the following crop. "Estimates of N credit of legumes to following crops range widely from less than 10 to more than 70 pounds/acre and will depend on legume yield, management practices and environmental conditions," writes Grant.

"A producer can also use the protein content of the crop as a rough estimate of how close N-management practices are to optimal," she says. "If you are growing Canadian Western Hard Red Spring Wheat and your protein content is consistently about 13.5 percent, that means your N management is in the right range for optimum yield."

Targeting applications

Site-specific application technologies can improve fertilization efficiencies by identifying highly productive zones in fields. "These areas may be able to release more nutrients through cycling and may not require as much fertilizer input," says Grant. "Alternately, they may require more nutrients to support the high yield in the zone. The producer has to be able to understand what is affecting crop yield in the various areas of the field."

To improve fertilization efficiency in low yielding areas, she suggests addressing the "limiting factors" before simply "adding nutrients that are being used inefficiently anyway." Problems with salinity or weed pressure, for instance, may need to be resolved.



Guy Lafond

Despite best estimates of efficient nitrogen application rates, room for error remains because each year presents unique and variable climatic conditions. "We have to find ways that will refine our ability to put on the 'right' amount of fertilizer," says production systems scientist Guy Lafond, AAFC Indian Head (Saskatchewan) Research Farm. "Nutrient cycling is driven by moisture and temperature, and farmers have no way of knowing what the current production year is going to be like."

GreenSeeker™ technology may provide such refinements. This technology, which is commercially available, uses optical sensors to measure in real time the characteristics of the crop during the growing season. The performance of the plants reveals their yield potential and the extent of nutrient cycling to that point in time.

"We are developing GreenSeeker™ algorithms based on the relationship between grain yield and optical sensors," says Lafond. "This is a tool that will let us refine nutrient management by monitoring crop performance and applying liquid nitrogen in-season if additional fertility is required."

Resilient soil

As producers look for ways to most efficiently match nitrogen supply to nitrogen use by plants, building soil organic matter in the process will yield resilient soils capable of adjusting to ebbs and flows in nutritional demands of plants.

"The buildup of mineralizable N acts as 'buffer' in years like 2009," says Grant. "Yield potential was far higher than expected, but in soils with a good supply of mineralizable N, the soil was able to supply the nutrients to support the crop. In contrast, soils that were depleted due to poor management could not support the yield potential and yield was restricted. The greatest benefit of the reserve of nutrients in the soil organic matter is the buffering potential, along with the other benefits that the organic matter offers in terms of water-holding capacity, tilth and resistance to erosion."

– by Raylene Nickel

Fertilizing Hard Red Spring Wheat and Durum in North Dakota

Dave Franzen

Nitrogen (N) recommendations for spring wheat and durum were completely revised in November 2009 for North Dakota. The change in recommendations recognize the increase biological activity and rate of nutrient cycling in long term (greater than 5 years continuous) no-till cropping systems, credits for organic matter levels exceeding 5%, previous crop credits as well as the cost of N and the price of a bushel of wheat. Also N adjustments can be made when issues such as denitrification, early lodging, protein issues, and crop residue quantities exceed a ton/acre.

These recommendations make it easier for producers to manage input risks on different areas of the fields when variable rating fertilizer. Yield goals are no longer used but productivity categories of high, medium, and low are used to determine the optimal N level.

The yield potential within each productivity category is defined for eastern regions of North Dakota Low = less than 40 bushels/acre, Medium = 40 to 60 bushels/acre and High = greater than 60 bushels/acre. In the western region Low = less than 30 bushels/acre, Medium = 30 to 50 bushels/acre, and High = greater than 50 bushels/acre.

Additional information can be found in NDSU Extension Bulletin SF-712, Fertilizing Hard Red Spring Wheat and Durum. An online tool for calculating the amount of N to apply with these new recommendations can be found at **www.soilsci.ndsu.nodak.edu/wheat/index.html**.

Information on adjusting phosphate application rates based on the cost of phosphate and the price of a bushel of wheat is also given in the bulletin.

Phosphorus Balance

Fertilizing with phosphorus (P) is a balancing act. As with nitrogen applications, annual P inputs should not significantly exceed a crop's annual removal rate in order to avoid excessive levels of P in soils and risk of surface-water contamination.

Most efficient matching of P input to plant uptake requires more than a precise matching of application rate to soil-test results. It also requires an understanding of additional efficiencies.

"In contrast to nitrogen, which moves readily through the soil once it is converted to nitrate, P is relatively immobile in the soil and so remains near the site of fertilizer placement," writes AAFC soil scientist Cynthia Grant. "Since P will not move easily in the soil, it must be in a position where the plant roots can contact it during early plant growth, when P is very important for crop development. Placing the P in a band close to the root allows the root to contact and utilize the band. Therefore, fertilizer P is most efficiently used when seed-placed, or placed in a band close to the seed."

An additional benefit of banding P in a no-till system is the elimination of soil mixing, which tends to encourage the fertilizer to form the phosphate compounds that decrease plant-availability of P. "By banding the fertilizer, the formation of these phosphate compounds is slowed, and the fertilizer remains in a plant-available form for a longer period of time," says Grant.

Role of fungi

A more delicate balancing act affecting efficiencies between P inputs and plant uptake involves P concentration in plants and its impact on mycorrhizal fungi. As the concentration of P increases in plants, it tends to depress the beneficial activity of these fungi. Yet when the fungi are given the environmental working conditions they prefer, their services actually reduce the need for P inputs.

"The fungi increase the ability of the plants to access P in the soil by increasing the volume of soil explored and by allowing P extraction from smaller soil pores," says Grant. "However, in the long run P extracted from the field by the crop will still need to be replaced in order to avoid nutrient depletion."

Plants colonized by a network of these mycorrhizal fungi can absorb more P from the soil than non-mycorrhizal plants. "A root system that has formed a mycorrhizal network will have a greater effective surface area to absorb nutrients and explore a greater volume of soil than non-mycorrhizal roots," writes Grant. "In one study, the volume was calculated to be at least 100 times greater with mycorrhizal association than in its absence. Moreover, mycorrhizal colonization may induce formation of lateral roots or increase root branching, further increasing the volume of soil explored."

No-till fosters mycorrhizal colonization of plants because the absence of tillage leaves intact the mycorrhizal networks in the soil. Colonization is also enhanced by planting mycorrhizal-dependent crops back to back.

Field runoff

"A critical production and environmental issue is the potential for movement of P from crop residues to the water under no-till, particularly where freeze-thaw cycles may enhance losses," says Grant.

"The long-term use of commercial fertilizers has increased the plant-available soil P of many agricultural soils to excessive levels," she writes. "Also, in areas of intensive livestock production, manure P, once considered a resource, is increasingly seen as a source of pollution.

"Where the risk of P movement to water is high, it may be important to maintain the level of P near the soil surface at very low levels. Mycorrhizal associations could be of great benefit in enhancing the ability of the crop to extract P from the soil and improve nutritional status of the crop."

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Producer Profile

Managing Mineralization

Research at Jim Halford's farm near Indian Head, Saskatchewan, shows the short- and long-term effects of no-till on soil organic carbon (SOC), mineralizable soil nutrients and crop yield. The research includes yield comparisons from varying rates of supplemental nitrogen (N) and phosphate.

Jim Halford

"The research shows that long-term no-till offers the potential of increased mineralization of soil nutrients from improved soil and, hence, the opportunity to reduce fertilizer rates," says Halford. "In the future, the potential savings on fertilizer inputs could be the next real benefit realized from adopting zero tillage. It will be of much greater interest if a pound of nitrogen or phosphorus costs $1 or more again, or if crop prices fall!"

Soil health

Researchers from the University of Saskatchewan and Agriculture and Agri-Food Canada (AAFC) analyzed soils on Halford's farm that have been in no-till for 12, 20 and 30 years. Some analyses include land tilled conventionally until its conversion to no-till in 2001. Also included is land seeded to brome-alfalfa in 2001. The AAFC on-farm field trials, coordinated by the Indian Head Research Farm, began in 2002.

The farm's topography is rolling, and the main soil type is Oxbow loam, comprising about 50 percent sand and 16 percent clay. In the past, the soil has had reduced water-holding capacity and has been subject to erosion. "Some fence lines were completely buried as a result of wind erosion in the 1930s," says Halford. "But no-till has virtually eliminated wind and water erosion."

Soil quality has improved as well. In fields under no-till management for the last 20 to 30 years, SOC has increased to about 90 percent of the amount found in native grass soils across the field even in spots with different topography suggesting the potential for better across-the-field uniformity in soil fertility after 30 years of no-till. "The soil organic carbon levels in conventional tilled soils were 50 to 70 percent of the estimated original soil organic carbon levels in unbroken native grass soils adjacent to the fields of study," says Halford.

This uniformity is not yet evident in Halford's fields in no-till for only eight years. In these once conventionally tilled fields, the level to gently sloping sites have SOC measuring 70 percent of native grass sites. The knolls in these short-term no-till fields have SOC that is 52 percent of native grass sites.

Fields growing brome-alfalfa for eight years after being conventionally tilled have 12 percent more SOC than fields annually cropped for eight years using no-till. The level areas of the hayfields have 83 percent the SOC of native grass sites, while the knolls have 63 percent.

Since soil organic matter is 58 percent SOC, the increased carbon levels indicate increased soil organic matter. "Before going into no-till, a lot of our land had degraded soils with only 2.5 to 3 percent organic matter," says Halford. "With our zero till system we pushed it back up to 5 percent. Its high quality organic matter in a form better prepared to release nutrients."

Nitrogen available

The increased organic matter contributes to increases in mineralizable N potentially available for crop uptake. Soil samples analyzed after 20 years of continuous no-till showed that level sites in no-till fields had mineralizable N of 131 pounds/acre, while level sites in conventional-till fields had 68 pounds. Knolls in no-till fields had 113 pounds of N/acre, while knolls in conventional-till fields had 62 pounds.

"Thus, an extra 50 to 63 pounds of nitrogen per acre were potentially available for the crop on the 20-year no-till fields than on the conventional-till fields," says Halford. "Using a value of 50 percent for nitrogen-use efficiency, this provides an extra 27 pounds/acre of available nitrogen for crops each year."

The mineralizable N explained yield differences. "In 2001 we started farming the adjacent land that had been conventionally farmed with a fallow-crop rotation for more than 100 years," he says. "In the first year we grew wheat crops on the previously conventionally tilled land and on our own long-term zero till fields, using the same no-till management and crop-input levels for both types of field histories. We produced 43 bushels per acre of 14.5 percent protein wheat on our long-term, no-till fields, while those previously conventional-till fields yielded only 23 bushels per acre with 13 percent protein."

The yield differences drew the interest of researchers, leading to the on-farm AAFC field trials running from 2002 to 2009. The trials evaluated yields resulting from five N rates applied to a wheat-canola rotation grown on long-term no-till fields converted in 1979 and short-term no-till fields converted in 2001. The fertilizer rates included N applied at 0, 27, 54, 81 and 108 pounds/acre. *(See Figure 1.)* Each plot received the same rate every year of the trial.

Figure 1

Table 3: AVERAGE YIELD OF WHEAT AND PROTEIN LEVEL FOR DIFFERENT RATES OF NITROGEN (3 year average)*

Nitrogen (lbs/acre)	Wheat Yields (bus/acre)		Protein Levels (%)	
	LTNT	STNT	LTNT	STNT
0	34.7	24.2	12.6	11.4
27	42.0	31.7	12.8	11.8
54	50.3	39.0	13.6	12.7
81	54.6	44.9	14.9	14.3
108	55.7	44.1	15.6	15.0

*2004 was omitted from the calculated averages due to severe frost in August

Because of mineralizable N in soils, the long-term no-till fields required 27 pounds/acre less additional N to produce yields similar to those in the short-term no-till fields receiving more fertilizer.

In the long-term no-till fields, 54 pounds/acre of additional N supported optimum yield and sufficient recycling of nutrients to the soil. Lower rates resulted in degradation in natural soil fertility. The long-term no-till sites receiving 0 and 27 pounds/acre of applied N, "had substantially lower wheat yields and protein in 2008 compared to 2002," says Halford. "This is due to the 'mining' of the soil, thereby lowering the mineralization potential of the soil due to nitrogen removal in the grain."

On both long-term and short-term no-till sites, N applied at 81 pounds/acre showed a yield increase of only 5 bushels/acre over the 54 pounds/acre N rate. Nitrogen applied at 108 pounds/acre showed a minimal yield increase on the long-term no-till sites and a decrease on the short-term no-till sites.

Fertility strategy

Based on the results of the field trials, Halford now applies a standard rate of 50 pounds/acre of supplemental N to the farm's long-term no-till fields seeded to cereal crops, and 80 pounds/acre to short-term no-till fields and fields with low-quality soils. The higher rate is intended to support continuing increases in soil quality.

This fertilization program results in average wheat yields of 30 to 55 bushels/acre across the farm. The area's average annual precipitation is 16.8 inches (427 millimeters).

At a supplemental N cost of 50 cents/pound, the 30-pound/acre difference between the high and low fertilization rates represents a cost savings of $15/acre for the land improved through long-term no-till.

When fertilizing canola fields, Halford applies the same rate of N to both long-term and short-term no-till fields. "Canola has a better response to nitrogen than wheat," he says. "At N rates of 81 and 108 pounds/acre, canola yields on the short-term no-till sites come close to the yields on the long-term sites." However, applying 108 pounds of N/acre gives a minimal yield advantage over the 81-pound rate.

Phosphorus

The research at Halford Farm also included treatments measuring crop response of a spring wheat/field pea rotation to five rates of phosphorus: 0, 10, 20, 30 and 40 pounds/acre. Both long-term and short-term no-till sites were included.

"On the long-term no-till site there was no yield benefit in the field pea or wheat from adding phosphorus in any of the six years of the trial," says Halford. On the short-term no-till site there was no benefit to adding phosphorus in the first two years of the trials. After the first two years, a definite deficiency of phosphorus was visible. Adding 10 to 20 pounds/acre of phosphorus provided yields equivalent to the 30- and 40-pound rates.

Restoration blueprint

Beyond showing crop response to varying levels of inputs, the AAFC trials at Halford Farm suggest management strategies for previously degraded land. Production systems scientist Guy Lafond of AAFC Indian Head Research Farm says, "One question we're trying to answer through this work is: If you take over a piece of land that's been managed poorly and has degraded soil quality, how do you bring it back to life? These studies give us some clues as to how we might do that."

"Maybe putting a lot of fertilizers on up front is not the way to do it," he notes. "You have to be aggressive with fertilizer, but not too aggressive."

The improving conditions on the farm's short-term no-till sites, building toward the stabilized soil health of the long-term no-till sites, suggests farmers might trust the healing work to time, coupled with low soil disturbance. "We learned that over a span of eight years we can make a tremendous improvement in soil quality by going to a one-pass [low-disturbance] system of seeding and fertilizing," says Lafond.

Yet not all no-till machinery yields the same results in soil improvement, says Halford. "The soil improvements recorded on our farm have been due to the Conserva Pak™ seeder, which we have used since 1983," he says. "With this seeder, a knife opener penetrates 3.5 to 4 inches deep in the soil and places the fertilizer. It fractures shallow tillage pans. The knife also lifts, rolls and mixes some soil each year. The seed opener then places seed 1.5 to 2 inches above and to the side of the fertilizer."

"With this system of no-till, we get optimum use of fertilizer, and the crop and machine work together to provide long-term soil improvements," he says.

– by Raylene Nickel

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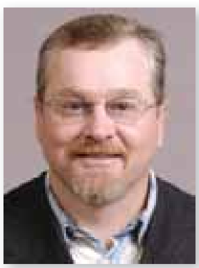
Biological Fertility



Ron Wiederholt

Applying biological nutrients to fields improves soil health besides providing fertility. Composted manure, for instance, increases soil organic matter and improves efficiency of a crop's use of nitrogen.

Researchers at North Dakota State University's Carrington Research Extension Center are conducting a long-term cropping systems trial to compare crop rotations, tillage and fertility treatments. The fertility treatments include an annual supply of 40 and 80 pounds of commercial nitrogen (N) per acre and composted beef feedlot manure at 40 pounds of N per acre. The tillage treatments include no-till, minimum-till and conventional-till.

"The no-till treatments receiving the manure supplying 40 pounds per acre of nitrogen annually yielded the same as the no-till treatments receiving 80 pounds per acre of commercial nitrogen annually," says Ron Wiederholt, the Center's nutrient management specialist.

"We're assuming that the increased efficiency of nitrogen use by the manure-treated crops results from the organic constituents manure contributes to soil, serving to increase organic matter," he says. "Soil organic matter levels in the manure-treated no-till plots were significantly higher than levels in the commercially fertilized plots. The added organic matter builds resiliency into soils so crops can maintain higher yields under adverse conditions."

Levels of soil nitrate in the manure-treated plots were significantly lower than in the plots receiving commercial nitrogen, suggesting a more efficient use of N by the crops fertilized with manure.

Soil pH was higher in the manure plots than in the commercially fertilized plots.

Water infiltration may have improved as well in plots receiving composted manure. "The manure produces an armor effect on soil," says Wiederholt. "Raindrops have less impact, and water infiltration is improved, even on no-till fields."

The area's average annual precipitation is 19 to 21 inches.

Applying manure

Composted manure applied to the soil surface releases nitrogen slowly, typically over a period of four years. Biological breakdown has already occurred, so the N tends to be stabilized. "Since excessive mineralization is not going on, the nitrogen tends to stay in the soil," says Wiederholt.

