The Manitoba-North Dakota Zero Tillage Farmers Association

Advancing the Art

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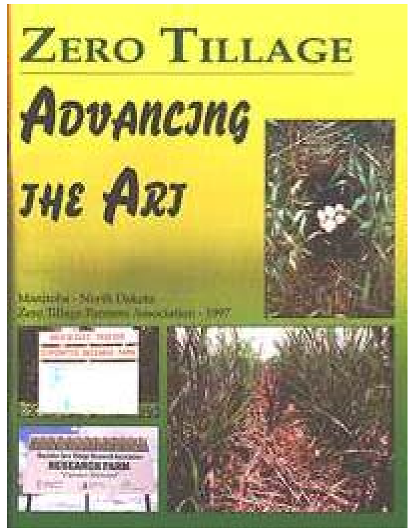

Advancing The Art ~ PUBLISHER'S NOTES

Front cover photos:

The unique cross-border relationship between farmers in the Manitoba-North Dakota Zero Tillage Farmers Association and the leadership being taken by zero till farmers on both sides of the border are emphasized by the farm signs from the Area IV Cooperative Research Farm at Mandan, North Dakota and the Manitoba Zero Tillage Research Association Farm at Brandon, Manitoba. The zero till farmer's desire to work in harmony rather than conflict with nature is illustrated by the duck nest between the rows of an emerging no-till crop and by the duff layer which is created in a zero till farming system.

ZERO TILLAGE ~ Advancing the Art

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Advancing The Art ~ From the Association

A few years ago, we published the *"Zero Till Production Manual"*. It was farmer driven, farmer written and farmer flavoured. It was, and is, a valuable guide for North American farmers as they moved into zero till and other conservation cropping systems. Indeed the basic techniques advocated caught a much larger audience. Copies of the manual found their way throughout Canada and the United States, and overseas to Africa, Australia, Europe and South America.

In the years since the manual was printed, ongoing farmer experiences coupled with inquiry by the scientific community have verified the soil and environmental benefits the early zero till producers spoke of. In view of this continuing flow of information, it seemed appropriate to publish a manual aimed not so much at getting started, but rather at using the advancing

technology to maintain systems now in place. This should help us to look forward and make changes as needed to ensure we are *"Advancing the Art"* of zero tillage.

The manual production has been guided by the Education Committee during the terms of two Association Presidents, John Raisler and Stan Rampton. 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 the future. Let's strive to make it hospitable and sustainable by *"Advancing the Art"*of zero tillage.

Stan Rampton Lyle Samson

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Advancing The Art ~ From the Editors

"Advancing the Art" presents recent findings and ideas that should further improve zero tillage farming systems. Throughout the assembly of this manual, members of the Manitoba-North Dakota Zero Tillage Farmers Association encouraged us to view farming as both a science and an art. These farmers want to keep the land productive and healthy for future generations by the continued use of zero tillage. Our goal was to publish information that would encourage farmers and agricultural scientists to further improve farming without tillage.

While producing this manual, we invited the contributors to focus on the Leading edge ideas where the science and art of agriculture overlap. We invited the contributors to submit thought provoking material - to challenge the reader to consider not only *what is* but *what might be* as we advance the art.

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.

We have generally avoided reference to trade names as their formulations, registrations and regulations vary between Canada and the United States. Pesticide and fertilizer information is presented in the context of research done in specific geographic areas. Please refer to product labels for recommendations, which must be followed. To ensure a broad international understanding, both metric and imperial measurements are used.

The diverse soils and weather of the Manitoba-North Dakota region are reflected in its agriculture. Given this diversity, it was appropriate for this publication to include information from the entire "northern plains" region of North America. This includes the northern Great Plains of the United States and the Prairie and Parkland regions of Canada. Enough similarities exist across this vast region to allow concepts developed in one area to be adapted to other locations.

Advancing the art is never quick or easy. In the case of zero tillage, it will take the commitment and cooperation of farmers and scientists. In producing this manual, we received generous assistance from all who were involved. For this we are grateful.

Daryl Domitruk Co-editor

Bill Crabtree Co-editor

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Advancing The Art ~ SUSTAINABILITY

The earth's thin covering of soil is very fragile. There is overwhelming evidence that over-cultivation is leading to its destruction. For centuries, tillage has been used to grow crops. Today, farmers are expected to produce food in ever increasing quantities. To meet this expectation, soil erosion will have to be conquered. Zero tillage farming can produce abundant food while protecting the soil. Additional benefits to air, water and wildlife make no-till farming the most sustainable choice for us all. Society and farmers need to work together to ensure that agriculture and the environment have a good future.

THE SOIL ISSUE

Soil erosion is the longest running environmental concern of farmers. But, for the greater urban population, environmental priorities are often diverted elsewhere. Media focus on more graphic environmental catastrophes has left our soil in the background. Against rainforest destruction and giant oil spills, the slow decline of our soil seems mundane. But, how different is soil erosion from wildlife extinction or pollution?

THE SOIL AND US

In communities dependant on agriculture, conserving biodiversity or preventing pollution means saving the soil. People in these regions know the essential links between the soil and environment.

The ecosystems which flourished in the northern plains prior to European settlement produced some of the most fertile soils in the world. This soil gave growth and prosperity to two young nations. But, as agriculture developed to provide food and fibre for a growing population, major changes occurred.

Crops and tillage replaced grasslands, the bison, forests, and fire and much land was drained. Life changed on the northern plains, from the largest animals down to microorganisms. Some species adapted and others disappeared. Some even found the new surroundings hospitable and flourished.

The soil changed as well. Tillage became an integral part of early farming's contribution to the new landscape. Tillage helped provide food and income in an era of small farms, cheap energy and low world food demand. Eventually with widely adopted mechanization, tillage gave rise to soil erosion.

EROSION AND US

The soil is alive. It lives, breathes, dies and lives again in a grand and complex web. Erosion of the soil breaks this web. Fungi, bacteria and insects, which provide food to plants, are among the first to go. Life in the soil world becomes difficult and, at this very basic level, biodiversity declines.

Eroded soil is deposited into streams and rivers. This slows their flow and diverts their course through silt deposits, which also fill dams. Nutrients which were meant for crops are washed into lakes with the soil. These nutrients feed algae which choke out plants and fish, destroy lakes and upset nature's balance.

When soil erodes, plants lose their anchor. Soil alone can not trap and hold most of the snow or rain that falls on it. Soils that have been degraded by excessive tillage lose their structure and instead of the water percolating down to the root zone where plants can use it, it rushes off the land creating even more erosion.