Application rates can be calculated from manure test samples showing N and P concentrations in composted or raw manure. When raw manure is applied to fields, 60 percent of the N is released in the first year, and the balance is released over the next two years. "With composted manure, about 25 percent of the total nitrogen is available in each year of a four-year period, with a small carryover into a fifth year," says Wiederholt.

Phosphorus and potassium are released more rapidly, even in composted manure. Seventy-five to 80 percent of these nutrients are released in the first year, with the remainder released in the second year.

Applying manure uniformly at rates matched to nutrient use by crops reduces the risk of building soil nutrients to the excessive levels leading to leaching and contamination of surface waters with N or P.

A related benefit of compost is its granular, soil-like texture, enabling a more uniform application than raw manure.

With composted manure and even with raw manure from beef wintering yards, the volatility of nutrients has stabilized, and this may lend flexibility to timing of manure applications.

"Timing is important," says Wiederholt. "The factors that should be considered include the crop species following the manure application and the environmental risk associated with fields receiving manure. Because most of the volatility has already taken place, in some cases fall applications of manure may be appropriate."

Nutrients in liquid manures have greater volatility. Injecting these beneath the soil surface with low-disturbance soil injectors places the manure where volatile nutrients are less subject to environmentally contaminating losses.

"When applying manure to no-till fields, be careful not to apply to areas where soils are channelized over bedrock," says Wiederholt. "In these places the ground water is typically near the surface, and surface moisture moving downward could carry manure particles into the ground water. A light surface tillage before applying manure could actually help seal these channels and reduce the chance for contamination."

As a rule of thumb, fertilizing with manure is more profitable than fertilizing with commercial N, he says, even in cases where yields are somewhat reduced.

Green manure

Growing green manure is another way of providing the soil with a biological source of fertility. "A full-season green-manure crop will satisfy all the nitrogen needs of the following crop," says plant scientist Martin Entz, University of Manitoba, Winnipeg.

Growing field peas, for instance, as a green-manure crop could yield 6,000 pounds/acre of dry matter. "About 2.5% of that would be considered fixed nitrogen added to the system," he says. "That would amount to 150 pounds of nitrogen. We have grown wheat crops yielding 60 bushels per acre on ground where we'd grown field peas as a green-manure crop the previous year."

However, the profitability of committing a full growing season to growing a green-manure crop sometimes falls in the red, says Entz. The economics improve when the cost of commercial N nears or surpasses 80 cents/pound.

Besides field peas, any legume such as sweet clover or hairy vetch makes a good candidate for green manure, as does a crop of oats and peas if grazing by livestock is to occur later in the season.

Green-manure crops not grazed can be terminated with a herbicide and mulched on the soil surface. Mulching or grazing should occur after flowering. "This gives the plants time to fix the maximum amount of nitrogen in the soil," says Entz.

Grazing a green-manure crop with livestock later in the growing season is a way to improve the profitability of the crop. The livestock will mulch some of the biomass by trampling it onto the soil surface. A large percentage of the nutrients they consume will be recycled and returned to the soil through manure and urine.

"Our work shows that animals consume between 40 and 60 percent of green manure through grazing," says Entz. "Assuming that 80% of the ingested nutrients are returned to the land through feces and urine when 50 percent of the forage is utilized, approximately 135 pounds of N will be returned to the land." This example assumes a pre-grazing green-manure yield of 6,000 pounds/acre of dry matter contributing 150 pounds of N/acre.

Short-season cover crops offer fertility as well. "These are less economically risky and can fit into a conventional no-till system," says Entz. "Planting a late-season legume after a crop of winter wheat is one option. We might be able to produce 500 to 1500 pounds per acre of biomass. If the plant mix includes 60 percent legumes, 2.5 percent of the biomass dry matter would be N fixed biologically in the soil, amounting to 13 to 38 pounds of N per acre."

Compost tea

Applying compost tea to soil or in a foliar application to plants offers yet another source of biological fertility. Making the tea requires steeping of composted manure in water.

"Adding a booster to the water helps extract valuable compounds like bacteria and fungi from the compost," says Wiederholt. "These multiply in the extract, and that is what makes the tea."

"When you put the tea on your field, you're adding beneficial bacteria and fungi that might have been missing from your soil," he says. "Adding these to the soil may improve long-term soil health."

Applying compost tea as a foliar treatment may potentially replace fungicide applications. "The foliar application of the compost tea coats the surfaces of plants and could reduce disease," says Wiederholt. The coating potentially acts as a physical blocking agent, preventing disease organisms from gaining access to surface tissues of plants.

The equipment needed to make compost tea is available commercially and is relatively simple and inexpensive. Field-scale applications require only a 10 to 20-gallon tank fitted with a pump.

Research is underway to evaluate the use of compost teas in the Northern Plains region.

– by Raylene Nickel

Chapter sources

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Carbon Management

Cropping Systems Capture Carbon

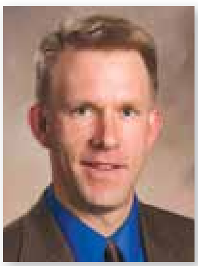
Inputting carbon into the soil through a cropping system that enables diverse plant growth will feed the microorganisms the balanced, diverse diet needed to drive the circle of life in soil and plant communities, yielding healthy soil and robust crops.

Ultimately, the feeding activity of the microorganisms leads to final-stage breakdown of plant material, resulting in the formation of organic matter and sequestering of some carbon from the atmosphere.

The most ideal diets for soil microorganisms contain a host of nutritional building blocks including elements such as nitrogen, phosphorus and sulfur. But, above all, the soil life requires carbon as a source of energy.

Roots and plant residue are major sources of carbon consumed by the soil life. Carbon molecules are building blocks of plant tissue and also account for about 58 percent of the makeup of soil organic matter.

The carbon cycle



Mark Liebig

The carbon cycle begins as plants take in carbon dioxide from the air. "The plants use the carbon to make roots, shoots and leaves," says soil scientist Mark Liebig, USDA Agricultural Research Service (ARS) Northern Great Plains Research Laboratory, Mandan, North Dakota. "That carbon can then be transferred to the soil via roots and residue as it decomposes. The decomposition involves the soil microbial community. Without the soil microbes, the residue would accumulate.

"The soil organisms use carbon from roots and residue as an energy source," he says. "By utilizing carbon, they themselves can create complex carbon compounds for incorporation into soil organic matter. Sometimes small pieces of roots and residue can get bound up in soil aggregates, and when that happens, they're less likely to be used as a carbon source by soil microbes. That's another way we can get carbon from the plant into the soil."

"Soil organic matter can be thought of as being comprised of different 'pools' or 'compartments' based on their relative decomposability," says Liebig. "One pool is very labile; it is easily decomposed. This is the pool that is always being worked on by the microorganisms."

The microorganisms also actively process a second pool of organic matter, though this pool is more resistant to decomposition than the first. The third pool is the most stable, the most resistant to break down. It accounts for about 85 percent of the organic matter in soil. "It takes a long time for changes in this stable pool of organic matter to show up in soil tests," says Liebig.

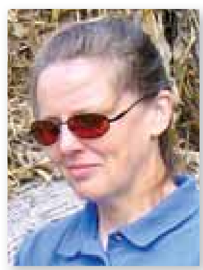
The labile pools of organic matter supply the microorganisms with essential nutrients. "They go after nitrogen, phosphorus and sulfur – whatever the limiting nutrients are – and they work through the carbon in the organic matter to get at other nutrients they might need," says Liebig.

Annually feeding the soil microorganisms an abundant, diverse source of plant roots and residue provides a diet of different carbon compounds that can contribute to labile soil organic matter and aggregate formation. With the soil organisms focusing their feeding activity on the current year's decomposing roots and plant residues, the pools of organic matter may be broken down more slowly. This gives opportunity for more of the material to enter the most stable pool of organic matter, where carbon can be sequestered in soil for the longest period of time.

Manage to input carbon

Providing the soil microorganisms a diet rich in plant and soil carbon requires management practices that put carbon into the soil and prevent it from being lost.

Underpinning these practices is this guiding rule of thumb: Roots are principal players in the process of inputting carbon and building soil organic matter.



Jane Johnson

"When it comes to making soil organic matter, the biggest contributor is the plant material that's below ground," says soil scientist Jane Johnson, USDA-ARS North Central Soil Conservation Research Laboratory, Morris, Minnesota. "Roots are more important than surface litter in the process of transferring plant material into the soil."

Because of the critical role roots play in adding carbon to soil, it follows that this process is most vigorous during the period when plants are actively growing. "In general, plants capture the most carbon during rapid vegetative growth up until they reach peak biomass," says Liebig. "That period is when the greatest amount of carbon is going into the soil via the roots."

Because of its lack of soil disturbance, no-till is among the management practices farmers can use to rebuild levels of carbon and organic matter in soil. "As you accumulate residue, it changes the community of soil organisms," says Liebig. "The fungal community increases, and fungi tend to be efficient in cycling carbon. Bacteria are usually more prevalent in tilled systems, and they tend to use nutrients and cycle carbon more quickly than fungi."

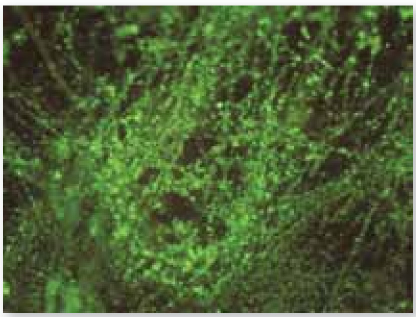
Fungi play a role

Indeed, fungi play a critical role in capturing carbon in the soil. "The fungi get carbon from the plant, and this is a way for the carbon to get into the soil," says soil microbiologist Kristine Nichols, USDA-ARS Northern Great Plains Research Laboratory.

"When the carbon is in the soil, the fungi use it to make glomalin, a glue-like substance," she says. "This glue helps plants obtain nutrients from the soil. The glomalin helps to make soil aggregates, and these aggregates give structure to the soil."

The aggregates enhance carbon sequestration because they help the soil organic matter resist decomposition, the process by which carbon is released into the air as carbon dioxide.

"Glomalin also puts a protective coating on the aggregates," says Nichols. "This keeps the aggregates stable when it rains, as opposed to falling apart and the organic matter and nutrients in the aggregates being susceptible to erosion.



"When aggregates fall apart, they release that organic matter and its carbon," she adds. "Through that process the carbon becomes decomposed into carbon dioxide that goes back up into the atmosphere."

Management systems where tillage is reduced or completely eliminated help the fungi maintain their soil network of fine threads. With these intact, the fungi continue to produce glomalin.

A study at the Northern Great Plains Research Laboratory showed how differences in cropping systems affect soil structure, glomalin and, ultimately, soil carbon.

Study results showed that soil from a spring wheat conventional tillage system had 14 percent water-stable aggregates with 2.4 milligrams of glomalin per gram of soil. The carbon in the top 3 inches of soil measured 6.6 tons/acre.

A no-till continuous cropping system of spring wheat/winter wheat/sunflowers had 47 percent water-stable aggregates with 3.2 milligrams/gram. The carbon in the no-till system measured 9.6 tons/acre.

A pasture managed under moderate but continuous grazing had 93 percent water-stable aggregates with 7.9 milligrams/gram. The carbon measured 12.8 tons/acre.

Yet variability in other research relating to carbon inputs tempers these findings, suggesting that factors such as geography, site-specific variables and management practices could play equally critical roles in carbon sequestration as does lack of tillage.

"Research done in the northwestern United States and in western Canada shows that, on average, converting from a tillage system to no-till continuous cropping added 240 pounds of carbon per acre per year, plus or minus 170 pounds per acre per year," says Johnson. "Similar research done in the Midwest showed that converting from conventional tillage to no-till added 360 pounds of carbon per acre per year, plus or minus 540 pounds per acre per year.

"That tells us that the variability is greater than the average," she adds. "We cannot precisely predict what's going to happen as a result of no-till in all locations. The reason no-till works particularly well in the Dakotas is because it conserves water."

Plant diverse crops

Besides reducing tillage, building soil carbon also requires planting diverse crops chosen for their effective contribution to the carbon cycle. "It's important to rotate crops in terms of root morphology," says Liebig. "Some plants have tap roots, while others have more fibrous roots, and still others have roots that are intermediate in morphology. Furthermore, different crops have different rooting depths."

The deeper-rooted plants translocate carbon into the deeper parts of the soil profile. Carbon captured at lower depths (below a foot) is less likely to mineralize and return to the atmosphere as carbon dioxide.

Shallower-rooted plants, on the other hand, concentrate carbon within the top 6 to 8 inches of the soil surface. It is possible for carbon captured this close to the surface to be easily mineralized by the microbes and released into the air as carbon dioxide.

Besides rooting depth, another plant trait affecting carbon fixing in the soil is a plant's root-to-shoot ratio. The more extensive a plant's root system relative to its above-ground plant material, the more effective it will be at inputting carbon into the soil.

Additionally, crop residues with a high carbon-to-nitrogen ratio, such as wheat straw, decompose slowly, thereby increasing the likelihood of carbon being retained.

Perennials and cover crops

Deep-rooted perennials have root systems efficient at inputting carbon, and they offer the added advantage of extending the period for capturing carbon. Because perennials begin growing early in the season and continue the process of photosynthesis into early fall, they "transfer more carbon into the soil relative to shorter-season crops," says Liebig.

Good choices for perennial crops depend on the region, but intermediate wheatgrass, switchgrass, alfalfa or sweet clover seem to work well in the Northern Plains of the US.

"Legumes also fix nitrogen and can have significant residual effects on nitrogen availability," says Liebig. "A study done in eastern North Dakota showed that the 'N effect' could be detected nine years after alfalfa. There's certainly a positive residual effect on available nitrogen after alfalfa."

Like raising perennials, planting cover crops is another way to lengthen the period of active photosynthesis that inputs carbon into the soil. "After producers harvest short-season crops such as wheat or peas, there may be an opportunity to plant cover crops," says Liebig. "Depending upon moisture and the number of temperature degree units left in the season, growing cover crops can extend the period of time that carbon can enter the soil."

Adding perennials and cover crops offers the option of grazing livestock and adding further carbon to the soil through manure. "The addition of manure to the system is a good use of recycled nutrients and may lower fertilizer rates for subsequent crops," he says.

Soil tests will measure increases in soil organic matter, of course, and these measured increases also indicate increases in soil organic carbon. But the effects of increased organic matter and carbon are also visible.

"Grab a shovel and dig a hole; look at the color of the soil, and feel its structure," suggests Liebig. "If the soil has poor structure and is light in color, but you return in three to five years to dig another hole in the same spot and find that the soil has taken on a granular, blocky structure and is dark brown in color with roots proliferating throughout the profile, you can be fairly certain carbon is being inputted into the soil. With time, you may see greater yields and use fewer inputs as a result."

– by Raylene Nickel

Soil Can Reduce Greenhouse Gases

Farmers' ability to manage soil through agricultural practices brings the debate over climate change right to the farm gate. There's little doubt farmers and ranchers are key participants in strategies devised to change climate for the better.

The three main greenhouse gases influenced by land management include carbon dioxide, methane and nitrous oxide. The term "global-warming potential" provides a relative comparison among greenhouse gases' ability to impact global warming. The global-warming potential of one unit of carbon dioxide is designated as 1. A unit of methane has a global-warming potential about 23 times that of every one unit of carbon dioxide, while nitrous oxide's global-warming potential is about 300 times that of carbon dioxide.

Through its energy consumption, agriculture contributes to greenhouse gas emissions, primarily carbon dioxide. Increasing energy efficiency in production methods by decreasing use of fossil fuels and synthetic nitrogen fertilizers can reduce this direct contribution.

Agriculture can also positively impact the net balance of emissions through producers' crop-management practices.

Carbon and carbon dioxide

Soil and plants hold the key to positive change because plants mediate carbon between carbon dioxide in the atmosphere and carbon sequestered in soil organic matter.

Because carbon molecules are the building blocks of plant tissue, the plants draw carbon dioxide from the air as they grow. As the soil microorganisms break down the plants' roots and residue, some of the material contributes to the soil's pool of organic matter, which comprises about 58 percent carbon.

The sum effect of this process is the storing, or sequestering, of carbon in the soil organic matter. As organic matter breaks down by microbial decomposition, the carbon is released into the air as carbon dioxide.

To maintain a balance in the plant-soil ecosystem, as much soil carbon must be sequestered through plant life as is lost from the breakdown of organic matter in soil as a result of agricultural and natural processes.

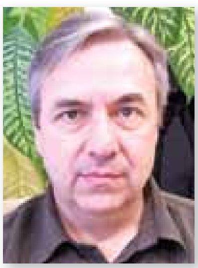
"For about the last 300 years globally, there has been more carbon released into the atmosphere than the plants are able to take up from the atmosphere," says USDA-ARS soil scientist Jane Johnson.

Much of this imbalance results from the burning of fossil fuels refined from the carbon stored in the earth.

But in North America, another major contributor to carbon loss was the conversion of the massive prairie regions from a perennial ecosystem to a tilled, annual-cropping system.

"After the Civil War, vast expanses of prairie were plowed under and turned into fields of annual crops," says Johnson. "It was a major change in land use. With the plowing, a large amount of carbon came out of the soil, where it had been stored, and was released into the atmosphere as carbon dioxide. Multiple studies estimate that 20 to 70 percent of the prairie soil's organic matter was lost."

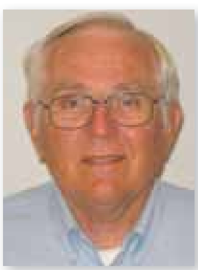
Nitrous oxide



Reynald Lemke

Besides causing losses of carbon dioxide into the atmosphere, the breakdown of organic matter can also lead to the release of nitrous oxide into the air. This loss is linked to the nitrogen component of organic matter.

"Along with carbon, nitrogen is an important building block of organic matter," says soil scientist Reynald Lemke, Agriculture and Agri-Food Canada, Saskatoon, Saskatchewan. "For every 10 units of carbon in organic matter, there is one unit of nitrogen. If soil loses organic matter, carbon dioxide is released into the air, and some of the nitrogen will be released as nitrous oxide."



Don Reicosky

In the Northern Great Plains, reduced tillage systems can result in overall reductions in nitrous oxide emissions, says Lemke. But this does not hold true for all geographical locations.

"No-till systems in eastern Canada may actually see an increase in nitrous oxide emissions," he notes. "We don't fully understand why we see this difference, but the soil-water regime is a factor. Rainfall is much higher in this region, and soils tend to be wetter longer, a factor contributing to emissions of nitrous oxide."

Nitrogen fertilizers increase the risk for nitrous oxide emissions. "Any form of nitrogen in the soil can be processed by the microbes and released as nitrous oxide, and this loss increases under wet conditions," says soil scientist Don Reicosky, USDA-ARS North Central Soil Conservation Research Laboratory, Morris, Minnesota.

Studies in Alberta and the subarctic region of Alaska have shown that nitrogen fertilization under dryland conditions increased nitrous oxide emissions from 40 to 300 percent.

Minimizing fall applications of nitrogen is one way to reduce these emissions. "In spring, when soil thaws, there can be a lot of nitrous oxide emitted, especially in fields where nitrogen was applied the previous fall," says Reicosky. "We need to figure out how to better manage fertilization."

Nitrous oxide emissions can also result from applying manure to fields, but manure's organic composition tends to produce these emissions at a lower rate than inorganic nitrogen fertilizers.

Methane

The role crop production plays in mitigating methane emissions is relatively small compared to its potential role in reducing emissions of carbon dioxide or nitrous oxide, says Lemke. "But given the large land area under agricultural production, even a small influence relating to methane is of interest," he adds.

Microbes in agricultural soils both consume and produce methane. "For most agricultural soils in the Northern Great Plains, consumption exceeds production, helping to reduce the concentration of atmospheric methane," he says.

Dryland cropping systems in semiarid regions may serve as a sink for atmospheric methane, but their effectiveness depends upon farming practices. Native prairie serves as the most effective sink for methane. One study suggests that the conversion of native vegetation to cropping may reduce soil's methane uptake by half.

A Nebraska study showed a difference, too, in methane uptake between soils in grass sod, no-till and moldboard plowing. The no-till system had a methane-uptake rate of 11 percent less than the uptake rate for grass sod. Moldboard plowing reduced the rate of methane uptake by 22 percent as compared to grass sod. Fertilization with nitrogen also tended to depress the rate of methane uptake.

Aside from consuming methane, soils may also produce it. "Soils can emit methane from poorly drained sites, such as low spots in fields where water tends to pond," says Lemke. "Larger areas of the field may briefly emit methane after a heavy rainfall."

Since saturated soils contribute to emissions of both methane and nitrous oxide, any cropping practices improving water infiltration will reduce emissions of these greenhouse gases. Reduced use of tillage and ammonia-based fertilizers will further contribute to retention of methane in soils.

The role of organic matter

Overall, building soil organic matter can decrease emissions from all three greenhouse gases. As organic matter forms, it stores carbon from decomposing plant material, sequestering it from release into the atmosphere as carbon dioxide. This process also ties up nitrogen, minimizing the risk for nitrous oxide emissions.

"If you're building organic matter, you tend to be reducing greenhouse gases," says Lemke. "More indirect benefits result from improvements in soil structure and better water-holding capacity of the soil."

The ideal amount of organic matter is finite, varying by site and depending upon climate and geography. Undisturbed native range in a specific locale can be used as a telling yardstick of an individual site's upper limit for organic matter content. This native capacity varies widely, but as a rule of thumb might range from 5 to 8 percent across the Northern Plains region.

– by Raylene Nickel

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Producer Profile

Managing Residue for Nutrients

Bill and Laurie Kuehn

Bill and Laurie Kuehn, Turtle Lake, North Dakota, started no-tilling in 1993, and every year they've returned as much carbon as possible to the soil through crop residue.

"Our goal is to leave crop residue undisturbed," says Bill Kuehn. "The microorganisms break it down, and over time it blends into the soil. It contributes to soil carbon and increases organic matter. The higher the level of organic matter, the greater the recycling of nutrients for use by subsequent crops. We have found that once this system of recycling is in motion and stabilized, we are able to grow better and healthier crops with fewer inputs."

The high yields and high protein levels of the Kuehns' spring wheat in 2009 illustrate the resiliency of their soil system resulting from increased natural fertility. In spring of 2009 they fertilized for a wheat yield of 50 to 60 bushels/acre. But optimum growing conditions contributed to actual yields of more than 80 bushels/acre.

While wheat yields across the state were generally high in the fall of 2009, the Kuehns' crop stands out because of its high protein content. In 2009 reports of North Dakota farmers harvesting spring wheat at 9% protein were commonplace. But the protein of the Kuehns' wheat ran from 14.8 to 14.9 percent.

"Without healthy, living soil, I don't believe we would have harvested wheat with such high yields and high protein," says Kuehn.

Soil fertility

Post-harvest soil tests reflected the bumper crop's high use of nutrients, and Kuehn plans to increase the fertilization rate in 2010 to restore balance to the nutrient cycle.

The increased rate is a short-term exception to the rule. "Given our soil organic matter and the nutrient cycling occurring at a faster rate, we can usually get by with applying fewer synthetic nutrients," he says.

Improvements in soil quality resulting from their no-till system are most evident to the Kuehns when land previously managed in a conventional-till system first comes under their management.

"The fields that have been in no-till for a longer period of time have ground that is mellow, and the surface has a thick thatch of residue," says Kuehn. "The fields just being converted to no-till have soil that is harder, and it compacts more easily. It's evident the soil requires a higher fertilization rate. It takes at least five years for the soil structure to show improvements resulting from no-till."

Uniform cover

Managing harvest residues effectively is key to getting the most efficient cycling and uniform release of nutrients across fields. "It's important to have a good chopper and spreader on the combine so crop residue is spread evenly across the soil surface," says Kuehn.

The most uniform spreading of residue results from matching the width of the combine header to the width of the chopper's spreading pattern. This prevents strips of thin residue cover between the combine's passes around a field.

Wherever these strips occur, the soil temperature changes, resulting in an uneven crop the following year and eventually, differences in soil organic matter and uneven cycling of nutrients across fields.

Trash flow through a seeder also impacts uniformity of residue distribution. If trash flow is poor, the seeder might drag residue and redistribute it unevenly across a field.

Diverse rotation

Rotation plays a role, too, in effective residue management. "Rather than growing a monoculture, we grow four types of crops in the rotation," says Kuehn. Enhanced crop health results in robust plant growth, which creates more residue to return to the soil.

"The diverse crops complement each other in residue breakdown," he adds. "They provide a diverse diet for the soil microorganisms. The more you feed them, the more active they are."

The rotation includes grass crops as well as broad-leaved crops. He grows two years of cool-season grasses such as winter wheat, spring wheat and durum. In some fields he follows this sequence with corn, a warm-season grass. Next, he grows two years of a broad-leaved crop such as canola, peas or sunflowers, and in troublesome fields follows this sequence with flax, a crop that can withstand most broadleaf diseases.

This diverse rotation, combined with the residue thatch at the soil surface, discourages weed growth. "By having a lot of crop residue lying on the surface and then by making just a small slit for seed placement, the crop has a competitive advantage," says Kuehn. "The crop gets up and growing and chokes out the few weeds that do try to get started."

He uses less herbicide as a result, applying it at rates of 25 to 75 percent of the labeled rates.

"Plants that are big and healthy not only produce a lot of residue, they also compete well with weeds and bugs," he says.

– by Raylene Nickel

Chapter sources

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Equipment

Choose Equipment to Match Goals

Alan Ness

Effective no-till production systems require field equipment capable of performing critical tasks reliably. "Your line of equipment should let you seed and fertilize into a fairly firm seedbed and enable you to apply pesticides and herbicides with accuracy," says no-till farmer Alan Ness, Underwood, North Dakota. "You also need equipment that lets you spread harvest residues evenly across fields."

During his 30-year career as a no-till producer and throughout his longtime service as executive secretary of the Manitoba-North Dakota Zero Tillage Farmers Association, Ness has seen an ongoing evolution in no-till equipment. Navigating the changes in equipment design and choosing mechanical tools wisely is a continuing challenge for producers, he says, but keeping in view the overarching purpose of ideal no-till management can guide the selection process.

Minimizing soil disturbance and providing a covering for the soil are the critical goals. "By cutting down on soil disturbance and by keeping the earth covered with residue, you'll have less moisture evaporating from the soil," says Ness. "When you have less soil disturbance, you're also helping the biological life in the soil by not disturbing it."

Opener design

Variations in the design of no-till seeding equipment produce differences in soil disturbance. Hoe openers, often called knife openers, serve to expose a narrow band of soil during seeding. Thus, they disturb more soil than do the disc openers, which simply cut through the residue and into the soil.

But each of the designs has their place, and differences in producers' soil types and growing seasons determine which is best adapted to a particular farm's production system.

Ness uses a seeder with a single disc opener because of the moisture-conserving benefit. "My crops tend to come up a little slower, but their growth seems to persist even if the weather turns dry," he says. "But many producers

farming farther north prefer using knife openers. In regions with shorter, cooler growing seasons, the exposing of a narrow strip of earth in the seeding process lets the soil warm up faster. This encourages quicker germination of seed."

Using seeding equipment that also has the capability to band fertilizer next to the seed is optimal. "When the source of fertility is close to the seed, it's readily available to the plant once it starts growing," says Ness. "If the plant's roots have to reach a distance through the soil in order to get to the fertilizer, it's harder for the seedlings than when the fertilizer is placed right next to where the seed germinates."

Spreading pattern

When harvesting crops, it's ideal to have harvesting equipment that can spread residues uniformly across fields. Ideally, the chaff spreader on the combine should have the capability to spread chaff and straw in a distribution pattern as wide as the combine header. This ensures an even distribution of residue across the field, allowing for uniform soil and growing conditions for the subsequent crop.

When the spreading width of the combine spreader is narrower than the header, the residue creates a swath-like effect across the field, leaving heavy ribbons of residue alternating with strips of uncovered ground.

"This can lead to uneven germination of the crop the following spring and encourages the germination of weed seeds," says Ness. "If weed seeds contained in the residue are concentrated in a thick mat, it's easy for them to stay wet long enough to germinate. When the seeds are spread in a thinner layer across the surface, they tend to decompose before germinating."

Newer models of combines often have the capability for wide distribution of chaff and straw from the back of the machine. But older models are more challenged, and some independent companies manufacture add-on spreaders to widen the spreading pattern of a combine.

Intentionally matching header width to width of the spreading pattern is another option. "I harvest with a 1994 model combine with a 25-foot header," says Ness. "That's as wide as the combine spreads the chaff."

The narrower header lets Ness combine at a higher groundspeed than he might with a wider header. The higher speed compensates for the narrower cutting width, letting him harvest as many acres in a day as he might by taking a wider cut.

"Overall, selecting equipment that lets you cut down on soil disturbance and spread chaff uniformly is important, not only because it conserves soil moisture but also because it helps improve soil quality," he says.

– by Raylene Nickel

A Comparison of Seed Openers

A Saskatchewan study of no-till seeding equipment evaluated the performance of four types of seed openers. The study's leader, conservation agrologist Eric Oliver, evaluated the openers' effect on soil, weed populations and crop establishment. The study also evaluated the performance of a diverse rotation given differing levels of soil disturbance. Oliver conducted the study for the Saskatchewan Soil Conservation Association.

The four-year study was conducted near Aneroid, Saskatchewan, in the Dry Brown Soil Zone on sandy-loam soil. The study evaluated four commercially available single-shoot openers producing increasing levels of soil disturbance. The four openers included a Barton Generation 1 angle disc, a .75-inch knife, a 2.25-inch spoon and a 12-inch sweep. The four openers were used with field-scale equipment to seed Kyle durum, Delta field peas, Harrington barley and Myles desi chickpeas in a four-year rotation that followed a cereal/broadleaf rotation.

The four crops were seeded side by side with all four openers seeding each crop. The plots were replicated four times for statistical accuracy. Although the crops were in a rotation between the plots, the openers were not. In other words, a specific opener seeded a particular plot for the entire four years of the study, permitting comparisons between weed densities and yields. The study also included glyphosate burnoff as a variable.

"Overall, the low-disturbance discs are a good option for producers in the brown soils, and in many areas of the dark-brown soils," Oliver notes. "But the discs can have problems in dry soil conditions with very stony land. There are pros and cons with any opener. As the level of soil disturbance decreases, the importance of pre-seed burnoff increases."

"I always caution producers that while low-disturbance discs are very effective in the dry brown and brown soils – and usually also in the dark-brown soils – other agronomic and environmental issues occur in the Black soil zone," he adds. "The discs can work very well, but the single-shoot types always have a problem with being able to place with the seed enough of the nitrogen fertilizer that the crop requires."

Overall, the study found that the angle disc was most effective in controlling weeds and produced good yields. The knife opener came close to those results over the last two years of the study. For more information visit www.ssca.ca/agronomics/pdfs/doubleshoot.pdf.

– by Bill Armstrong

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Selecting Spray Equipment

Sprayer technology is one of the fastest-changing areas in the agricultural machinery world. This provides producers more options for doing an effective job, but it also increases the complexity of choosing equipment.

Tom Wolf

"Before you make a sprayer change, think about what you're trying to accomplish and how your current sprayer is meeting those goals," says Tom Wolf, research scientist with Agriculture and Agri-Food Canada (AAFC) Saskatoon (Saskatchewan) Research Centre.

Often, he notes, design and marketing of new sprayers does not focus on an individual producer's needs. Careful scrutiny of each machine is needed to determine whether or not it's a good fit for an individual's operation.

The major features to consider, Wolf suggests, are tank capacity, time spent filling the sprayer, ease of cleaning, automatic boom height and level, navigation capability using GPS guidance, spray pressure range and pressure drop along the boom, ability to monitor nozzle flow, sprayer weight and nozzle technology.

A key consideration relating to nozzle design it to make sure the nozzle's pressure capabilities match potential fluctuations in groundspeed. For example, a doubling of groundspeed requires a quadrupling of spray pressure, he notes.

"Make sure you obtain nozzles that produce acceptable patterns over your expected pressure range and be aware of changes in droplet size that accompany these changes," he writes. "Most air-induced nozzles, while requiring overall higher pressures, maintain larger and more consistent droplet sizes over a wide pressure range, [when compared to] conventional nozzles."

The four common types of nozzle include conventional flat fan, pre-orifice, low-pressure air-induced and high-pressure air-induced.

If you're looking for better drift control, Wolf suggests the latter three. Nozzles with the best pressure range are the pre-orifice and low-pressure air-induced nozzles. If you're looking for nozzles with very low water volumes, the flat fan and pre-orifice types work best. All nozzles will give good results provided you use them properly, he adds.

Water volume

The coarser the spray, the higher the water volume must be. There are two main reasons for this, Wolf writes. First, you must have enough droplets per square centimeter to hit your target. This is most critical for pre-seed burnoff where weeds are smallest, and low-volume, very coarse sprays will likely miss weeds entirely. Second, you need sufficient coverage on the target pest for the pesticide or herbicide to do its job.

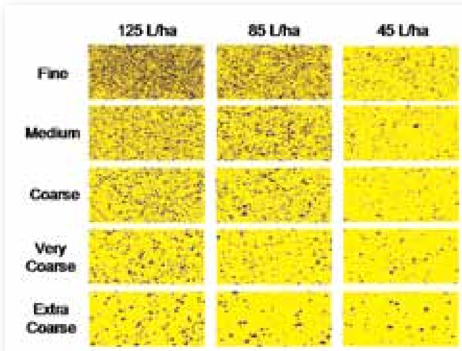
"This is most important for contact herbicides such as bromoxynil, glufosinate and diquat, and for insecticides and protective fungicides," Wolf writes. "It is also important for grassy weeds, most of which have a hard time retaining very large droplets. Use at least 5 to 7 gpa for in-crop herbicides; 10 to 12 gpa for fungicides. The taller your crop canopy, the more water is required."

Pressure

Air-induced and some pre-orifice nozzles require higher pressures to operate properly, Wolf notes. When the spray pressure of a low-drift nozzle is too low, poor spray distribution between nozzles can result.

He recommends spraying at these pressures for the various nozzle designs: conventional, 20 to 50 psi; pre-orifice, 30 to 60 psi; low-pressure air-induced, 40 to 60 psi; and high-pressure air-induced, 60 to 80 psi. "Higher pressures increase drift potential, but less so for pre-orifice and air-induced nozzles," says Wolf.

Ensure good patterns



Finer sprays from conventional nozzles can be re-distributed by wind or turbulence, but the coarser droplets produced by low-drift sprays will go where they're directed. That means you have only one chance to get uniform coverage across the boom, Wolf says.

For coarse sprays he suggests achieving a nozzle pattern width that is twice your nozzle spacing at the target height. To do this, select wider-angle nozzles, increasing pressure or adjusting the boom height. This will ensure that the coarsest droplets at the pattern edge are mixed in with the more abundant finer droplets found in the middle of the pattern.