Unless you live on or near 'the land', these events are hardly noticed. However, when soil erosion causes water pollution; or when electricity-generating dams silt up, causing energy costs to rise, or when recreation, transportation or other forms of commerce are interrupted, the effects of soil erosion become more well known.

In extreme examples throughout history, unchecked soil erosion has reduced the capacity of people to feed themselves and civilizations have collapsed as a result.[1]

THE ZERO TILLAGE SOLUTION

A few decades ago many northern plains farmers recognized the soil erosion problem. When it threatened their way of life and that of their children, they took action. Considering the importance of soil, these farmers adopted the practice of zero tillage which quickly improved the quality of the soils and viability of their farms. These farmers have now mostly conquered soil erosion.

Zero tillage benefits farmers in ways described in this manual. Mostly, zero till offers a better chance to make a decent living by farming in a more soil-caring way. Zero tillage also benefits the whole of society as it allows farmers to produce a secure and stable food supply.[2]

Zero till helps maintain and improve the environment, too. Zero till farms use less fossil fuel since tractor use is dramatically reduced. This reduces emissions of green house gases and other pollutants. As well, zero till soils build up their organic matter which is made of decomposing plant material, insects and earthworms. Carbon from the air is a big ingredient of organic matter. Gains in soil carbon reduce the amount of CO_2 in the atmosphere where greenhouse gases may already be excessive.

The study of how no-till effects wildlife is still young. Well-managed zero till soils can develop to more closely resemble the original soils of the native grasslands.[3] Healthy soils support a greater diversity of insects and microorganisms which are important to the broader ecosystem. Studies in Manitoba[4] and North Dakota[5] showed improved habitat for ground-nesting birds especially where fall-seeded crops are planted, in zero till systems. Cultivation in the spring would otherwise destroy their nests. In addition, these same birds survive better in zero till fields because their predators feed on insects and small mammals which are abundant in no-till fields.

NO TILL - THE PERFECT SYSTEM

Of course, no system is perfect. Organic farmers, often viewed by the public as a panacea for sustainable agriculture, must deal with problems of soil erosion and reduced yields. Likewise, no-tillers must ensure their crops efficiently use the extra water they trap to avoid it carrying nutrients and herbicides into ground-water. Zero till rotations (component 4) can alleviate this problem while being profitable today and sustainable tomorrow.

Long-term sustainability will only be achieved if farmers are allowed to make economically viable choices in the short term. Without these short-term options farmers can be forced into mining, rather than nurturing the land. Lingering frontier-day myths about the boundless resources of the plains must be rejected and the development of superior farming systems must be encouraged. For their part, zero till farmers want to keep "advancing their art" to ensure their precious capital, the soil, will continue to improve.

Pesticides are an important tool of conservation-minded farmers. Without doubt less expensive glyphosate, the non-selective herbicide used in place of tillage to control weeds, gave farmers the means to adopt zero tillage. Today's zero till farmers use pesticides as part of a planned and integrated pest management (IPM) strategy. The economic advantages of IPM help farmers earn a living in both an environmentally and socially responsible way. At present, neither would be possible without pesticides.

ADOPTING ZERO TILL

With society's support, it is up to farmers to ensure that zero tillage stays with us. So - how can farmers adopt and maintain zero till?

Each farm is a system. No single part of the system, like soil, location, climate, crops, weeds or tillage, can be viewed independently from the others. The farmers who manage the operation, and their families, must also be thought of as a part of the system. One of the fundamental mistakes made by many beginning zero tillers is to view the change in tillage method as independent from most other parts of their system.

Simply substituting a spray where tillage was previously used is a recipe for long term disaster. It can work agronomically for about 6 years or so, but invariably, problems occur. Financially this approach never takes full advantage of the benefits of zero till and may eventually lead the producer to return to tillage. Failure might occur if zero tillage is used in crop rotations that are designed for tillage. In order to optimize the benefits of zero till, it is imperative that every part of the system be designed and directed specifically for zero tillage.

We offer these comments to help orient the reader to the thought processes needed to most successfully use this manual. By necessity, this manual is broken down into chapters which are subsequently referred to as components. The reader must gather the information from these components and other sources and design a system that works in an individual situation. For instance, using a diverse rotation to exhaust weed supplies does little good if high disturbance seeding or fertilizing operations are also used.

Among successful, veteran zero till farmers, the process of learning to use a systems approach is often referred to as 'the brain transplant'. There will be similarities and differences among systems designed by neighbouring farmers, just as with their conventional systems. There are no set recipes for success. Success comes from understanding the system and managing it to take advantage of the substantial benefits of zero tillage.

"Archaeologists can show where, in the past, tillage has destroyed 'milk and honey' soils and caused civilizations to collapse. We don't want to repeat their error! We now have the technology that will help us save the soil - if we use it wisely."

*Bob McNabb, Minnedosa, Manitoba*

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Advancing The Art ~ THE NO-TILL SOIL

The switch to no-till causes many soil changes. The type and extent of changes depend on soil type, climate and farming history. Farmers who have no-tilled for some years usually notice more soil moisture, better seedbed tilth, more organic matter and earthworms, less soil erosion and improved trafficability. These improvements are due to changes in soil physical, chemical and biological conditions which occur with successive years of low disturbance seeding into standing crop residues. On the northern plains, mature zero tilled soils often resemble soils in their natural state. In tillage-based systems, cultivation is used to create a seedbed every year. Zero till creates a permanent seedbed - one that must be maintained rather than re-built each year.

ORGANIC MATTER (OM)

Zero tillage normally increases organic matter, especially if summer fallow has been eliminated. Organic matter (OM) consists of living and dead plant roots, microorganisms, insects and earthworms. The active fraction of OM, which is either alive or rapidly decomposing, greatly increases with no-till practices. In some soils OM does not increase much, even after successive years of no-till. These soils are likely to have a large natural OM content or a high turnover of OM.

No-till improves soil structure. This results when OM combines with soil mineral particles to form aggregates. Conventional tillage destroys soil aggregates. One advantage of the aggregates formed in no-till soils is the large network of pores which form between them. This network serves as a subway system for the movement of nutrients, air and water to crop roots. Like aggregates, these pores are destroyed by tillage.

THE "DUFF LAYER"

The "duff" layer is the thatch of plant material on the surface. No-tilling allows this layer to build up to useful levels. This duff layer suppresses weeds and reduces evaporation. However, the duff can become too thick if the cropping system is not managed properly. This occurs most when high residue and non-legume crops are grown back-to-back.

The duff layer can be managed to optimal levels using diverse crop rotations. Useful crops are those that have low residues, decompose quickly and are rich in nitrogen, like lentils, field peas or beans. Growing these crops will improve subsequent crop emergence. Mechanical shifting of some of the duff layer from the seed row into the inter-row will further suppress weeds and reduce evaporation. It will also create a warmer soil zone, giving quicker crop emergence.

No-till soils evolve over time. Changes in structure and OM affect water and nutrients. Crop management must be adapted to fit these new conditions.

THE ROOT ZONE

Below the duff, in the root zone, important natural cycles of OM formation and decomposition occur. Decomposition occurs through chemical oxidation, when the OM contacts oxygen. Soil aggregates formed with no-till will slow this decomposition by protecting some OM from exposure to oxygen. This soil building process continues until a new equilibrium between OM formation and decay occurs.

SOIL MOISTURE

No-till fields catch more snow and hold more melt water than conventional fields. In addition, the duff layer reduces water losses to evaporation. A properly structured no-till soil should make this extra water available to crops.

Contrary to popular opinion, roots do not seek water. Rather, water moves through soil pores to roots, like electricity through a conductor. Water movement is determined by the distribution of soil pore size and the degree to which soil pores are connected.

No-till soils maintain a network of hair-like pores which are particularly good at supplying water to plant roots. Due to increased continuity among pores, drainage in most no-till soils actually improves over time. Using forages, like alfalfa, in the rotation will further improve deep drainage as after the roots decay they leave channels for the water to move through.

Soil water should be used and not lost, this is possible with good crop management and rotations. An appropriate crop rotation will remove all of the water from the larger pores by harvest time. The cycle of snow catch and infiltration is then able to begin again next spring.

In poorly drained soils, growing high water using crops in the rotation may be required to make no-till viable. This can be achieved by continuous cropping, or by growing crops such as alfalfa, sunflower or corn (see component 4).

SURFACE SOIL TEMPERATURE

The surface 5 cm (2"), or the seed zone, of no-till soils, may warm more slowly in spring and cool more slowly in autumn than in cultivated soils.[1] Snow trapped by standing stubble insulates the soil from the cold during winter. This insulation is essential for the survival of winter wheat, but it may delay spring warming if the soil is saturated.

With common hoe-type seeding tools, enough in-row tillage occurs to warm the seed zone, allowing spring sown crops to germinate and emerge in good time. Zone tillage using row cleaners mounted on planters has been used to grow heat responsive row crops like corn, soybeans and dry beans. Low disturbance disc drills may also require row cleaners to encourage soil warming.

The duff layer reduces the frequency of freeze-thaw cycles in the seed zone, maintaining aggregates and preventing crusting.

In clay soils, the seed zone may compact, and the duff layer may prevent the freeze-thaw cycles from effectively loosening it. Ice lenses can form horizontal to the surface and, as they melt, the soil subsides to its original position without being softened.

DEEP SOIL TEMPERATURES

Below 5 cm, in the root zone, no-till soils may be warmer and wetter from fall through to spring. Warmer root zone temperatures in the fall can increase nitrogen and sulphur release from organic matter.

Losses of mineralized and fall-applied nitrogen through denitrification, immobilization and leaching may be somewhat higher in this slightly warmer soil zone. Warmer winter temperatures may also raise the frost line. This can increase water infiltration in no-tilled soils, particularly if a network of large pores has been established.

The cold winters and short summers in the northern plains override tillage effects on root zone soil temperature. In this short growing season, most roots are in the top 60 cm (24") of soil. Temperature differences among tillage systems in the rooting zone are small and probably do not effect the uptake of water or nutrients by plants (Table 1).[1]

Table 1: Effect of tillage on average monthly soil temperatures at three depths (1991-1994) in 0C.(1)

	40 cm (16")		80 cm (32")		120 cm (48")	
Month	ZT	CT	ZT	CT	ZT	CT
May	10.1	9.8	6.9	6.7	4.8	5.3
June	13.1	12.7	9.2	9.6	7.7	8.1
July	15.6	14.8	11.8	12.2	10.4	10.7
August	16.5	15.5	13.2	13.3	12.1	12.0

SOIL LIFE IMPROVES

Living things in the soil consist of microorganisms like bacteria, fungi, algae, protozoa, nematodes, and larger organisms like insects and earthworms. These organisms break down OM making nutrients available to plants. Before commercial fertilizer, crop residue breakdown and manure were the main source of nutrients for crops.

In general, soils that grow only grain crops are less biologically diverse than either pasture or undisturbed natural soils. Little is known about the relative importance of soil biodiversity to agriculture.

No-till changes the size and diversity of the community of organisms living in the soil. Tilled soils contain relatively more bacteria than no-till soils. These bacteria rapidly decompose OM, giving a quick release of plant nutrients. In contrast, no-till soils house relatively more fungi, which decompose residue slowly. The result is more gradual nutrient release.

While the moisture in no-till soils favours soil life, saturation reduces it. Early in the season, no-till soils commonly have a majority of their pores filled with water instead of air. If more than 60% of the soil pores contain water, aerobic (oxygen requiring) microorganisms give way to anaerobic (oxygen avoiding) microorganisms. At this stage, some nitrogen will be lost through denitrification.

Research on the heavy clay soils of the Red River Valley shows that, below 10 cm (4"), crops can be starved of oxygen regardless of the tillage system used. In heavy soils, high water using crops like alfalfa and corn are helpful in the rotation.

Standing stubble and the duff layer decompose more slowly than residues in the root zone. This occurs because contact with microorganisms is less and the low N content of crop residues, especially of cereal crops, slows the feeding of microorganisms. The rate of stubble and duff breakdown is also affected by the weather. Dry weather, and therefore soils, slows microbial feeding and activity while moist soil increases these.

The goal of managing soil life is to optimize residue decomposition and nutrient release for crop growth. Although this is easier said than done, crop rotation is critical. Residues from cereal crops contain much more carbon than nitrogen and may stimulate microorganisms to tie up nutrients. In contrast, legume residue has more nitrogen, which favours nutrient release by microorganisms. Legume residue is also a preferred food source for earthworms.

EARTHWORMS INCREASE

The best time to observe earthworms is in the spring or fall. The presence of earthworms is an outward sign of a healthy soil, although their effect on crop production is indirect and long term. Earthworm numbers are highest in pastures and lowest in conventionally farmed annual crop land (Table 2).[2] Earthworms help increase pasture production. As a result animals return more manure to the soil which, in turn, also supports earthworms.