Variable-rate spraying

The ability to change travel speed while maintaining good sprayer performance is important. Maintaining rate control with sprayer nozzles is difficult because pressure changes usually have dramatic effects on droplet size and pattern uniformity. This becomes critical at faster travel speeds, Wolf notes.

"One way to measure consistency is with droplet size," he writes. "We now use a standardized way to describe droplet size – very fine, fine, medium, coarse, very coarse and extremely coarse. The spray quality of application can have a strong effect on pest control."

The major nozzle manufacturers publish information about spray quality in their catalogues, which are available online or from retailers. Spray quality can range from extremely coarse to coarse for some low-drift nozzles and from very coarse to medium for others, depending on the pressure.

"Hydraulic nozzles do not have a good flow rate response to pressure," Wolf notes. "To double the flow rate you need to quadruple the pressure. However, pressure has significant effects on spray quality. If you require a specific spray quality for reasons of effectiveness or spray drift, this limits the range of pressures and travel speeds you can use."

– by Bill Armstrong

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Working in Wet Soil

Wet soil conditions can challenge no-till planting operations, but adaptations to seeders and tractors can help equipment accomplish the work.

Dwayne Beck

High-volume tires, for instance, are better able to transport equipment under wet working conditions. "This means tires that can carry the weight of the machine or the tractor at operating pressures of 6 to 10 psi," notes Dwayne Beck, research agronomist and farm manager, South Dakota State University (SDSU) Dakota Lakes Research Farm, Pierre, South Dakota.

"Most producers have tractors that come close to this," he says, "but they are pulling seeders with small frame tires and tank tires operating at high pressures. When these drop through the surface, everything stops.

"One way to handle wet situations is to simply not fill the tanks full," he suggests. "This allows lower tire pressure on the tank wheels. The seeder frame can still be an issue. Hopefully, you have the flotation option. Machines with tracks have good flotation capability. They are more expensive, but they have more rolling resistance than high-volume tires."

Seeder design

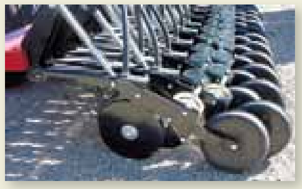
Low-disturbance seeders handle wet conditions better than those that move more soil. It is important to keep down-pressure at a minimum when it is wet, Beck writes. In addition, the units on these machines must be properly set. Special attention should be given to adjusting the depth gauge/wiper wheels so they contact the blade. These wheels are designed to hold the soil in place as the opener blade exits the soil, he explains. If there is a gap between the blade the wheel, mud will be able to follow the blade around.

Any disc opener (seed, side-band fertilizer or mid-row band fertilizer) not equipped with a wiper wheel will not function well in wet soils. In South America, the depth/wiper wheels

Soil disturbance

– by Roger Ashley

Generally, reducing the amount of soil disturbance during crop production lowers carbon losses from soil. The Natural Resources Conservation Service (NRCS) has developed a Soil Tillage Intensity Rating (STIR), which assigns a numerical value to each tillage operation. Crop management decisions implemented for a particular field affect the rating value. Lower numbers indicate less overall disturbance to the soil layer. STIR ratings are affected by crop rotation and sequence, travel speed of openers, and soil physical characteristics. Soil surface disturbance may be the same for two different openers, for example a hoe opener in heavy residue and a double disc opener (65%), but may have a significantly different STIR rating (16.9 vs 6.33) as STIR rating incorporates surface disturbance as well as subsurface disturbance.



Disc openers on seeders generally cause less soil disturbance and maintain more residue on the soil surface, resulting in less soil temperature change, less soil erosion potential and a greater potential to conserve existing soil moisture, compared with hoe openers. Hoe openers generally cause more soil disturbance than disc openers by partially burying straw and bringing soil to the surface. Narrow points cause less soil disturbance than a wide hoe. Disturbed soil exposed to solar radiation will warm sooner than undisturbed soil, but it also will cool faster. Combination disk-tine opener, is a design that integrates disc and hoe features, causes less soil disturbance than a single disc opener. As technology advances expect to see problems associated with older designs to be resolved.

Low-disturbance, angle discs on seeders have shown significant advantages in both wet and dry conditions in reducing weed germination. Increasing soil disturbance increased completion from weeds and decreased crop density. Weed seeds left on the soil surface are exposed to predation and environmental extremes, resulting in fewer viable seeds to germinate and infest the next crop. When low-disturbance no-till is used in combination with diverse crop rotations and appropriately selected and timed herbicide application, weed control costs can be reduced by 50 percent because lower weed density reduces the need for herbicides.

For more information on STIR visit a USDA-NRCS field office or http://stir.nrcs.usda.gov.

are constructed using a spoked wheel design, or at least a slotted wheel. This allows mud to escape from the area between the blade and the wheel when conditions get wet.

Once the slot is cut and the seed placed in the slot, the duties of pressing the seed into the soil and covering it remain, he continues. Seed pressing in wet conditions takes much less pressure than when soils are dry. A properly designed disc seeder has a narrow vertical wheel running in the slot. The spring tension on this wheel should be set at the minimum setting. If the seed press wheel is too wide or too much pressure is used, mud will follow the wheel around, causing plugging.

Closing the slots used to be one of the most difficult task, Beck notes. However, there are now short-line manufacturers making wheels designed to close trenches on very wet soils. These are standard equipment in South America, where no-tilling into clay soils under wet conditions is common. "Some of the best designs are homemade," he adds. "The idea is to perform just a little tillage right on the edge of the trench."

Management options

Seeding with a disc seeder during the night and early mornings on days when the soil freezes at night offers a way to work around excessively wet soil conditions, says Beck.

Broadcast seeding presents another alternative.

Because wet soils occur mostly in early spring, using fall-seeded crops lets producers avoid the problem. Similarly, dormant seeding crops after soil temperatures drop in late fall has potential. These options are particularly helpful for rotation sequences where large amounts of surface residue are present or where soils are shallow and heavy textured.

Late-seeded crops like sunflower, millet, buckwheat, beans, forage sorghums and corn are helpful because they provide more time for soils to drain and dry out. This is especially true if winter-annual cover crops are used, notes Beck.

The best solution is to prevent the problem as much as possible by using crop rotations with adequate intensity. These offer the added benefit of helping to improve soil structure. Soils with good structure and intact macropores are less likely to become excessively wet.

– by Bill Armstrong

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Producer Profile

Evolving Into Precision Ag

Darren Whetter

Darren Whetter farms with his father, Rod, on about 2,600 acres near Hartney, in southwestern Manitoba. Their first step into precision farming came in 2002 with the addition of a Trimble guidance light bar to the tractor, to assist in spraying with a pull-type sprayer. They had changed their air drill size so that it no longer matched up to the sprayer for tramlines. Their choices were to use disc or foam makers or start using GPS guidance.

"It seemed like a lot of money to invest at the time," Darren Whetter recalls, "but we quickly recognized the payback with the ease of operation and the reduced fatigue factor."

Next, in 2006 the Whetters purchased a John Deere Autotrac™, which steers the tractor, using GPS guidance, primarily for seeding. This system virtually eliminates overlap on seeding, fertilizing and spraying, creating both economic and environmental benefits for the farm.

"We could easily move the Autotrac system from one piece of equipment to another, so we used it in the combine for straight cutting," says Whetter. "Again, it maximized efficiency in the cutting width and reduced operator fatigue. Dad really appreciated this feature!"

Creating yield maps

The following year the Whetters added John Deere Apex™ farm software, which allows them to record their field operations and produce yield maps. By this time most combines had yield monitors, says Whetter, but until they could use the monitors to produce yield maps, "they were just something to look at in the cab," he says. "The mapping software gives you valuable information on crop production from soil fertility, soil type, moisture, crop varieties or pesticide applications throughout the field."

Armed with information from yield mapping, soil tests and satellite imagery, the Whetters tried some variable-rate fertilizer application. They purchased a rate controller for their liquid fertilizer system on their air drill. Using the same software, they were able to make prescription maps to apply the variable-rate fertilizer.

"I worked with a local agronomist to determine field zones and application rates to correspond with the yield goals we aimed for," Whetter says. "So far, we have only varied the nitrogen rate because of equipment limitations. It has allowed us to retain close to normal application rates, but placed in different areas of the field,

depending on productivity. The total amount of nitrogen used is the same, but it is used more efficiently within the field. And, we've now had successful crops for two years using this method."

Technology has advanced rapidly over the last 10 years, Whetter notes, and producers can look forward to further advanced practices – such as seeding between stubble rows, strip tillage, RTK guidance, automatic sprayer boom control and variable-rate pesticide applications – becoming more common.

"The information about all of the equipment options can be overwhelming, so each producer needs to recognize what will benefit them most," he advises.

– by Bill Armstrong

Producer Profile

Learning Equipment Needs


Mike Zook

Mike Zook's mantra is, "Residue is your friend!" Experience has shown him the soil-saving benefits of residue, and from trial and error he's learned what no-till equipment best fits his needs.

Zook farmed with his father near Beach, North Dakota, back in the 1980s, and he got tired of watching their land blow and wash away. On a windy spring day he would get a "horrible, wrenching feeling" driving by fields where he could barely see because of soil blowing in the wind. "That was the primary reason for trying no-till; anything more than that was a bonus," he says.

Zook and his father were cooperators in the local soil conservation district, and in 1982 they used a Haybuster 1206 disc drill to seed hard red spring wheat into wheat stubble. "It did not blow, and I was hooked," Zook recalls.

However, the experience also showed that they were not prepared for residue management. He finished seeding the second field after a short rain shower and added a new word to his vocabulary – hairpinning.

For their second season Zook and his father bought a Concord air drill and added a residue/chopper spreader to their combine. To this day, says Zook, the Straw Storm was one of the best spreaders he's ever seen.

In 1987, Zook leased 3,000 acres to farm on his own, and he continued to experiment. He and his wife, Leah, bought a 280-horsepower tractor, a truck, a sprayer, a 24-foot Haybuster hoe drill, a combine, a 30-foot header and pickup header. He quickly replaced the 30-foot header with a smaller one that allowed the straw and chaff spreader to do a better job of spreading the residue.

Modifications

He switched from the high-disturbance hoe drill because it made the field too rough and caused too much soil disturbance. He found a single disc opener system that he still uses today, modifying the openers to make them more effective. Adding Seed-Lok™ wheels that fit the seed slot has been the most effective modification, he says.

Zook also removed the cast iron smearing-crusting wheel with spoke closing wheels that collapse the sidewall. He added spring shims on the openers that run directly in the wheel tracks, and he has used air brakes just above the openers to eliminate seed bounce. He suggests to pulse growers that they add a plastic seedliner to the tower lids to minimize seed damage.

While he was experimenting with seeding equipment, Zook was tackling residue-management problems with different attachments to his combine, and with different crop rotations. He estimates he must have tried 20 different attachments on the combine.

"After much frustration and time and money, we tried a stripper header and finally found the solution to that problem," he says. "That was in 1998. We tried to go to a wide draper head, but within three rounds my operators were back in the yard because they know they can't seed into poorly spread residue. They insist on using the stripper header."

The stripper header also leaves taller stubble that catches more snow. In addition, the stripped stubble supports the parasites that attack the wheat stem sawfly. Another benefit, Zook notes, is the increasing abundance of wildlife on his fields, a welcome indicator of the improving overall health of his farm.

"In my lifetime there has never been so much wildlife; if you build it they will come," he says.

A shift in rotations

Zook's first rotation was wheat on wheat on winter wheat, what he refers to as the "cide" rotation. "I called it that because you needed a lot of herbicide, fungicide and insecticide, and then you felt like suicide, since you created the perfect environment for cheatgrass, wild oats, leaf disease, wheat stem sawfly and root," he says. "By incorporating high- and low-residue crops we were able to keep our residue manageable. As the biology returned to our soils, maintaining enough residues became our problem; we had to rethink our rotations to maintain enough surface cover."

Zook considers record keeping a component of his equipment arsenal. In years when there is good fall moisture and snow catch he will adjust his cropping patterns on those fields with stripped stubble, and either collect the reward or pay the price, as he puts it. He does a moisture profile on every field in the fall to see how much plant-available water is there. Combined with projected snow and growing season precipitation, he takes "a good stab" at yield goals for the coming season.

"We use Apex™ farm management software and keep detailed records of every operation on this farm, with history dating back to the first year we farmed each field," he says.

Zook is optimistic about agriculture's opportunities. "Young producers have good reason to be excited about the

Continued on page 58 ▸▸

Pest Management

Integrate Practices to Control Pests

Randy Anderson

Growing competitive crop rotations and employing other creative cultural management practices go a long way toward reducing problems associated with weeds, insects and crop diseases. Indeed, using a multifaceted, integrated strategy to manage pests can pay off in increased yields and reduced need for herbicides.

"Designing no-till rotations in a cycle of four with a diversity of crops doubles land productivity, increases net returns fourfold, and reduces cost of weed management 50 percent compared with conventional systems," says Randy Anderson, agronomist at the USDA Agricultural Research Service (ARS) North Central Agricultural Research Laboratory, Brookings, South Dakota.

"Growing crops in cycles of four is effective as well in reducing crop diseases," he says. "For example, if we grow winter wheat once every four years as opposed to once every two years, we can increase the yield by nearly 20 percent with the same level of inputs, because of reduced incidence of disease."

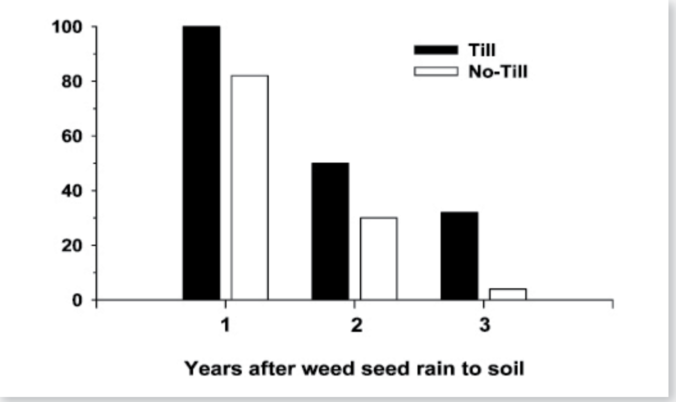
Integrated pest management

Anderson's system of IPM, or integrated pest management, centers on five key management practices. When all five are woven into a long-term management matrix, populations of plants, insects and soil life live in a dynamic state of flux discouraging the invasion of pests into the system.

The five critical management elements include rotation design, diversity within the life cycle of crops, no-till, crop residues on the soil surface, and competitive crop canopies. *(See Figure 1.)*

Putting the five to work in a unified whole-systems approach to management is key to realizing the benefits of reduced weed, insect and disease problems and cost-savings from reduced herbicide use. Working together, the five management elements exert a synergistic control of pests.

Figure 1



Five components of a prevention approach to reduce weed community density in the semiarid steppe of the United States. The 2 : 2 designation refers to rotations comprised of two cool-season crops followed by two warm-season crops. Cultural tactics in each component disrupt weed population dynamics by minimizing weed seed survival in soil (seed bank), seedling establishment, or seed production.

In the control of weeds, for instance, synergistic management can accomplish this three-pronged strategy: enhance natural loss of weed seeds in soil, reduce the establishment of weed seedlings, and minimize seed production by established plants.

"A single cultural tactic has minimal impact because the pest population is plastic and flexible; it can easily adjust to one tactic," says Anderson. "If several tactics are used in different ways to suppress weed-population growth, for instance, weeds have trouble adapting. Thus, weed density declines over time."

Declining weed populations permit reduced use of herbicide. The reduction in herbicide use was measured in an economic assessment of farmers in northeastern Colorado showed the cost-savings possible from using a multi-pronged management strategy. "The farmers using a multi-tactic approach to weed control were spending half of what conventional winter wheat/fallow farmers were spending for weed control," says Anderson.

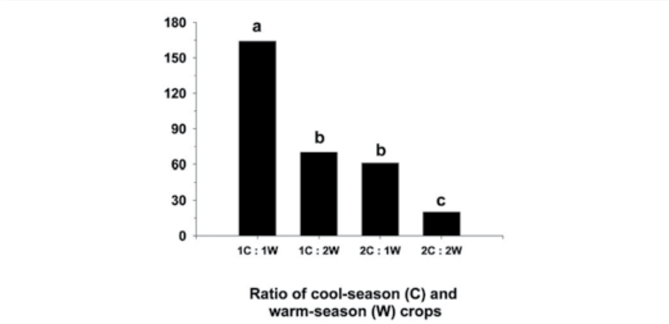
Rotation design

The rotation design most effective in fostering dynamic pest suppression is a rotation arranged in a cycle of four, with two cool-season crops followed by two warm-season crops.

"Different planting and harvest dates among these crops provide more opportunities for producers to prevent either plant establishment or seed production by weeds," writes Anderson. "For example, green foxtail emerges between mid-May and early July, then begins flowering in early August. Winter wheat is harvested in early July, thus producers can control green foxtail before it flowers and produces seeds. A similar opportunity occurs with cool-season weeds; they are easily controlled before planting warm-season crops such as corn or sunflowers to prevent seed production."

Weed pressure increases when the cycle-of-four cropping strategy is simplified to a two-crop rotation alternating between just one cool-season and one warm-season crop. "Comparing trends across three long-term rotation studies, weed seedling density was eightfold higher in two-crop rotations compared with four-crop rotations comprising cool- and warm-season crops," says Anderson. *(See Figure 2.)*

Figure 2



Weed community density among rotations comprised of various ratios of cool- and warm-season crops. Cool-season crops included winter wheat, spring wheat, and dry pea; warm-season crops were corn, proso millet, sunflower, chickpea, and soybean. Data averaged across three long-term studies in the U.S. steppe. Bars with an identical letter are not significantly different based on Fisher's Protected LSD (0.05). (Adapted from Anderson, 2008).