Table 2: Earthworm in a silty clay loam in Indiana.(2)

Crop	Management	Earthworms/m^2
Continuous Corn	Plow	10
Continuous Corn	No-Till	20
Continuous Soybeans	Plow	60
Continuous Soybeans	No-Till	140
Bluegrass-Clover	Alleyway	400
Dairy Pasture	Manure	340
Dairy Pasture	Manure (heavy)	1300

There are two types of earthworms; deep burrowing (nightcrawlers) and shallow dwelling. No-till soils have both types, particularly nightcrawlers which use the duff layer for food.

Nightcrawlers form large, permanent burrows into the root zone. As they burrow, the worms perform "biological tillage" by mixing crop residue from the duff layer with the soil below. The burrows improve drainage and increase soil aeration. Plant roots proliferate through the soil using the burrows as easy passage. Earthworm castings cling to the walls of burrows and provide nutrients to plants.

No-till soils support several times more earthworms than conventionally tilled soils. Low soil disturbance keeps the worm burrows intact, and the duff layer provides food and protection from temperature extremes. Any soil disturbance is harmful to earthworms. Even minimum tillage soils have fewer earthworms than no-till soils.

However, no-till does not guarantee more deep burrowing nightcrawlers. For nightcrawlers to become established in a field, they must migrate from a nearby field, ditch or fence-row. Neighbouring conventional tillage fields may not be a good source of nightcrawlers. It may be necessary to collect nightcrawlers from a pasture or roadside and "seed" the target field by placing 4-5 worms under a mulch every 12 m (40') in the field.

Herbicides are considered safe for earthworms. Soil applied insecticides and anhydrous ammonia fertilizer may kill some earthworms in the narrow zone of application. However, the effect on the total soil population is small compared to the killing effect of cultivation.

Earthworm activity is probably a better indicator of soil biological health than soil organic carbon levels. Organic carbon is not necessarily an accurate indicator of a soil's potential to release nutrients or of soil building benefits. Perhaps the following business analogy is useful. A healthy business is one that has a good cash flow regardless of the assets. If soil assets are carbon and cashflow is microbial activity then zero tillage systems are seeing much more healthy soil businesses despite sometimes static organic carbon levels.

NUTRIENTS RECYCLE

Mineralization is a bacteria-driven process which turns the N within OM into ammonium. Nitrification is the conversion of ammonium into nitrate.

In tillage-based systems, mineralization is "boom and bust". Booms occur after tillage with busts following shortly after. In contrast, mineralization in no-till soils is more evenly spread over the season. For this reason, spring sown no-till crops should receive adequate fertilizer early in the season to help establish the crop.

Nitrification in no-till soils may continue even under dry conditions due to more soil moisture. However, in very wet conditions, nitrification may be inhibited sooner in no-till than in a cultivated soil because of a lack of oxygen. Nitrification of OM-derived ammonium, or of ammonium fertilizer, is rapid. If too much nitrate accumulates, then losses to leaching can occur.

Denitrification is the bacteria-driven process which turns N fertilizer into N gas which is then lost to the atmosphere. Compaction in the seed zone can create an oxygen-starved environment which favours denitrification. However, actual losses of N vary a lot within all tillage systems.

Over time, immobile nutrients such as P and K may become layered in no-till soils. For example, banded P may remain in the band for several seasons. This can give false soil test results. In contrast, studies in Manitoba have shown that K becomes concentrated in the upper root zone even when K fertilizer is not added.[3]

The distribution of the more mobile N and S nutrients may also change in no-till. However, these changes are difficult to predict because they depend on water content, pore size and the rate of OM oxidation.

In general, N mineralized from surface residues accumulates in the top 7.5 cm (3") of the soil. At the same time, some no-till soils show a build up of nitrate below the rooting zone. These N losses may occur because the crop rotation is not intense enough to use either the available N or water. Using deeper rooted or longer season crops may be necessary in some environments to avoid N losses.

What effect does nutrient stratification have on the crop? Under drought stress, nutrients can become stranded near the surface and be unavailable to crops. Conversely, P and K are less likely to be tied-up, making them more available to the crop.

With bands of P remaining intact, a downward shift in pH (toward acidic) may be noticed in the band. This does not mean the soil is being generally acidified. In fact, a reduction in pH of northern plains soils may often increase plant availability of micronutrients like Mn, Cu, and Zn, but not Mo.

Due to a poor environment for mineralization, standing stubble and crop residue in the duff layer are generally not good sources of N in no-till systems. However, surface residue is a better source of K and P since these nutrients are released by leaching from the residue as well as by microbial activity.

"With conventional tillage there is more run off and more puddling in low areas. Cultivated soils with a pulverized surface make it harder for the moisture to penetrate.... If you've got a pretty low spot on a zero till field where a conventional farmer would say 'I better go around that one' - we would lust go through it."


Ron Bell, Birtle, Manitoba

"There is so much that we don't know yet about what is going on under the ground's surface and what's taking place when you start mimicking Mother Nature, utlizing her whole array of plants for cropping...the opportunities ahead of us are amazing."


John Raisler, Beach, North Dakota

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Advancing The Art ~ ECONOMICS

Zero tillage improves the short and long term economics of farming and protects the soil and water on which we all depend. This is as true in Australia, Africa or South America, as it is in our northern plains. The idea behind zero tillage is to increase net returns through higher yields and lower costs. In nearly all conditions this is possible provided other issues like tradition and management abilities do not upset the decision making process. This component will show that once zero tillage is adopted management is as important as technology in making it pay.

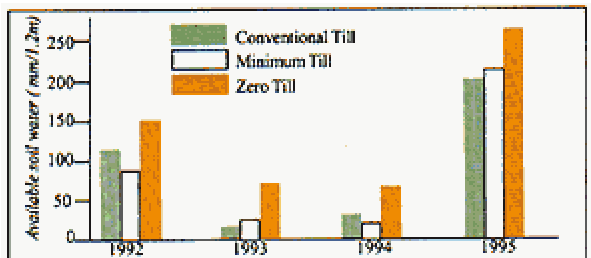

Figure 1: Effects of tillage on soil water at seeding at Minto, MB (1992-95).

WHY ZERO TILLAGE?

Zero tillage is now economical due to less expensive glyphosate and increasing costs for fuel, labour and interest relative to the value of grain. As well, improved seeding equipment and good agronomic practices give the opportunity for higher and more consistent yields. Whether the incentive to adopt zero tillage is yield or lower cost of production depends largely on farm location. In wetter areas of the northern plains, lower costs have been a great incentive. In the more arid regions, farmers have adopted zero tillage to save moisture and increase their yields.

Farmers everywhere are using zero tillage to manage risk and diversify their income. This is the first step toward achieving long term environmental, economic and social sustainability.

IMPROVED SOIL MOISTURE

Zero tillage can supply about 50 mm (2") more soil water at seeding time (Figure 1).[1] Up to 100 mm (4") of extra soil moisture has been measured in zero till fields. These water savings can protect crops from drought and translate into higher yield (Table 1).[2]

Table 1: Impact of tillage systems on the yields (kg/ha) of field peas, flax and spring wheat under different growing conditions on a thin black soil at Indian Head, SK (Gold Highlight shows % improvement of zero till over conventional till.

Tillage system	Growing season conditions**								
	Hot (1988)		Dry (1989)		Moist (1987)		Wet (1992)		Average
Field pea ZT	1181	*64*	1434	*24*	2134	*2*	2771	*14*	*26*
CT	718		1157		2089		2424		
Flax ZT	942	*52*	888	*99*	1691	*19*	2108	*19*	*47*
CT	621		446		1427		1775		
Spring wheat ZT	1957	*64*	1315	*76*	2396	*8*	3588	*-2*	*36*
CT	1196		746		2224		3655		
Average		***60***		***66***		***10***		***10***	***36***

* ZT-zero till, CT= conventional till

** Hot=temperature above normal with near normal precipitation

Dry=normal temperature with below normal precipitation
Moist=temperature and moisture in the normal range
Wet=temperature below normal with above average precipitation

Higher average yields make zero tillage less risky than conventional tillage systems. Moisture savings translate into an increased net return in a zero till system (Figure 2).[3] In this Manitoba example, less evaporative loss, increased snow trap and better infiltration of rain and snow with zero tillage gave higher yields and profits.

Typically, catching 250-300 mm (10-12") of snow returns 25 mm (1") of water. Broadleaf crops especially respond to this extra water because they are more sensitive to drought stress. Diversifying farms by growing broadleaf crops is a good economical strategy made less risky through zero tillage.

Even in the wetter, heavy clays of the Red River Valley, zero till systems can improve permeability of the soil, while protecting the crop from midsummer drought stress. Farmer yield comparisons in the wet Red River Valley show that zero tillage works comparatively well, particularly in dry years (Table 2).[4]

Table 2: Yields in t/ha (bu/ac) in the Red River Valley (Homewood, MB).

Crop	Year	Conv. till		Zero till	
Wheat	'77	2.4	(36)	3.2	(48)
	'83	3.1	(47)	3.1	(46)
	'85	5.7	(85)	5.1	(76)
	'87	3.2	(48)	3.5	(53)
	Avg	**3.6**	**(54)**	**3.7**	**(56)**
Winter wheat	'79	0	0	3.7	(56)
	'81	3.5	(52)	2.2	(33)
	Avg	**1.7**	**(26)**	**2.9**	**(44)**
Flax	'76	1.5	(23)	1.7	(26)
	'82	2.1	(32)	1.7	(26)
	'86	2.0	(30)	2.1	(32)
	Avg	1.9	(29)	1.9	(28)
Canola	'78	2.5	(35)	2.3	(34)
	'84	2.0	(30)	1.9	(28)
	'88	0.7	(11)	1.8	(27)
	Avg	**1.7**	**(25)**	**2.0**	**(30)**

In the majority of soils farmed by the members of the Manitoba - North Dakota Zero Tillage Farmers Association, the use of zero till has eliminated the need for fallow. The expense of having land idle is avoided.

More uniform soil moisture in zero tilled fields allows crops to ripen evenly. Crops can then often be straight harvested to reduce losses from predators and bad weather.

COSTS ARE LOWER

Everyone appreciates increased yields, but at what price? A recent survey of 300 farmers in Manitoba showed the cost savings with zero tillage.[5] Net savings of $5.62 per acre combined with about $14.00 extra per acre of grain, resulted in $19.60 per acre more returns for zero tillage over conventional tillage.

Savings for the zero tillers on a per acre basis included N ($1.01); P ($0.81); fuel and lubricants ($1.54); repairs ($2.17); machinery depreciation ($2.53); and crop labour ($0.98). There were increased costs for herbicides ($2.08), S fertilizer ($0.55), and seed ($0.79). These last two costs are most likely not due to a change in tillage systems, but perhaps reflect no-tillers general awareness of better agronomic practices.

With lower costs, zero tillage is more profitable even in years when there is no yield advantage over conventional tillage. Other work confirms this result.[6]

DIVERSE ROTATIONS PAY!

In general, returns from growing broadleaf crops outweigh the risks of growing them in the northern plains. Returns have been high enough to encourage farmers to solve their associated agronomic and engineering obstacles.

More diverse rotations are probably necessary to maximize profits in zero till. A Manitoba study showed that when both zero till and diverse rotations were used farm profits were greater than any other combination of rotation and tillage (Table 3).[1] The better profits came from higher yields and lower machinery costs. In contrast, diversifying into broadleaf crops with conventional tillage was less profitable than staying with continuous wheat.

Table 3: Average revenue and expense for rotation and tillage at Minto, MB (1991-95).(1)

	Conventional Tillage			Minimum Tillage			Zero Tillage		
	100%	75%	50%	100%	75%	50%	100%	75%	50%
Revenue	$204	$206	$190	$215	$207	$196	$207	$216	$229
Expenses									
Machinery	$46	$47	$47	$37	$39	$39	$29	$30	$30
Herbicide	20	26	26	22	27	27	24	30	30
Fungicide	3	10	10	3	10	10	3	10	10
Fertilizer	34	31	29	34	31	29	34	31	29
Seed	11	10	9	11	10	9	11	10	9
Other Costs**	47	47	47	47	47	47	47	47	47
Total Expenses	$161	$171	$168	$154	$164	$161	$148	$158	$155
Net	$43	$35	$22	$61	$43	$35	$59	$58	$74

** Other costs = Storage, crop insurance, land taxes, land investment, interest

Crop Rotations

100% Cereals: wheat/wheat/wheat/barley (1991-93) wheat/wheat/wheat/wheat (1994-95)

75% Cereals: wheat/ barley /wheat/mustard (1991-93) wheat/wheat/wheat/canola or peas (1994-95)

50% Cereals: wheat/flax/barley/mustard (1991-93) wheat/flax/wheat/canola or peas (1994-95)

This is an important point! It is common for no-till wheat-fallow or continuous wheat rotations to fail due to diseases, weeds and poor seedbeds. These rotations are less risky as part of a tillage-based system. However, with non-cereal crops, the risk is greater with tillage than no-till because of moisture limitations. No-till and non-cereal crops further complement each other as the added diversity minimizes concerns about pests and improves the relationship between risk and return for the farm.