Results of one long-term study showed that a no-till rotation of field pea-winter wheat-corn-soybean was 13 times more effective at controlling weeds than a no-till rotation of winter wheat-chickpea.

Diverse crops

"Diversifying crops with different planting dates within a life-cycle category, such as warm-season crops for instance, accentuates the benefit gained with rotations comprised of two-year intervals of cool- and warm-season crops," says Anderson.

A warm-season sequence comprising corn and sunflowers, for instance, can be more beneficial than a warm-season sequence of corn followed by corn.

"The reason for this impact of crop sequence is related to the region's weed-community pattern of seedling emergence," writes Anderson. "Cool-season weeds represent the first peak, whereas warm-season species dominate the second peak. Corn is normally planted in early May whereas sunflower is planted three to four weeks later. This delay with planting provides producers with an additional opportunity to control 35 to 50 percent of potential weed seedlings before planting sunflower. If corn was planted two years in a row, these seedlings would emerge in corn and require post-plant control with herbicides.

"A similar trend occurs with cool-season crops," he says. "Density of cool-season weeds escalates when the same crop is grown two years in a row. In one rotation study, downy brome density was 40-fold higher with rotations that included two years of winter wheat compared with a four-crop rotation where dry pea replaced winter wheat in one year."

Besides working to reduce weed pressure, rotational diversity minimizes crop disease. "Diversity of crops in rotations reduces severity of root diseases by disrupting population dynamics of pathogens," says Anderson. "In a Colorado study, crop yield was related to how frequently the crop was grown in rotation. Grain yield of sunflower, corn and winter wheat was 17 to 60 percent higher when grown once every four years compared with a cropping frequency of two years."

Research showing yield losses of winter wheat due to root rot provides an additional example of how frequency of related crops increases disease. Common root rot is a prevalent root disease of winter wheat, and proso millet is a host for the disease organism. Because of this commonality, winter wheat yields are low when winter wheat follows millet in either a wheat/millet rotation or a wheat/corn/millet rotation.

Indeed, in such rotations, Anderson's work shows that yield losses can amount to 50 percent, as compared to yields of winter wheat grown in rotations comprising wheat, corn, millet and flax.

Replacing proso millet with chickpea in the wheat/corn/millet rotation increased yield of winter wheat by 28 percent. Chickpea is a legume that does not host the organism causing root rot.

Summing up the overall role of rotations and crop diversity in managing weeds and diseases, Anderson says: "For weed management, the key is having crops with planting dates differing by at least three weeks. For example, corn is usually planted in early May, while proso and sunflower are usually planted in early June."

"For disease management, it's helpful if crops alternate between grass and broad-leaved crops, and if planting dates still differ," he says. "Some grass crops, such as wheat and barley, are hosts to the same diseases."

Role of no-till

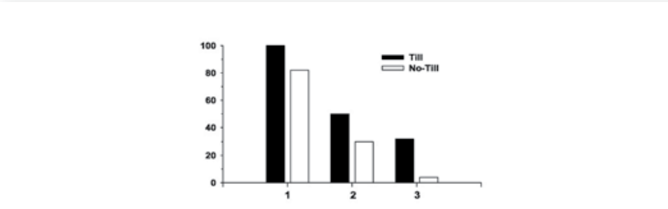
A third key component of an integrated weed management system is no-till. Zero tillage reduces or eliminates the soil disturbance that encourages germination of weed seeds.

"Tillage buries weed seeds in the soil, which increases long-term survival of the seeds," says Anderson. "But weed seeds die rapidly if left on the soil surface, where they are exposed to extremes in temperature. On the surface they also experience alternate periods of wetting and drying, and this process starts splitting the seed coat, causing the seed to deteriorate. Lying on the surface, the seeds are exposed, too, to predation by insects, birds and mammals."

An illustration of no-till's suppressing effect on weed seeds comes from a study comparing weed-seedling emergence over a three-year period in a conventional-tillage system and in a no-till system. No weed seeds were added to the soil after the start of the study. In the first year, the highest number of weed seedlings emerged in the tilled system and nearly the same number emerged in the no-till system. But by the third year, seedling density was eight times higher in the tilled system compared with the no-till system.

"This interaction among seedling emergence, tillage, and time is one reason why no-till rotations with two-year intervals of cool- and warm-season crops are effective in reducing weed density," writes Anderson. "By preventing weed seed production across two years, such as eliminating seed production of cool-season weeds during the warm-season crop interval, weed seedling density is drastically reduced when a cool-season crop is grown in the third year with no-till." *(See Figure 3.)*

Figure 3



Effect of tillage on weed seedling emergence across time. Weed seeds were not added to the soil after initiation of studies; tillage occurred in the tilled treatment each year. Data expressed as a percentage of the treatment with highest number of weed seedlings in each study, and are averaged across four studies. Standard error bars were derived from yearly means among studies.(Adapted from Anderson, 2008).

Anderson cautions that trying to use no-till alone as a weed-management tool – without help from diverse cropping rotations – could potentially lead to increased need for herbicides to control weed populations. "When producers initially began using no-till, they actually increased their weed problems because they didn't diversify crops," he says. "But when used along with diverse rotations, no-till actually helps manage weeds."

Surface residue

Crop residue on the soil surface is the fourth factor playing a key role in an integrated approach to managing weeds. The residue serves to suppress establishment of the weeds. "If you have a thatch of residue on the soil, weed seedlings may emerge, but they often die," says Anderson.

Surface residue sets up environmental conditions inhibiting germination of weed seeds and establishment of seedlings. Depending upon crop species producing the residue, allelopathy may also contribute to the suppression of weeds.

One study reported a 12 percent reduction in weed density for every 1,000 pounds/acre of winter wheat residue on the soil surface, and similar results occur with proso millet. "If you have a wheat residue amounting to 5,000 pounds per acre, you could have 50 percent fewer weed seedlings that couldn't get established because of light suppression," says Anderson.

To increase production of crop residue, Anderson suggests planting wheat at higher seeding rates, banding low rates of nitrogen and phosphorous with the seed at planting, and growing taller varieties of wheat.

Crop canopies

If weeds do get started, odds are they won't go to seed if a competitive crop canopy is in place. Several tactics working together are most effective in establishing a competitive canopy, says Anderson. He suggests planting crops in narrower rows and at higher seeding rates to produce higher populations of plants. Depending on the crop, delayed planting and banding fertilizer can help, too.

The management tactics intended to produce a competitive canopy are most effective when used together. With sunflowers, for instance, using only one or two cultural tactics to create a competing canopy – such as using a narrower row spacing, seeding at higher rates or delaying planting – reduces weed biomass 10 to 25 percent, compared to conventional practices. In contrast, three tactics used together reduce weed biomass by nearly 90 percent.

"This synergistic trend in weed suppression when several cultural tactics are combined together also occurs with other crops," writes Anderson. "With proso millet, a single tactic of banding nitrogen by the seed, increasing crop density or growing a taller cultivar, reduced seed production of redroot pigweed by 20 percent. When these three tactics were combined, however, seed production was reduced more than 90 percent."

Benefit of legumes

Building diverse rotations to manage weeds, insects and crop disease offers opportunities to add legumes to the cropping mix, benefitting soil in the process. "The cycle-of-four rotation design provides a niche for growing legumes to improve crop yield and accelerate soil restoration," says Anderson. "Even with short growth intervals, dry pea or other legumes will increase soil organic carbon, soil organic nitrogen and soil microbial activity."

"Dry pea suppresses root diseases in winter wheat, for instance, and favors microbial interactions with winter wheat," he says. "The roots of winter wheat following dry pea are more readily colonized with mycorrhiza and contain more endophytic rhizobia. These microbial associations improve the plant's ability to withstand drought stress and to absorb nutrients. Also, root exudates of dry pea improve photosynthesis efficiency of cereal crops."

Northern rotations

Dry pea is one grain-legume crop that performs consistently in the growing conditions of Manitoba and other Prairie Provinces. In this region short, cool growing seasons can challenge the building of fixed rotations arranged in a cycle of four, with two cool-season crops followed by two warm-season crops.

Scott Day

While low prices for peas and disease pressure within the crop are potential drawbacks for Canadian growers, peas have the advantage of providing diversity to rotations while also contributing to soil quality and yielding cost-savings of purchased nitrogen, says Scott Day, a no-till producer from Deloraine, Manitoba, and diversification specialist with Manitoba Agriculture, Food and Rural Initiatives.

"When the price of nitrogen is high, peas are particularly valuable because of the cost savings resulting from not having to apply nitrogen to the crop following the peas," says Day. "Peas make a great seedbed for the following crop, too, so a lot of people grow them for a rotational benefit. If we could find ways to add more value to peas, thus increasing the price, Prairie producers would grow a lot more of them."

Soybeans are beginning to offer opportunities, too, for broader crop diversification in Canada. "Newer varieties of soybeans are finding their way into Manitoba, and these have lower requirements for heat units," says Day. "Soybeans are becoming very popular in Manitoba because of their ability to handle standing water as well. This can be very important in zero till systems, where more water is often stored in the soil profile. When most other crops were drowned out this year in the Red River Valley, it was the soybeans that survived and still produced well despite the flooding."

In his farm's no-till cropping operation Day grows pinto beans, black beans and other edible beans in rotation with canola and cereal crops including hard red spring wheat, winter wheat, durum wheat, and malt and feed barley. As a warm-season broad-leaved legume, the beans offer the opportunity to delay planting and harvesting dates, thus providing windows for weed control occurring at different times of the season than those occurring with either canola or the cereal crops.

"While peas, beans and soybeans are good broad-leaved legume options in Manitoba," says Day, "Saskatchewan is much different. It has become one of the world's largest producers of lentils and chickpeas. Both of these legume crops thrive in the drier, less disease-stressed environment of southern Saskatchewan." Peas, on the other hand, are popular in northern Saskatchewan.

"To define a northern rotation for the Prairies is difficult because it changes dramatically [from region to region]," he says. "About 100 miles east of my location the legumes in the crop rotation are almost exclusively soybeans and dry beans. About 100 miles north of me the legume is entirely peas. Then, 100 miles west of me the legumes are mostly lentils and chickpeas. Most regions in western Canada do have suitable legume options for their crop rotations; economics is the main factor [deciding their inclusion in a farmer's rotation]."

Alfalfa

Alfalfa is a legume offering yet another option for diversifying crop rotations in cooler regions. Alfalfa adds nitrogen, increases soil carbon, and like other deep-rooted crops, scavenges nutrients from depths beyond the reach of shallower-rooted crops, says plant scientist Martin Entz, University of Manitoba, Winnipeg.

"Because alfalfa is cut regularly, any weeds that get started, like Canada thistle, are defoliated regularly before going to seed," he says.

But because alfalfa is typically fed to livestock, its economic return is linked to demand from livestock operations, either as a crop fed to a farmer's own herd or as forage marketed to other livestock producers. "That's a limiting factor that increases challenges for crop producers," says Entz. "As farms have become increasingly specialized, opportunities to work alfalfa into grain rotations have decreased. But necessity is the mother of invention, and as we encounter problems in our specialized systems, we'll find ways of working out solutions."

Other crops

Forage legumes can be grown as green-manure or cover crops, and both practices effectively disrupt weed populations. Sweet clover makes a good fit as a green-manure crop for the drier regions of the Prairies, while red clover grows well in the Prairies' wetter regions.

"In addition to their ability to fix nitrogen, both species are strong competitors with weeds, and decaying sweet clover residues are known to release allelochemicals that inhibit weed growth," says Neil Harker, weed scientist, Agriculture and Agri-Food Canada (AAFC) Lacombe (Alberta) Research Centre.

Like the clovers, winter rye exerts a similar depressing effect on weeds when grown as a cover crop. Winter rye grows vigorously, and its decaying residues release weed-inhibiting allelochemicals.

Forage legumes along with cereals lend themselves to the production of silage crops. The harvesting of these crops effectively reduces weed populations because harvesting occurs before weeds produce mature seed. "Early-cut silage for two to three consecutive years can be more effective than herbicides in reducing wild oat weed seed banks," says Harker. "Silage crops can be a particularly valuable option when trying to control herbicide-resistant weed populations. The real key to delaying the occurrence of herbicide-resistant weeds is to apply herbicides less often."

Systems research

Neil Harker

Canadian research has documented superior effectiveness of weed-management practices when combined within a systems approach rather than singly. For instance, problematic populations of foxtail barley were controlled after several years of using the combined practices of crop rotation, higher crop seeding rates, sub-surface banding of nitrogen fertilizer, and timely use of herbicides.

A four-year study measured the annual and cumulative effect on weed management of combining several crop-production practices. These included crop rotation, seed date, seed rate, fertilizer timing and herbicide rate.

"Combining early seed date, higher crop seed rate, and spring-applied subsurface-banded fertilizer resulted in the most competitive cropping system within this study," says Harker. "Weeds were well controlled, and at two of three sites the weed seed bank was not greater after four continuous years of applying herbicide at 50 percent of the recommended rate."

Another study of integrated crop-management practices compared wild oat control in both low- and optimal-management systems. The low-management system was continuous production of short-statured barley seeded at 200 seeds/square meter. The optimal-management system was tall statured barley seeded at a rate of 400 seeds/square meter. The barley was rotated in alternate years with canola and field peas.

"After five years of herbicide applied at one-quarter recommended rates, the densities of emerging wild oats were 311 plants per square meter in the low-management treatment and eight plants per square meter in the optimal-management treatment at Lacombe," says Harker. "Barley yields in the fifth year were often greater in the optimal system with one-quarter herbicide rates, than in the low-management system with full herbicide rates. Weed control is more about crop management than herbicide application."

A single weed-control practice to augment a systems approach is the selection of competitive varieties within crops. For instance, tall varieties of barley are typically more competitive with weeds than are semi-dwarf varieties, says Harker. Hulled varieties of barley are more competitive than hull-less varieties because hulled barley has faster emergence and more vigorous early growth. Varieties of leafed field pea are more competitive with weeds than semi-leafless varieties because of their increased ability to shade weeds.

Synergy between crops

Crop synergy is an additional factor to consider and to watch for in planning diverse rotations and a whole-systems approach to managing weeds. "We have found that certain crop sequences improve a crop's tolerance to weeds," says Anderson. "For instance, when winter wheat follows field peas, the wheat will be more tolerant of wild rye. Winter wheat yielded more following dry pea in both weed-free and rye-infested conditions."

One study showed that when wild rye was present, winter wheat yielded more than 75 bushels/acre following dry pea, but less than 60 bushels/acre following either soybean or spring wheat. Compared to weed-free conditions, yield loss due to wild rye was only 11 percent when winter wheat followed dry pea. Yield loss was 32 percent when winter wheat followed soybean.

Corn also tolerates more weeds when grown after dry peas than after either corn or soybeans.

"Synergism is a condition that is difficult to measure or explain," says Anderson. "It may be related to internal physiological factors."

Just as a synergism between crops produces a robust hardiness to withstand weeds, so the broader synergy at work in a multicultural system of managing crops helps plants and soils resist invasions of weeds, insects and diseases. "No single management practice can stand alone," says Anderson. "They supplement each other and provide an ecological framework for managing weeds and reducing need for herbicides."

– by Raylene Nickel

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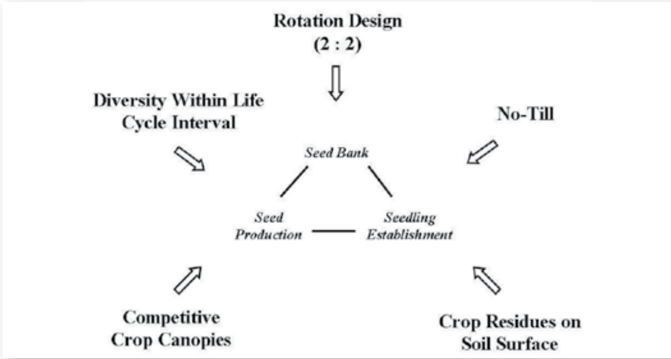
Figure 4



Five components of a prevention approach to reduce weed community density in the semiarid steppe of the United States. The 2 : 2 designation refers to rotations comprised of two cool-season crops followed by two warm-season crops. Cultural tactics in each component disrupt weed population dynamics by minimizing weed seed survival in soil (seed bank), seedling establishment, or seed production.

Managing Disease Risks

Growing diverse no-till rotations can help decrease crop disease, but environmental conditions may yet trigger disease outbreaks. In no-till systems, diseases are most likely to get started in crop residues, cool or wet soils, or in volunteer or invasive plants growing in fields.

Disease organisms overwintering on crop residue can be particularly troublesome in no-till systems. Examples of crop diseases that can possibly result from the presence of infested residue include tan spot in wheat, Fusarium head blight, sunflower rust or Ascochyta of chickpea.

Marcia McMullen

The fungus causing wheat tan spot, for instance, overwinters in the wheat residue. If wet weather occurs early in the following season, fungi may be released from fruiting structures in the wheat residue, and severe infection may occur on plants from the one to five-leaf stage, says North Dakota State University Extension plant pathologist Marcia McMullen. Severe tan spot infection at these early growth stages can affect root development and survival of young leaves and tillers.