A strategy which can provide better net returns would combine less herbicides in wheat, variable seeding dates, and a crop rotation that includes cereals, oilseeds and annual legumes.[8] This allows a more timely and cost effective use of herbicides, boosting returns in no-till more than in conventional systems, making no-till the more profitable system.

Using fixed labour and capital efficiently is important. Diverse cropping schemes spread costs over more acres by keeping labour and machinery busy for longer.[9] Net returns, in suitable areas, are higher when at least 50% of the rotation is corn, soybean, millet and sorghum. Traditional wheat-based systems may not cover variable and land costs in a no-till system. Clearly, crop rotations are more important with zero tillage than with tillage-based systems. No-till farmers in the northern plains have learned that no more than 50-75% cereals in the rotation is optimal. Zero till has been good for their soil and their family's income. However, some are wary of an over-reliance on herbicides as the lone replacement for tillage. By rethinking their system from the bottom up, they have recognized that crop rotation can play a larger role in their operations.

OTHER BENEFITS

Surveys and research give an important snapshot of improvements from zero tillage. But they rarely cover the human side. For example, farmers report that by zero tilling they spend less time in the tractor cab and more time planning their cropping system and capturing important market information. And then there's the time that always seems to be in short supply - family time. Families report an improvement here too!

OTHER ECONOMIC FACTORS

Increasing net returns requires identifying the factors most limiting farm profit. Water is less limiting in zero tillage. But, as Figure 3 shows, there is little sense in filling the barrel with water only to have it cascade out because of a weakness elsewhere in the system.[7]

Gaining an economic advantage is a lot like setting a combine. A new and improved combine provides the potential to harvest and save more, but if it is not properly adjusted, economics could be worse than staying with the old one.

Zero till is the thoroughbred of tillage systems. Decision making is intensified and information needs are great. To win the race, farmers must develop a timely, cost effective system which capitalizes on economic opportunities. The question many are asking today is not "Will zero till work?" but "How do I make it work better"? or, perhaps more importantly, "Am I ready to rethink my zero till system?" For this, a little imagination goes a long way.

The future viability of zero tillage is not guaranteed. Potential problems like herbicide resistance, disease outbreaks and unusually wet seedbeds need to be resolved. Part of the challenge is to identify the problem, its causes and possible remedies. A trouble shooting guide is provided (Table 4) to give insight into reasons why a farmer may not see economic advantages to zero till or, alternatively, why previous economic advantages are declining.

Table 4: Limiting factors to economic viability of zero till cropping.

SYMPTOM	POSSIBLE CAUSES	REMEDY
Lo yields	Delay in seeding	Use better rotation, alternate between high and low residue crops, use lower draft openers, use a 2 pass system with fall banding (which dries out soil) to increase area sown per day rather than a

		one-pass system, emergency measure may include burning or tillage
	Competition from weeds	Better crop establishment, restrict weed access to fertilizer through timing or placement, use best herbicides at the right time, rotate crop types to the disadvantage of weeds
	Foliar diseases	Rotate crops to minimize disease inoculum, use more resistant or tolerant varieties, monitor crops and use fungicides, increase years between like crops, use IPM, investigate KCI
	Root diseases	Use optimum fertilizer levels, use a seed opener that aerates the soil, improve rotation
	Insect damage	Insect problems will be similar to conventional tillage, in fact diverse rotations with zero tillage may reduce insects. However scout and treat as necessary
	Low water availability	Less intensive rotations, higher stubble
	low water use	Rotate crops to reduce diseases, increase fertility to match yield potential, increase rotation intensity
Thin strands	Excessive N (or P) near seed	Fall band, band N away from seed, less N with seed, dual opener paired rows
	Poor seed placement	Poor seed boot design, adjust spring tension or trip pressure to reduce opener movement, slow seed flow (fan speed in air seed), slow ground speed to match opener design
	Very wet seed beds	Delay seeding, plant fall sown crops, rotate crops with different residue levels
High weed control costs	Lack of a strategy	Study weed dynamics, develop least cost strategies, try fall seeding crops to reduce wild oat competition, use preharvest glyphosate to reduce Canada thistle
	Shift in weeds to absinthe, horsetail	Use preventative strategies, field border sanitation, use cleanup procedures, do strategic tillage grow competitive crops, higher

	and dandelion	seeding rates, use more of the seedbed area, restrict weed access to fertilizer
	Lack of early vigour	Warm the seedbed with a hoe opener to create a micro environment that favours crops
High fertilizer crops	Attempts to increase yields	Match fertilizer rates to yield potential, reduce limiting factors, grow legumes, soil test
Cost machinery	Under-used equipment	Sell tillage equipment, a 2 pass system can lower investment costs
Free time after harvest	Increased efficacy	Spend more time with family, develop value added enterprises, farm more land

The other challenge is to develop ways to manage problems in a cost effective manner. Technology will provide some solutions. However, as zero tillage evolves, farmers need to do more than replace tillage with herbicides. They need to balance their reliance on technology with the use of cultural practices.

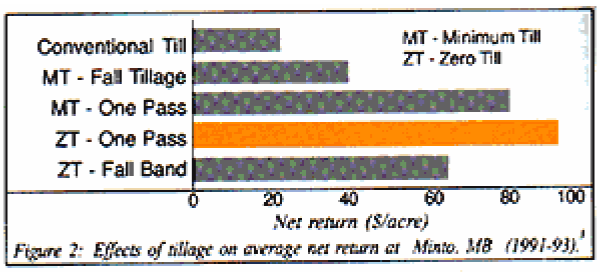

Figure 2: Effects of tillage on average net return at Minto, MB (1991-93).[1]

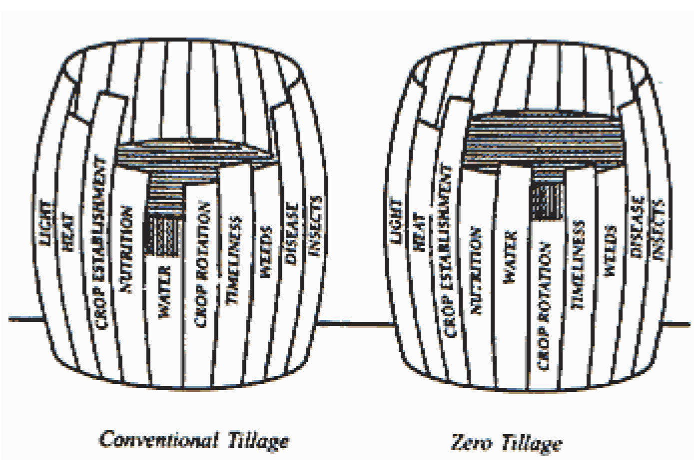

Figure 3: An illustration of the principle of limiting factors. The level of water in the barrels represents the level of crop production. (Left) In conventional tillage, water is shown as the most limiting factor. Even though other elements are present in more adequate amounts, crop production can be no higher than that allowed by the water. When water is added (right) under zero tillage, crop production is raised until it is controlled by the next most limiting factor, in this case crop rotation.7

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Advancing The Art ~ ROTATION

Good rotations are the key to creating and managing a viable zero till program. Rotations influence every aspect of a zero till system.

Zero till catches and stores more soil moisture. This enables, and may actually require, farmers to diversify into more profitable rotations. These rotations can be optimized by discovering which crop sequence best suits individual environments, labour force, size of farm, attitudes to risk and other economic, social and agronomic factors.

Understanding the intensity and diversity of different rotations is a solid platform for determining which rotations might best suit which environment and farmer.

THE SYSTEMS APPROACH

Designing a proper crop rotation for no-till is both an art and a science. A systems approach to crop sequences is needed because agronomic, economic and engineering factors will overlap.

Many factors must be considered in the process of planning a proper crop rotation. Among them are crop water use patterns, historic rainfall patterns, snow catch ability, disease organisms, insect cycles, phytotoxic effects of residue, weed control problems, herbicide rotation, profit potential, equipment needs, optimum row widths, seeding and harvesting dates, workload spread, individual attitudes and access to markets.

Using successful crop rotations requires good management skills. In any environment there is a range of rotations that give an appropriate balance of risk and profitability. This range varies according to the amount of tillage used. In any environment, good crop rotations effectively catch and use water by converting it into the most economic gain.

The best no-till rotations differ greatly from those used in tillage-based systems.[1] In most of the northern plains, zero tillage saves enough moisture to allow rotations not possible with conventional tillage. However, in some very dry regions, a combination of herbicides and reduced tillage might be more cost effective than zero till alone in a wheat: fallow rotation.[2]

There are a few concepts to consider in designing a proper crop rotation for your farm, particularly cropping intensity and crop diversity. *(Editor's note: these concepts are still quite new and are yet to be tested extensively but we believe they help explain what many zero tillers have experienced.)*

USE APPROPRIATE INTENSITY

Rotation intensity is the level of demand for water created by the rotation. Growing high water using crops will increase intensity. The level of intensity should match the water supply. Therefore, zero till rotations should be more intense than conventional till rotations.

Producers in dry areas should strive for a mix of high and low water use crops. In less arid areas more high water use crops should be adopted. Soils with high water holding capacity support greater intensity than coarse soils. If fields are consistently too wet, then the current rotation lacks intensity. If fields are too dry, intensity is too high.

Failure to use the extra water in a no-till soil increases weeds and diseases and lowers profits.

Several generations of experience in an area have probably found the appropriate level of intensity for tillage-based systems. This is not so with the newer zero tillage systems. By using common conventional till rotations as a starting point, rotation intensity can be calculated by using Table 1.[3]

Table 1: Calculating Crop Intensity:	

Step1) to compare rotation intensity assign a number to each spot in the rotation based on its crop type . Cool season annual crops rate as 1, warm season annual crops and perennial forages rate as 2, summer fallow rates as 0. Step 2) Average the intensity values for all crops in the rotation to obtain an intensity rating. Some intensity rating examples: wheat-fallow = ... 0.5 wheat-spring wheat-fallow = ... 0.7 wheat-barley-canola = ... 1.0 wheat-canola -millet-pea= .... 1.2 spring wheat-corn-pea= .... 1.3 alfalfa-alfalfa-wheat-wheat-pea= ..... 1.4 winter wheat-sunflower-corn-flax= .. 1.5 wheat-corn-sunflower= .... 1.7 corn-soybean = ... 2.0	Since an area's native vegetation integrates precipitation, temperature and soil factors, it serves as a general indicator of suitable cropping intensity. An understanding of native vegetation is useful in developing a no till program. ***Forest and tall/mixed grass areas with trees:*** • are cooler and may have excess water at times • support most intensity, if growing season permits • no fallow • high water users can often be grown ***Tall grass prairie areas with few trees:*** • may sometimes be too dry for high intensity • fallow is limited • some high water users may be grown ***Mixed and short grass prairie areas:*** • usually too dry for very intense rotations • fallow may be used in some cases • a single high water user may be grown

Rotation intensity can be increased by growing crops that use more water or adding crops where fallow currently exists. For example, a wheat-fallow rotation could become wheat-corn-fallow or wheat-wheat-lentil.

High water use crops like corn, alfalfa and sunflower increase cropping intensity. The practice of cover cropping also increases intensity. This involves broadcast seeding a forage legume such as sweet clover into a ripening wheat crop. The legume uses water and competes with weeds until it is sprayed out the following spring.

Adopting zero tillage typically increases crop intensity capacity by 20-50%. However, increasing intensity by moving from fallow to continuous zero tilled wheat will increase weeds, diseases and insects. This could also require more labour at peak times and require larger equipment. As shown in Table 3 of the Economics section, this approach reduces profits.

In developing rotation intensity, risk must be considered. In a dry year, wheat in a wheat-corn-fallow rotation would yield better than in a continuous wheat rotation. Yet according to Table 1 both rotations have an intensity of 1.

Adding intensity without increasing crop diversity can lead to management problems. So, to complete the job of rotation planning, crop diversity should also be assessed.

USE ADEQUATE DIVERSITY

Crop rotation diversity depends on how many types of crops are used. More crop types means more diversity! Diversity can spread risk, allow varied herbicide rotations to manage weed populations, reduce plant diseases, manage workloads and create good seedbeds for subsequent crops. As managing no-till rotations advances, more acres can be farmed with smaller equipment.

Crop characteristics, listed in Table 2, are helpful when planning balanced rotations.[3] A potential limitation to some rotations could be a lack of approved herbicides. State and provincial weed control guides are available to determine this.