Fusarium head blight is another small grain disease resulting from organisms overwintering in crop residues. Residues of wheat, barley and corn are most likely to serve as hosts. The disease spores develop during warm periods of rain or high humidity during the following growing season. The highest risk for developing Fusarium head blight is when wheat or barley is planted into corn stubble under no-till conditions, says McMullen.

"The fungus causing head blight also causes corn stalk rot," she says. "The fungus survives longer on corn residue than on small grain residues because the corn residue doesn't break down as fast as the grain residue under northern climatic conditions. The fungus also produces thousands of times higher populations of spores on corn residue than on residues of wheat."

A combination of management strategies is most effective in controlling leaf and head diseases. For instance, using integrated crop rotations with broad-leaved crops, resistant varieties and appropriate timing of fungicide applications can manage the diseases.

"Considerable evidence has been produced showing the value of rotations in reducing leaf and head diseases in wheat," says McMullen. "Rotating between broad-leaved crops and cereal crops can break the disease pathogen's cycle on residue."

For more information about the role of crop rotations in reducing disease, read: Managing Plant Disease Risk in Diversified Cropping Systems - Joseph M. Krupinsky, Karen L. Bailey, Marcia P. McMullen, Bruce D. Gossen and T. Kelly Turkington, Agronomy Journal 2002 94: 2: 198-209, doi:10.2134/agronj2002.1980.

Other diseases

Soil-borne diseases caused by fungi surviving – or thriving – in cool, wet soil can also cause problems in no-till systems. These diseases include root rots caused by the Pythium organism, or some Rhizoctonia species.

Preventive strategies include crop rotation, the use of more disease-resistant varieties and seed treatments, says McMullen.

Increased populations of weeds or volunteer plants from the previous crop can also host disease organisms, thus serving as the source of disease outbreaks. For instance, sunflower rust may get started in weeds, native sunflowers or volunteers from the previous crop of sunflowers.

"This possibility requires some increased scouting efforts," says McMullen. "Early detection of the disease may require more frequent scouting and also signal the need for fungicide on sunflower later in the season."

In wheat, epidemics of wheat streak mosaic typically get their start in volunteer wheat plants and even in green corn. Many grassy weeds also harbor the virus and the mite vector triggering the disease. Beginning in these infected plants, wheat streak mosaic then spreads through a crop as the wheat curl mite transmits the virus from plant to plant. In order to survive, the virus requires a green host plant.

"Because control of wheat streak mosaic is not possible with miticides or insecticides and because resistant varieties are few and far between, most preventive management focuses on cultural practices," says McMullen.

One preventive strategy is to interrupt the life cycle of the virus by ensuring a two to three-week break between green crops. "When planting spring wheat, for instance, don't plant into volunteer wheat or grassy weeds like quack grass," she says. "Prior to planting, make sure there are no host plants in the field for a period of at least two weeks."

Planting at the cooler phase of the timeframe recommended for planting wheat is another way to prevent wheat streak mosaic from getting a foothold in a crop. "The mites are most active in warm temperatures, so late-planted spring wheat is at the highest risk," says McMullen. "Don't plant too late for spring wheat, or too early for winter wheat. In North Dakota, it's best not to plant winter wheat before September 1 in the northern half of the state, and [not] before the second half of September in the southern half of the state."

For more information on cultural practices to prevent wheat streak mosaic, visit www.ag.ndsu.edu/pubs/plantsci/smgrains/pp646.pdf.

Predicting outbreaks

Predicting the potential for outbreaks of certain crop diseases and insect pests is possible by using information provided by the North Dakota State University (NDSU) Small Grain Disease Forecasting Model. The information helps growers decide whether or not to apply pesticides, and it can also help determine the most effective timing of the applications.

The Forecasting Model posts on its website disease-predicting information pertaining to cereal-grain diseases such as tan spot, Stagonospora leaf blotch, leaf rust and Fusarium head blight. It also reports information relating to disease in sunflower and canola.

The system predicts infection periods for diseases based on weather information from the North Dakota Agricultural Weather Network. The weather data is gathered from multiple sites throughout North Dakota and western Minnesota.

Daily information reported by the websites for the Disease Forecasting Model and the Agricultural Weather Network includes: predictions of infection periods for diseases, average temperature, relative humidity, total rainfall, estimated hours of wetness and background information for interpreting the data.

Using this information about environmental conditions as a decision-making framework, website users can key in actual planting dates of their crops to help them determine whether a particular crop's growth stage presents vulnerability to diseases or insects.

"The information tells you the risk of these pest problems at a particular time and place," says McMullen. "The risk is based on environment, weather variables and crop growth stage. It gives growers information needed to decide whether or not a pesticide is warranted."

To get most effective use of the information, growers should scout crops and monitor their own field conditions. "Checking your own fields will show you exactly what's happening there," says McMullen. "The information on the Forecasting Model doesn't take into account other variables such as variety, crop history and soil nutrient levels."

The website for the NDSU Small Grain Disease Forecasting Model is www.ag.ndsu.nodak.edu/cropdisease/. The site for the Weather Network is www.ndawn.ndsu.nodak.edu. The toll-free telephone number reporting disease forecasting data is (888) 248-7382.

Manitoba Agriculture, Food and Rural Initiatives offers a similar disease-forecasting service at www.gov.mb.ca/agriculture/crops.

Yet another similar service, WeatherFarm, is offered by the Canadian Wheat Board. It provides weather data from more than 700 reporting stations on the Prairies. It also provides modeling tools and risk maps for pests and diseases. In addition, it gives warnings of severe weather and information relating to commodity market prices. Potential users can sign up for WeatherFarm at http://weatherfarm.weatherbug.com/farm/login.aspx.

– by Bill Armstrong and Raylene Nickel

Avoiding Pesticide Resistance

Potential for the development of pesticide resistance in weed and insect populations presents the need for watchfulness and preventive practices. Agronomists have confirmed glyphosate resistance in common ragweed in North Dakota and Minnesota. They have also confirmed resistance to glyphosate in giant ragweed and waterhemp in Minnesota and possibly in lambsquarter in both states.

Jeff Stachler

"The area around Hutchinson, Minnesota, has the highest frequency of glyphosate-resistant giant ragweed," says Jeff Stachler, agronomist at North Dakota State University (NDSU). "At least 90% of this area has some frequency of glyphosate-resistant giant ragweed."

Stachler says two other types of herbicides commonly used in North Dakota – ACCase (Group 1) and ALS (Group 2 inhibitors – are likely to encounter additional resistance problems in the future, especially with grass weeds. The worst case scenario, he adds, is multiple resistance, such as giant ragweed resistant to glyphosate and ALS-inhibiting herbicides, or wild oat and green foxtail resistant to ACCase and ALS-inhibiting herbicides. Another concern, says Stachler, is resistance in key broad-leaved species to PPO (Group 14) – inhibiting herbicides.

"Glyphosate resistance differs from previous resistance to ACCase, ALS and triazine herbicides," Stachler explains. "I like to describe glyphosate resistance as low-level resistance when compared to the other three, which I refer to as high-level. Actually, resistance to most modes of action are examples of low-level resistance, including PPO and synthetic auxin herbicides."

"When you are scouting fields, you need to know the telltale symptoms of low-level resistance," he says. "It's usually identified in the field when a high percentage of plants are killed, while a small portion of plants are normal in appearance – although appearing injured when compared to an untreated plant. The next most frequent number of plants will show a complete continuum of responses, from nearly dead to nearly normal in appearance. This is especially true if all species present in the field are controlled, except for one."

Removing resistant plants from the field prevents these from going to seed, thus restricting potential increases in the resistant population.

Pesticide resistance can get started when producers plant the same crop continuously and use the same herbicide every year. A high density of weeds in a field and the presence of multiple plant stressors also invite pesticide resistance," says Stachler.

Practicing diverse weed-management strategies guards against resistance. Use all tools available, he suggests, including cultural and mechanical weed control. When using herbicides, use as many different modes of action as possible on a yearly basis. Pre-emergent herbicides provide a way to include additional modes of action that are not available when using only post-emergent herbicides.

Fungicide resistance

Mohamed Khan

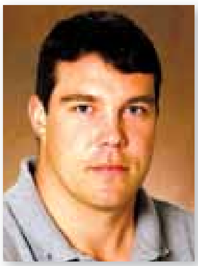
Like weeds, disease pathogens can also develop resistance to pesticides. For example, sugarbeet growers experienced fungicide resistance in 1981 and again in 1998, reports Mohamed Khan, NDSU Extension sugarbeet specialist. The pathogen that developed resistance causes Cercospora leaf spot (CLS), which begins with light-brown, circular spots on the plant's lower leaves. The pathogen developed rapidly in warm and wet conditions.

Rotating fungicides with different modes of action, from different chemical classes, has reduced the pathogen's ability to resist pesticide. "Growers have done an excellent job of rotating the strobilurins with the triazoles and thiphenyltin hydroxide (TPTH), which has helped immensely in managing resistance," Khan writes. "They have also used better CLS-resistant varieties, minimum three-year crop rotations and incorporated infected debris at least once during the rotation to hasten decomposition of the leaves and the pathogen."

A pathogen attacking chickpea has shown fungicide resistance as well. In 2005 the Ascochyta pathogen causing blight developed resistance to fungicides categorized by the Fungicide Resistance Action Committee (FRAC) as Group II fungicides (Headline and Quadris).

Ascochyta blight can infect all above-ground chickpea plant parts and can be found at any time after crop emergence. Ascochyta blight first appears as gray areas on the leaves, stems or pods, and these areas quickly turn into brown lesions with dark borders. The disease develops rapidly in cool and wet conditions.

The Ascochyta fungus can overwinter in field stubble for several years, and the pathogen is also borne on seed. Sexual spores can travel up to five miles, which allows disease to spread quickly to new areas. Spores landing on chickpea leaves and stems need at least two hours of surface moisture to germinate, and the likelihood of infection increases if leaves and stems are wet for more than six hours.



Sam Markell

Managing Ascochyta blight requires an integrated approach, according to Samuel Markell, NDSU Extension plant pathologist. Management steps include choosing disease-resistant plant varieties, rotations, using certified seed, applying seed treatments and using fungicides. However, as this is written, there are no chickpea varieties that have complete resistance to Ascochyta blight, although some varieties do have moderate levels of resistance under North Dakota conditions. The small kabuli/desi-type chickpeas will make disease management easier, notes Markell.

Markell advises that chickpea should be grown on the same ground only once every three years, avoiding growing them on fields adjacent to where they were grown the year before. Plant certified seed, he adds, but if you do use bin-run seed, test it each year for Ascochyta blight infection.

"Several foliar fungicides are available for use on Ascochyta blight of chickpea," Markell writes, "and these can be effective when used along with other disease-management strategies."

– by Bill Armstrong

Reference
Markell, Samuel et al, 2008. Ascochyta blight of chickpea. North Dakota State University Extension Service.

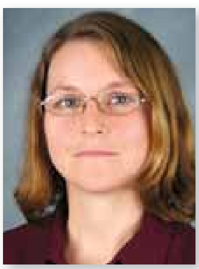
Early Ascohytra blight symptoms on chickpea leaf. Note gray center witth black margin.

Asochyta blight lesions on chickpea leaf. Note raised black dots (pycnidia) arranged in concentric rings.

Guard Against Sawfly and Midge

The wheat stem sawfly can pose problems for producers in North Dakota, Montana, Manitoba, Saskatchewan and Alberta. The sawfly larvae tunnel along wheat stems, causing lodging of the crop, and losses in yield and grade.

Since insecticides are not effective in controlling wheat stem sawfly and may harm beneficial species that could be present in wheat fields, preventive practices are best options for control.



Tatyana Rand

"The wheat stem sawfly infests wheat crops from the previous year's stubble," says research ecologist Tatyana Rand, USDA Agricultural Research Service Northern Plains Agricultural Research Laboratory, Sidney, Montana.

"Thus, continuously cropping wheat and strip cropping, which creates a maximum amount of wheat-fallow edge, will tend to favor sawfly populations," she adds. "In contrast, crop rotations using non-host species such as broadleaves or oats, and planting in larger blocks can reduce sawfly problems."

Native parasitic wasps can help with control. The parasitoids paralyze the larger sawfly larvae within a wheat stem, deposit one or more eggs on it, and the hatching parasitoid larvae feed externally on the sawfly larva, eventually killing it. The parasitoids generally emerge a couple of days before sawflies and are active throughout the wheat-growing season.

Research has shown that tillage has a negative effect on parasitoids, notes Rand.

Reducing tillage and leaving tall field stubble can encourage population growth in the parasitic wasps. Because they pupate within the wheat stem, Rand suggests leaving at least two-thirds of the height of the stems standing at harvest.

Some varieties of solid-stemmed wheat resistant to sawfly are currently available. Additional varieties are being developed at Montana State University and North Dakota State University.

Midge-tolerant wheat

Infestations of the orange wheat blossom midge can be economically devastating. The adult female midge lay eggs on newly emerged wheat heads during warm, calm evenings. When the larvae hatch, they feed on the developing kernels, causing them to shrivel or stop growing. Both grade and yield suffer.

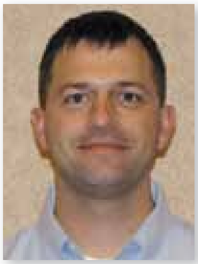
Three midge-tolerant wheat varieties were made commercially available in 2010. The new varieties contain a gene, which when triggered, causes an increase in the naturally occurring phenolic acids in wheat kernels. The acids cause the midge larvae to stop feeding and starve to death. The mechanism triggering the production of phenolic acids does not operate if midge larvae are not feeding on the seed. When activated, these acids return to normal levels by the time the wheat reaches maturity.

A broad-based industry group called the Midge Tolerant Wheat Stewardship Team is supporting the new technology.

– by Bill Armstrong and Raylene Nickel

Producer Profile

Diverse Rotation Reduces Pests



Mark Jennings

After 13 years of no-tilling and growing a diverse array of crops, Mark Jennings, Washburn, North Dakota, sees a continuing decline in crop disease as well as in weed populations in fields.

"When I started farming, we had problems with wild oats, kochia and other broad-leaved weeds," he says. "With no-tilling and going to a more diverse rotation, we're getting control over the broadleaves. The more diversity we incorporate into the rotation, the easier it is to control the weeds. I'm seeing big dividends from lengthening the rotation."

His goal is to alternate between cool and warm-season crops of the same plant family as well as to alternate between crops of the grass and broad-leaved plant families.

Jennings' seven-year rotation begins with spring wheat, followed by winter wheat, corn and then sunflowers, followed by either barley or spring wheat. Next, he reverts back to a cool-season broad-leaved crop like flax or peas. In the seventh year he begins the rotation again but adds a short-season cover crop.

"I'm trying to use every opportunity to grow warm and cool-season crops of both grass and broad-leaved plant families," he says. "The cool-season crops may get piggybacked, but it appears to help with control of some weed species. In the case of winter wheat following spring wheat, I have excellent cover for snow catch and protection of the winter wheat over the winter."

The corn-sunflowers sequence of the rotation works particularly well. "There's usually some residual nitrogen left from the corn, and the deep rooting of the sunflowers can take advantage of this," says Jennings.

While he continues to experiment with types of cover crops to grow during the seventh year of the rotation, overall diversity remains his aim. "We're trying a seven-way polyculture mix of radish, turnip, millet, barley, corn, sunflowers and forage peas," he says.

He's also experimenting with standard cover crops of just one species or a two-crop mix of peas and radishes planted at random years throughout the length of the rotation.

"If I'm going to plant a broad-leaved crop in the field the following year as the full-season crop, I'll try to plant a grass-type cover crop," he says. "If I'm going to plant a grass-type crop as the full-season crop, I'll plant a broad-leaved cover crop. My thought is that alternating between grass and broad-leaved crops should help break up the disease cycles."

Throughout the annual sequence of the overall rotation, he aims to minimize the frequency of Roundup Ready™ crops. "I try to grow a Roundup Ready crop only one year in seven; that crop is usually corn," he says.

As the diversity of the rotation continues to depress weed populations, Jennings has been able to reduce the overall use of pesticides. "As an example," he says, "I have been able to eliminate a broadleaf herbicide pass from the peas and sunflowers in my rotation and have just used a grass herbicide in the crop the last two years. A few broad-leaved weeds do come up, but I have seen just as many in fields that have been sprayed."

Searching for the broadest range of diversity and most beneficial crop sequences to include in his rotation, he experiments with crop combinations planted in field plots. Follow-up soil tests are part of his on-farm research.

"I'm alternating growing peas and radishes in strips in the same field plots to see if there is a symbiotic relationship between the two crops," he says. "For example, I'm growing peas alone, peas and radishes together, and radishes alone. I'll probably follow the pea-radish sequence with a cool-season small grain like barley or wheat, marking the different passes to see if there is a difference in the following crop."

"Like many other farmers, I'm trying to find the right mix of crops to grow in a rotation," he says. "I'm trying to develop a rotation that more closely mimics nature. Nature's ideal plant populations are multiple species all growing together."

– by Raylene Nickel

Chapter sources

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Economics

Economics is the principal driver in the decisions crop producers make in operating their farms. That hasn't changed since the Manitoba-North Dakota Zero Tillage Farmers Association published its "Advancing the Art" manual in 1997. However, with a better understanding of the science behind zero tillage cropping systems, many of the components that factor into the economics of zero tillage have changed. The overarching theme for "Beyond the Beginning" demonstrates that equipment and agronomic practices have advanced, based on extensive research into the specific needs of zero tillage, and producers' own observations and experience. One reason why zero tillage has flourished is because it offers producers significant economic benefits, often associated with production and environmental benefits such as better soil, water and air quality. While some critics focus on agriculture's use of energy and chemicals, potential environmental benefits can include agricultural practices to reduce greenhouse gases, and the emerging field of carbon sequestration. (Greenhouse gas emissions, carbon management and carbon sequestration are addressed in the Carbon Management section of this manual).

Farmers in many areas of the world have adopted zero-till as a means of managing risk and diversifying their income streams. In moister areas of the Northern Great Plains zero till has enabled producers to trim costs and provided for a more efficient use of resources. In more arid areas, zero till practices reduce costs, reduced erosion both wind and water, made annual cropping possible, while boosting crop yields.

Farmers continue looking at ways they can refine their zero till practices by reducing costs – represented by equipment complement and/or size, hours of equipment operation, labor, inputs, and depreciation – and increasing yields and/or the quality of the crops they produce. Concurrent with that is another increasingly important driver, the need to adopt more energy-efficient technologies, to reduce reliance on chemicals to control weeds and insect pests, and to implement practices that contribute to the health of soil, water and air.

Economic and environmental sustainability

Is it possible to be economically as well as environmentally sustainable? There's enough evidence now that zero-tillage improves the economics of farming in the short and the long-term. One of the management and financial challenges facing producers is to incorporate technologies and practices that will improve the environmental performance of their operation, with the potential of giving a financial payback over the longer term.

Dave Archer

Dr. Dave Archer, an agricultural economist at the USDA Northern Great Plains Research Laboratory at Mandan, North Dakota, agrees. Making changes that are sustainable in the long-term may require significant investments in the short-term, and this can serve as a barrier to adopting more sustainable practices. The challenge is to find low-cost changes that begin to build environmental conditions, and have a positive feedback on economic returns, he adds.

Know yourself

When making choices about which crops to plant, which crop rotations to follow and which management practices to use, producers are often faced with trade-offs between increases in annual net returns and increases in income variability or financial risk. The final choices depend on individual producers' attitudes to risk, expectations or projections of product prices and input costs, and the probable net returns that can be earned using selected management practices.

In a 12-year study during the period 1987 to 1998, when farmers were moving from conventional tillage (CT) to min-till (MT) or zero till (ZT), R. P. Zentner, Guy Lafond and three other colleagues with Agriculture and Agri-Food Canada concluded that, "… producers can expect to achieve similar or higher crop yields with most crops when using conservation tillage management methods. Yields of field pea, flax and spring wheat grown on cereal stubble averaged about 7-13 percent higher with MT and ZT compared to CT practices."

While the study focused on the economic performance and relative risk in the sub-humid Black Soil Zone of Saskatchewan, and included CT methods have largely been discarded, the study does confirm the benefits of zero till management practices such as crop residue management, natural weed and pest control, and diversified crop rotations. The study is also significant because of its focus on integrating oilseed and pulse crops into cereal-based rotations. The results demonstrated the potential to capture significant agronomic benefits, such as higher grain yields and grain protein, when compared with traditional production systems. The study team's findings also substantiated that by employing zero till practices and diverse crop rotations, summer fallow practices for water conservation are not needed in sub-humid regions.

The study notes that, "Yields of spring wheat and winter wheat were further enhanced by an average of 12-22 percent when grown in mixed cereal and oilseed (spring wheat-spring wheat-flax-winter wheat) or cereal-oilseed-pulse (spring wheat-flax-winter wheat-field pea) rotations, reflecting the combined effects of reduced disease pressure and improved nutrient and water supplies with the diversified cropping systems."

The report also states that the MT and ZT practices had lower expenses for fuel, machine operation and labor, but these savings were offset by higher herbicide costs. Using a base grain price averaged over the course of the study, it found that the 12-year net returns were highest for the most diversified rotation and lowest for the monoculture cereal rotations.

The study's authors concluded that from an economic viewpoint, "Income variability or riskiness was clearly lowest with ZT management practices and for the mixed crop rotations. CT management practices displayed the highest level of financial risk for all crop rotations and grain price scenarios, and would generally not be selected by producers who are averse to risk."

Roger Ashley

In research trials conducted at the North Dakota State University Dickinson Research Extension Center under semi-arid conditions by Dr. Patrick Carr, agronomist, no-till practices properly implemented increased grain yields an average of 47 percent (22.2 bushels per acre) in southwestern North Dakota, when compared with conventional tilled yields. Rotations are an integral part of no-till and when the proper diversity in the rotation occurs, producers have increased yields by about 30 percent (9.6 bushels per acre) over continuous wheat according to Roger Ashley, Area Extension Cropping Systems Specialist for NDSU at Dickinson.

Producers who use no-till seeding practices must build a systems approach to managing inputs for profitability. No-till systems with rotations having little diversity will fail in the long run. Crop rotations are the most effective way of reducing many pest populations. Soil environments created by some crops remain after their growth and improve the growth efficiency of following crops. This rotation effect is specific for some crop combinations and sequences. A positive relationship between these crops in a rotation can make some rotations more profitable than other rotations in the long run.

Rather than looking at the return per acre for one crop producers should be using net return per rotational acre to measure profitability of different crop rotations correctly. In a rotational acre analysis, net returns for each crop year in the rotation are summed and divided by the number of years in the rotation, thereby standardizing all rotations to an acre basis. An example of a western North Dakota rotation budget is shown below. Note spring wheat following field pea requires less fertilizer and less fungicide compared to the spring wheat-winter wheat rotation. The return per rotational acre is understated for the more diverse rotation that includes field pea as cereal yields are greater if the preceding crop is a broadleaf crop rather than another cereal crop.

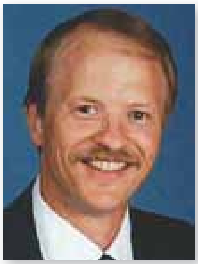
Composite budget for spring wheat-winter wheat-corn-pea crop rotation in southwest North Dakota updated January 2010. Highlighted number is the return to labor and management per rotational acre.					
	Year 1	**Year 2**	**Year 3**	**Year 4**	
	Spring Wheat	**Winter Wheat**	**Grain Corn**	**Field Pea**	**Composite Budget**
Crop Composite (% of rotation)	25%	25%	25%	25%	100%
Market Yield	27	37	57	30	NA
Market Price	5.31	4.63	3.63	6.00	NA
Market Income	143.37	171.31	206.91	180.00	175.40
Direct Costs					
-Seed	10.50	7.50	40.85	31.50	22.59
-Herbicide	18.90	15.40	14.00	25.50	18.45
-Fungicide	2.00	9.00	0.00	0.00	2.75
-Insecticide	0.00	0.00	0.00	0.00	0.00
-Fertilizer	15.39	29.25	22.23	2.82	17.42
-Crop Insurance	9.90	9.90	0.00	7.10	6.73
-Fuel & Lubrication	9.04	8.87	10.84	10.40	9.79
-Repairs	12.04	11.67	13.03	13.96	12.68
-Drying	0.00	0.00	11.00	0.00	2.75
-Miscellaneous	6.00	6.00	6.00	4.50	5.63
-Operating Interest	2.43	2.56	3.10	2.51	2.65
Sum of Listed Direct Costs	86.20	100.15	121.05	98.29	101.42
-Misc Overhead	4.50	4.44	5.51	4.96	4.85
-Machinery Depreciation	13.65	13.28	18.64	16.40	15.49
Machinery Investment	7.57	7.15	10.18	9.01	8.48
Land Charge	30.00	30.00	30.00	30.00	30.00
Sum of Listed Indirect Costs	55.72	54.87	64.33	60.37	58.82
Sum of all Listed Costs	141.92	155.02	185.38	158.66	160.25
Return to Labor & Management	1.45	16.29	21.53	21.34	15.15

Composite budget for spring wheat-winter wheat in southwest North Dakota updated January 2010. Highlighted number is the return to labor and management per rotational acre.			
	Spring Wheat	**Winter Wheat**	**Composite Budget**
Crop Composite (% of rotation)	50%	50%	100%
Market Yield	27	37	NA
Market Price	5.31	4.63	NA
Market Income	143.37	171.31	78.67
Direct Costs			
-Seed	10.50	7.50	9.00
-Herbicide	18.90	15.40	17.15
-Fungicide	9.00	9.00	9.00
-Insecticide	0.00	0.00	0.00
-Fertilizer	15.39	29.25	22.32
-Crop Insurance	9.90	9.90	9.90
-Fuel & Lubrication	9.04	8.87	8.96
-Repairs	12.04	11.67	11.86
-Drying	0.00	0.00	0.00
-Miscellaneous	6.00	6.00	6.00
-Operating Interest	2.43	2.56	2.50
Sum of Listed Direct Costs	93.20	100.15	96.68
-Misc Overhead	4.50	4.44	4.47
-Machinery Depreciation	13.65	13.28	13.47
Machinery Investment	7.57	7.15	7.36
Land Charge	30.00	30.00	30.00
Sum of Listed Indirect Costs	55.72	54.87	27.65
Sum of all Listed Costs	148.92	155.02	75.99
Return to Labor & Management	-5.55	16.29	5.37

The economic value of thorough and timely decision-making

"Responding to changing conditions and doing things in a timely manner has real economic benefits," writes Dr. Dave Archer. "Research has shown this typically has a greater economic impact than fine tuning input use. However, there are also costs to maintaining timeliness and flexibility, for example, buying larger equipment. It is important to look at both sides of the equation."

Archer poses the question, "Reducing equipment size may look like a way to reduce costs and improve profitability, but what are the impacts on the timeliness of field operations? On the other hand, purchase of a specialized piece of equipment might greatly improve timeliness of field operations, but at what cost? How does it affect ability to adjust future production in response to changing market conditions?" These are questions producers need to ask as they weigh all of the variables involved, Archer suggests, as they aim to make their operations as efficient as possible.


Andrew Swenson

Dr. Andrew Swenson, a farm and family research management specialist at North Dakota State University, adds that the new products being introduced in the marketplace make it difficult to weigh the costs and benefits. "I think the challenge is to identify and accurately measure as best as possible ***all*** the costs and benefits of new pesticide, fertilizer, equipment or processes that have become available. However, this is a real challenge for a couple of reasons," he says.

The first reason, Swenson explains, is because so many interrelationships exist in agricultural production. It is a challenge to capture every item that needs to be factored into the decision-making process, and an additional challenge to measure the impact of each item accurately.

"The producer should look at a crop budget as a reminder of all the items that might be impacted by the proposed alternative: yield and quality, direct costs such as seed, fertilizer, fuel and repairs, and fixed costs such as depreciation and machinery investment. It is also important to consider the impact on labor, both the quantity required and the timing."

"Another important concept," Swenson continues, "is to evaluate not only the change in an item – whether it is a revenue item such as yield or grain quality, or a cost – but how the alternative will impact the variability of the item. Generally, a reduction in variability is desired, because it reduces predictive risk."

Swenson adds that the farm's financial balance sheet is another important point to consider. Purchasing a major item with debt capital will increase financial risk (by raising the debt-to-asset ratio on the balance sheet), but if the purchase does what it was intended to do, over time it will deliver sufficient payback to improve the balance sheet. He notes that increasing the debt-asset ratio does put the farm in a more precarious position, emphasizing the importance of making the right purchase decision.

In his second point Swenson observes that production agriculture is "very fluid." Analyzing whether to make a change in equipment or production practice would be simpler if we knew what the weather, the markets and new technology will be in the future.

"For example," he says, "in evaluating application methods of nitrogen, a major consideration is the volatility rate of surface applied urea, of which weather is the main determinant. As another example, careful analysis may indicate a major machine purchase is warranted. However," Swenson asks, "what if the analysis was based on a certain price level for a commodity, and the price plummets because of a change in the world supply-demand balance? What if development of new technology next year makes this year's investment obsolete? An analysis that is well thought out will increase the odds that a decision will provide a positive outcome, but it is not guaranteed," he concludes.

How much are you really spending on energy?

A group of Canadian scientists and researchers examined the direct and indirect costs of energy use in farm operations on the Prairies. As they noted in a paper published in 2008 containing the results of their study, agriculture on the Canadian prairies is very dependent on fossil fuel energy, but nitrogen fertilizer is the main energy input. Fertilizer energy accounts for about 50 per cent of prairie agriculture energy input. Fuel energy is not quite 30 per cent.

The paper, *Decoding your fuel bill: What is your farm's real energy bill?* examines the direct and indirect energy inputs required for crop production activities, including fuel, fertilizer, herbicides, machinery use, cropping systems, crop choices, and crop rotations and sequences. The study found that no-till production practices reduce energy requirements for fuel and machinery, and reduce total energy use by up to 20 percent.

The study's authors note that the costs associated with fertilizer-based energy inputs potentially can be reduced through increased fertilizer use efficiency, but there is limited knowledge and technology available to do this. They suggest, however, that producers have three options to reduce their use of nitrogen fertilizer:

- Grow nitrogen fixing legume crops
- Use grain legumes such as field pea, lentil or sweet clover as a green manure crop
- Grow a legume hay, such as alfalfa, in rotation with annual crops

The researchers note that grain legumes like field pea and lentils will supply their own nitrogen needs and supply a small amount of residual nitrogen for the following crop. They also point out that green manure crops might only be feasible if fallow is already part of the crop rotation. Alfalfa production would have the greatest impact on the cropping systems, and on farm returns, they state. However, they add, some different equipment is required, and cattle and sheep herds would have to increase to use the additional forage production.

The following table from the paper illustrates the various energy inputs for selected crops using no-till and conventional tillage practices, expressed in MegaJoules (MJ) per acre. A MegaJoule is the energy required to move a one-ton vehicle at 160 kilometres (100 miles) per hour.

Table 1. Energy inputs (MJ/ac) for selected crops and tillage practices

	Cereals		Canola		Pulse		Rotation Alfalfa	
	Conv.	Zero	Conv.	Zero	Conv.	Zero	Conv.	Zero
Seed	100	80	13	10	80	71	8	8
Fuel	1309	717	1441	758	950	717	1110	846
Fertilizer	1448	1448	1404	1404	145	145	120	120
Herbicide	72	212	52	192	156	295	46	119
Machinery	402	235	423	263	314	235	161	117
Total	3331	2692	3333	2627	1920	1797	1445	1210

Values will differ from other studies, especially the energy for fertilizer. Studies that used the energy values reported in earlier studies, for example, will be about 40% higher those reported here. The energy reported by Natural Resources Canada to produce nitrogen is 20.5 MJ/lb.

The entire paper can be downloaded for free from Prairie Soils and Crops, www.prairiesoilsandcrops#AF3FFD, but you need to create a login identity to do so. The findings in the paper are for the Canadian prairies, including the more moist Parkland area, so you may need to adjust these findings according to your location.

Other studies of interest examining the effects of management practices on the performance of specific crops include, "Influence of alternative management methods on the economics of flax production in the Black Soil Zone", and "Effects of alternative management practices on the economics, energy and GHG emissions of a wheat-pea cropping system in the Canadian prairies". Links to these studies are provided under "Additional Resources" at the end of this chapter.

Management strategies

Ideally, most producers would be happy spending less time in the tractor cab and more time gathering information, planning for the future of their operation and making management decisions based on their plans. A connected goal would be to spread out the workload at seeding and harvest times. Making a few more dollars at the end of the day would be a nice bonus from the entire process.

Subjects such as crop rotations and crop sequencing are covered in detail in the Pest Management section of this manual, but these management practices also have significant economic impacts on farm operations. These impacts include not only crop yields, but also input, machinery and fuel costs. The time and effort required to make the operation sustainable also comes into the equation. The following sections provide insights into various approaches to managing no-till operations.

Integrating livestock into a no-till operation

The Manitoba Zero-Till Research Association (MZTRA) is a non-profit, producer-directed operation that conducts field-scale research into zero till production problems. The Association operates a farm located north of Brandon, in southwestern Manitoba.

MZTRA farm manager Lindsay Coulthard spoke about the farm's research activities at the 2010 annual meeting of the Saskatchewan Soil Conservation Association. Those activities include using forages in direct seeded rotations, assessing reduced input cropping systems, using legumes to "grow" nitrogen in the soil and incorporating an integrated pest management system through effective crop rotation strategies.

Lindsay Coulthard

The farm conducts its research on eight fields, with four in annual crop production and the remaining four with livestock included in rotations of cereal, flax, pea and alfalfa production. The alfalfa is grown for three years. It is baled as dry hay, or yearlings are grazed on the field. No fertilizer is added during the years the alfalfa is grown. After the second cut of alfalfa, Coulthard says, the plants are terminated with glyphosate, 2-4D, or amitrol.

"We leave the taproots in the soil to improve water infiltration and nutrient cycling," Coulthard says. "Integrating livestock into the operation has reduced our inputs, but has not made a big difference in the economics of the operation." This is largely because of depressed livestock prices in Canada. However, he says the MZTRA will continue to look at refining the system because livestock grazing returns most of the nutrients harvested in feed back into the soil. Between 2005 and 2009 weight gains averaged 290 pounds per acre and 2.92 pounds per day.

Coulthard notes several advantages gained by including alfalfa in rotations on the research farm. These include high nitrogen fixation, deep rooting for nutrient cycling, soil structure improvements, better water holding and infiltration, reduced soil salinity and reduced use of herbicides.

"Growing alfalfa for three years also means we're using excess water, which allows us to get on the fields earlier than in areas with annual crops. This rotation does limit your crop flexibility" says Coulthard. The increased water requirement may reduce yields in drier years. This rotation does change the weed spectrum you're dealing with, but I don't know if that is an advantage or a limitation," he says.

Coulthard adds that integrating livestock into the no-till operation means more labor is needed to move livestock around, and for haying and baling. It will also likely mean a larger investment in fencing.

"Choose plant species that will provide solutions for your soil and operation," Coulthard advises. "Use legumes in your rotations to get nitrogen release and cycling. And choose plant species that won't become weeds in subsequent years."

Dollars can flow from a dynamic approach to crop sequences

No-till cropping systems allow producers to implement more intensified and diversified production, but this ability means the decision about what crops to grow becomes more complex. Dr. Dave Archer and colleagues at the USDA-ARS Northern Great Plains Research Laboratory at Mandan, North Dakota, have published a paper proposing a dynamic cropping approach, where management decisions are adjusted annually based on changing climatic and economic conditions. However, the paper cautions, "… profitable cropping decisions require not only identifying what crop is likely to generate the highest net returns this year, but also the impacts on future production options."

Field research was conducted near Mandan from 1998 to 2005 to determine the influences of previous crops and crop residues on seed production in a no-till system. This project was done in two phases. One phase initiated in

1998 collected data on barley, canola, crambe, dry bean, dry pea, flax, safflower, soybean, sunflower and spring wheat. The second phase initiated in 2002 collected data on buckwheat, canola, chickpea, corn, dry pea, grain sorghum, lentil, proso millet, spring wheat and sunflower. During the first year of each phase crops were seeded in adjacent strips. The following year the same 10 crops were seeded perpendicular to the original strips, creating a 10 by 10 crop residue matrix.

A second site the year following the initiation of the phase was begun, so each crop sequence would be present for two years. Fertilizer was applied to all crops at seeding (just before seeding for corn and sunflower) to all crops except dry pea, chickpea and lentil. Precipitation during the 1999 and 2000 was average to above average while the 2003 and 2004 growing seasons were below average of the long-term average.

For the 2002-2005 study, net returns for each crop sequence were calculated based on the estimated costs and observed yields using 2006 marketing year average prices. Using these prices, the researchers were able to calculate the net return for each crop relative to the average net return for all crops within a given crop residue. The study includes a table based on averages within rows which makes it easy to identify the highest and lowest net returns, and those in between, from crops grown on spring wheat residue, for example. Based on the 2003 and 2004 crop yields the values in the table show that buckwheat would have been the most profitable crop of the 10.

Table 1

Relative Crop Profit Matrix

Crop Residue \ Crop	Buck-wheat	Canola	Chick-pea	Corn	Dry Pea	Grain Sorg.	Lentil	Proso Millet	Spring Wheat	Sun-flower
Buck-wheat	55	-8	-30	-46	2	-31	9	27	51	-31
Canola	52	-32	-8	-24	-10	-36	2	20	39	-4
Chick-pea	35	-30	-30	5	-3	-29	-18	22	44	3
Corn	50	-19	-26	-27	5	-43	7	15	39	-2
Dry Pea	66	-43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44	-2
Grain Sorg.	33	-22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43	-3
Lentil	41	-41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48	-6
Proso Millet	31	-36	2	-10	11	-59	13	7	37	4
Spring Wheat	47	-50	-1	-10	-2	-46	18	2	39	1
Sun-flower	51	-30	-23	-21	20	-37	5	25	43	-34

1st Year Net Return advantage for growing Buckwheat rather than Spring Wheat:

$47-$39 = $8/acre

However, the paper's authors caution that the profitable net return for buckwheat in their snapshot does not account for the effect of growing buckwheat on net returns next year, which they call the rotation effect. A second table, based on averages within columns, shows that crop sequence can have a substantial effect on net returns. For example, in this study the net returns varied as much as $72/acre for corn, depending on the sequence in which it was grown.

Continuing the example, the second table shows that, working backward from the second year, using 2006 prices, the highest net return following either buckwheat or spring wheat occurs when growing buckwheat, as shown by the circled row in Table 2. The rotational effect of buckwheat on buckwheat was -$3/acre and the rotational effect of spring wheat on buckwheat was +$16/acre, meaning buckwheat had a net -$19/acre rotational effect compared to spring wheat. Overall, the researchers concluded that spring wheat residue was relatively more beneficial than buckwheat residue on a subsequent buckwheat crop, regardless of price.

Table 2

Rotation Effect Matrix

Crop Residue \ Crop	Buck-wheat	Canola	Chick-pea	Corn	Dry Pea	Grain Sorg.	Lentil	Proso Millet	Spring Wheat	Sun-flower
Buck-wheat	-3	11	-26	-43	-9	-3	-3	-2	-3	-35
Canola	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Chick-pea	-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Corn	-5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Dry Pea	38	6	28	29	-8	15	11	19	19	23
Grain Sorg.	-26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Lentil	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Proso Millet	-12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Spring Wheat	16	-4	30	20	14	8	32	0	11	23
Sun-flower	-8	-12	-20	-19	8	-11	-9	-6	-13	-40

Average effect of Buckwheat on net return for subsequent crops: -$12/acre
Negative effect on 9 of 10 subsequent crops.

Average effect of Spring Wheat on net return for subsequent crops: +$15/acre
Positive effect on 8 of 10 subsequent crops.

Table 2 can be used to look at the rotational effects for a specific crop residue across all 10 crops. For example, with buckwheat crop residue there was a negative rotational effect on nine of the 10 crops. The only exception was canola, where net return on buckwheat residue was $11/acre higher than the average net returns across all 10 crop residues.

The study's authors note that taking rotation effects into account may help increase profitability, if (and it's a big if) you can anticipate what prices and yields will be two years into the future. They note that while the magnitudes of crop sequence effects in Table 2 are affected by crop prices, the relative rankings within each crop are not affected by price. The information in Table 2 is also useful for anticipating risks to changing prices. For example, spring wheat had a beneficial rotational effect for nine of 10 crops, while buckwheat had a beneficial rotational effect for only one crop.

Archer and the other researchers involved in the study emphasize that it is important to use current crop and input prices in making comparisons of net returns for different crops. They recommend using a tool like the Interactive Crop Sequence Calculator, which can be requested from USDA Agricultural Research Service at www.ars.usda.gov/Main/docs.htm?docid=10791 to assist in making these comparisons.

Finally, the study's authors warn that, "Yield impacts could be drastically different in average and wetter-than-normal years. The approach we have illustrated here is a general approach that can be used with additional information on crop sequence effects, including yield under other climate and soil conditions, as well as more detailed information on underlying causes for yield effects, such as soil water relationships, diseases and weed pressures, and soil quality effects."

A round-up of management tools for your farm

On-farm research is one of the most effective ways of answering the question, "Will it work on my farm?" Throughout this chapter several tools have been mentioned that have the potential to deliver economic paybacks and environmental benefits. If a product or practice is consistently successful out in the field, then it can be implemented with confidence. Failures can also be learning experiences, saving time and money by experimenting on a small scale before introducing a new product or practice on the farm. Check out the following useful tools to assess whether they might give your bottom line a boost.

Interactive Crop Sequence Calculator

The Northern Great Plains Research Laboratory has available an interactive crop sequence calculator on a CD that you can order from the NGPRL online, at www.ars.usda.gov/Main/docs.htm?docid=10791. The application currently is based on information from two research projects conducted at the lab.

On-Farm Research Guide and Data Analysis Tool

The Indian Head Agricultural Research Foundation at Indian Head, Saskatchewan has developed two tools to assist producers. The research guide offers guidance on how to plan and implement simple on-farm research experiments. The Data Analysis Tool is a spreadsheet application designed to enable producers to compare results of two treatment experiments. These experiments could include crop yields with or without fungicide, herbicide or fertilizer applications, or straight harvesting versus swathing. Both can be downloaded from the IHARF website, www.iharf.ca/.

Web Soil Survey

The USDA – NRCS offers an online soil survey tool that provides soil maps and data for almost every county in North Dakota, and for more than 95 percent of the counties in the United States. Soil surveys can be useful tools for farm-specific, local and wider area planning. Access the soil survey at websoilsurvey.nrcs.usda.gov/app/HomePage.htm.

Yield Data Cleaner

Yield monitors are useful tools, but some of the numbers they report at the upper and lower ends likely don't exist. These numbers are caused by gaps and spurts in the grain stream being monitored, incomplete passes on the combine and other errors. Spreadsheet applications recognize that these odd numbers pop up in many situations, and provide a way to remove these "outliers," thereby providing cleaner data. The USDA-ARS has also developed yield data-cleaning software that is available online for anyone who wants it. You can download the application at www.ars.usda.gov/services/software/download.htm?softwareid=20.

UMAC ZoneMap

This free service utilizes satellite imagery to build zone management maps. To utilize the potential of variable rate technology, it is necessary to know and locate the changes in nutrient content, soil characteristics, yields, or plant conditions within a field. ZoneMap tries to capture these variabilities using information provided by remote sensing technology and/or routine field surveys and helps users to design variable rate application maps. You can go to the web address below to register and utilize this NASA-UND application at http://zonemap.umac.org/.

Financial Analysis

Several university websites provide producers opportunities to download software and spreadsheets to help answer such questions as, "How much does it cost to grow and acre of wheat?" "Is it better to own or lease equipment?" "Is it better to own or rent land?" "What is my ability to service debt?" The following websites can provide you with the information and tools to answer these questions.

NDSU Extension Service - www.ag.ndsu.edu/pubs/farm_management.htm

University of Illinois - www.farmdoc.illinois.edu/pubs/FASTtool.asp

Ohio State University - aede.osu.edu/programs/FarmManagement/Budgets/download.htm#MachCosts

University of Idaho - www.cals.uidaho.edu/aers/r_software.htm

Producer Profile

Necessity is the mother of invention, and a foundation for sustainability

Two of Art Cowan's favorite sayings are, "Where there's a will there's a way", and "Necessity is the mother of invention." A review of his life farming near Hartney, Manitoba, proves the wisdom of both sayings.

Art Cowan

Art began farming with his father in 1951. He married in 1953 and the couple raised two boys and three girls on the farm. Necessity came into play in the early 1960s when the couple bought a half-section just west of the home farm.

"It was highly erodible sand, with large sand ridges where the old fences had been. It was a legacy from the dirty thirties," Art says. "It had basically been abandoned, and the native grasses had come back to protect the soil. It was obvious that if the weeds didn't get you, then the wind would."

Art first began continuous cropping the land, using minimum tilling to keep cover on the soil. After a while, he was losing the battle to quack grass and Canada thistle. By this time Roundup was available, and even though it was very expensive at the time, it allowed him to reduce tillage even more. That's when he began to experiment with no-till.

Art began by seeding 40 acres of fall rye, using a Haybuster drill rented from a local dealer. The crop was encouraging. Air tanks were available, so the will and the necessity came together again. He converted his old cultivator to an air seeder.

"We tried a wide variety of openers over the years," Art says. "We decided not to try to kill weeds and seed at the same time, because seeding depth and seed contact with the soil were the most important factors."

"By this time," he continues, "we were able to produce as much from our so-called poor land as from our good land. In 1986 we decided to go 100 percent no-till and have been that way ever since."

Art describes his crop rotation at that time as "pretty basic." It usually followed a rotation of wheat, canola, wheat, peas, wheat, sunflower, with some variation based on market prices. Over the years he added some legumes, such as peas and lentils to the mix. It has made a difference. "Our organic matter has improved considerably," Art observes. "The earthworm population has increased dramatically and soil tilth is much better."

By 2000 the family had 8,000 acres to look after. Art and his youngest son Bill decided to bring livestock into the operation, and to expand the rotation to include alfalfa for soil health and nitrogen fixing, and corn or barley for weed control using new chemical classes.

"We knew absolutely nothing about the livestock business," Art says, "but a neighbor, Mike Morrison, had a feedlot available. Mike had studied feedlot management at Olds College (an agricultural college in Olds, Alberta), so we decided to build a 2,000 head feedlot. Mike and a grandson, Dane Cowan, run the feedlot. Two other grandsons, Nick and Del, run the grain farm and pitch in at the feedlot when they need help there."

Manure from the feedlot side of the operation is spread on the fields, including any areas that need special treatment, Art says. The goal is to make the entire operation as sustainable as possible. Asked for his final thoughts about his life farming, Art states, "I would like to thank the members, directors and advisors of the Man-Dak Zero-Till Association – especially Jim McCutcheon of Carman, Manitoba and Dwayne Beck at the Dakota Lakes Research Station – for their contributions to sustainable agriculture."

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Additional Resources:

"Profitability of Grazed vs. Hayed Forage in the Rotation", Manitoba Zero Tillage Research Association.
www.mbzerotill.com/files/Profitability%20of%20Grazed%20vs.%20Hayed%20Forage%20in%20the%20Rotation.pdf

"Influence of alternative management methods on the economics of flax production in the Black Soil Zone". M. Khakbazan, C. A. Grant, R. B. Irvine, R. M Mohr, D. L. McLaren and M. Monreal. Download at: http://pubservices.nrc-cnrc.ca/rp-ps/absres.jsp?jcode=cjps&ftl=CJPS08179&lang=eng

"Effects of alternative management practices on the economics, energy and GHG emissions of a wheat-pea cropping system in the Canadian Prairies". M. Khakbazan, R. M. Mohr, A. A. Derksen, M. A. Monreal, C. A. Grant, R. P. Zentner, A. P. Moulin, D. L. McLaren and C. N. Nagy. The article was published online in 2009 by Soil & Tillage Research. The abstract can be viewed at: www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TC6-4V8FF96-2&_user=10&_coverDate=06%2F30%2F2009&_rdoc=4&_fmt=high&_orig=browse&_srch=doc-info(%23toc%235162%232009%23998959998%231024689%23FLA%23display%23Volume)&_cdi=5162&_sort=d&_docanchor=&_ct=27&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=ad0a2b6de37d33c1000f5990e10d9d56. The downloadable pdf of the entire article can be purchased at the same source.

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future," he says. "Accountability to consumers and the environment is where we are headed, and therein lies the opportunity."

– by Bill Armstrong

Chapter sources

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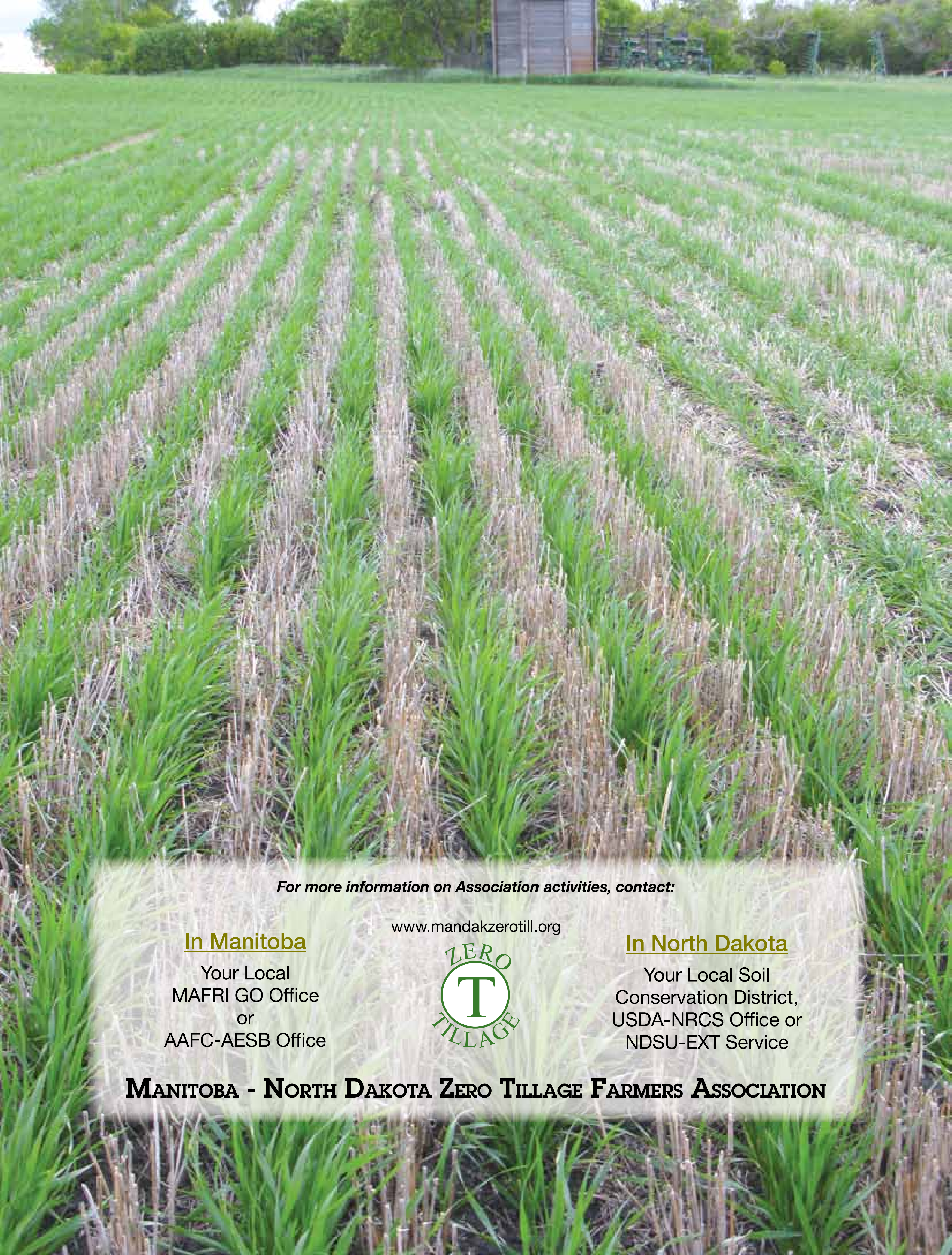

For more information on Association activities, contact:

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