Table 2: Crop Characteristics important in rotation planning (3) (** Cool season crops which grow best in hot weather)

Crop	Type	Seeding	Harvest	Snow catch	Water use	Harvesting Method	Critical water use period
Winter Wheat	Cool Grass	Sept-Oct	July	Excellent	Low	Straight/Flex	Oct-June
Spring Wheat	Cool Grass	April-May	July-Aug	Good	Low	Straight/Flex	June-July
Corn	Warm Grass	April-May	Sept-Oct	Good	High	Corn Head/ All Crop	July-Aug
Sorghum	Warm Grass	May	Sept-Oct	Excellent	High	Straight/Flex/ All Crop	August
Soybean	Warm Broadleaf	May	Sept	Poor/None	High	Flex Head	August
Sunflower **	Cool Broadleaf	May-June	Sept-Oct	Fair/Good	High	Pans/ All Crop	August
Millet	Warm Grass	June	Sept	Poor/Good	Low	Swath/ Flex	August
Flax	Cool Broadleaf	April-May	Aug-Sept	Fair/Good	Low	Flex/ Swath	June-July
Safflower	Cool Broadleaf	April-May	Aug-Sept	Fair	Low/Moderate	Flex/ Swath	July
Canola	Cool Broadleaf	April-May	July-Aug	Fair/Good	Low	Swath/ Flex	July
Barley	Cool Grass	April-May	July-Aug	Fair/Good	Low	Straight/ Flex	June-July
Oats	Cool Grass	April-May	July-Aug	Fair/Good	Low	Straight/ Flex	June-July
Peas	Cool Broadleaf	April-May	July-Aug	Fair/Poor	Low/Moderate	Flex/ Swath	June
Field Beans**	Cool Broadleaf	Late May	Aug	Poor	Low/Moderate	Swath	July

There are four types of plants available as crops that can be grown in rotation:

- *cool season grasses*
- *warm season grasses*
- *cool season broadleafs*
- *warm season broadleafs*

Different plant types will have different growth and maturity habits. These traits will affect seeding and harvest periods, pest susceptibilities, and water use capacities. These help determine the intensity and diversity of the rotation.

Crops of the same type have similar pests and similar water and heat needs. However, both cool and warm broadleaf crops have common diseases.

Cool season crops, like wheat and canola, prefer short growing seasons and cool temperatures. In northern areas, more warm season grass options are required to improve diversity. Warm season crops, like corn and soybean, need more heat. In southern parts, the option of a cool season broadleaf crop is needed.

GETTING THE RIGHT MIX

Planning rotations is made easier when using crop types as a guide. However, even using different species within a crop type, like wheat, oats or barley, can add useful diversity to a rotation.

Specific crops can be selected to fit particular conditions. For example, lentils and peas are both cool season broadleafs but lentils are better in drier areas. Winter and spring wheat are both cool season grasses but differ in their seeding and harvest dates.

It could be useful to compare the diversity of different crop rotations by creating a diversity index (See reference #4). Briefly, rotation diversity increases according to:

- the years separating the same crop type
- the presence of both grasses and broadleaf crops
- the presence of both spring and fall sown crops
- the presence of warm and cool season crops

Diversity decreases if crops must be seeded and/or harvested during the same time period.

ECONOMICS

Crop rotations can be viewed at two levels - across the whole farm and on individual fields. This is important because substituting crops changes the level of economic risk of the rotation while the risk of growing each crop depends on its place in the rotation.

Above all, diversity should improve profitability. Diverse rotations will be most profitable only if they have proper water use intensity and include adapted crop types.

Estimations of total returns expected for a given rotation should be compared for wet and dry years; government programs; and low, medium and high market prices.

Crops can be selected which best fit current economic conditions. Changes in economic, agronomic, engineering or political factors may force more changes in the future.

To make the most economic use of farm machinery and labour resources which were formerly used in doing tillage, they must be redirected, not left idle. Cutting the number of tractor hours by 50% doubles the fixed costs associated with each of those hours. Growing more types of crops will allow the machine to be used more efficiently in a zero tillage system.

TWO CROP-TYPE ROTATIONS

In the northern plains these rotations combine a cool season grass with a cool season broadleaf crop. In warmer areas a warm season grass is followed by a warm season broadleaf. Here are some examples of two crop-type rotations in order of increasing diversity.

- *Wheat-canola*
- *Corn-soybean*
- *Winter wheat-canola*

- *Barley-winter wheat-sunflower*

As shown in Table 3 of the Economics section, two crop-type rotations have improved yields and lowered machinery costs for early no-till farmers.

Simple two crop-type rotations work for a while, but over time, problems with weeds, insects and diseases can develop. These rotations can be intense enough with proper crop choices but they lack diversity.

A crop pest is rarely eliminated in a single year. With only a one year break between the same crop type, and no control applied in alternate years, surviving pests may gradually build up. At the same time, other pests invade because they are adapted to the window of opportunity offered in narrow rotations. Two crop-type rotations may also mean poor workload spreading. This can result in increased machinery and labour costs per acre and limit the number of acres a family can farm.

Many no-tillers face the challenge of managing two crop-type rotations more effectively. Strategies for avoiding the introduction and buildup of pests are developed in this manual in the following components on weeds, diseases and forage crops.

Diversity can play a role in managing two crop-type rotations. For example, substituting a fall sown cereal such as winter wheat for a spring crop is an easy way to improve diversity.

For good crop establishment and overwintering, winter wheat should be seeded by recommended seeding dates. Potential conflicts with harvesting other crops should be considered when planning rotations with winter wheat.

A winter wheat-canola rotation will have better workload spread than spring wheat-canola. Winter wheat competes better with wild oats but used too frequently, it will invite foxtail barley problems. Canola is usually harvested in time to get the winter wheat seeded. In some areas, barley-winter wheat-canola improves the chances of timely winter wheat seeding while keeping the profit potential of canola. This rotation is slightly more diverse but has the same intensity as winter wheat-canola.

Barley-winter wheat-sunflower increases intensity and spreads harvesting. Spring wheat before winter wheat has greater potential in dry areas where disease carryover to the winter wheat is less. Two cereal crops between either sunflower or canola improves the control of sclerotinia and breaks broadleaf weed cycles.

The value of flax in no-till rotations is often underestimated. Flax can substitute for a cool season grass or broadleaf. It breaks disease, insect and grassy weed cycles in rotations dominated by grass-type crops. Flax-canola-winter wheat or flax-sunflower-spring wheat are good options when cereal prices are low. Although flax catches snow well, in short season areas, it is often harvested too late for seeding winter wheat. Flax must be planted shallow (1-2 cm;-1/2 in).

Cool season legumes like peas and lentils are well established as no-till crops. Diversity is increased by substituting field beans in the legume year. Field beans are seeded in late May. The later burndown adds diversity to weed management. Field beans are a row crop which have been adapted to seeding on narrow rows with conventional no-till seeders. However, no-till row planters offer more precise seed placement. Field beans should follow a cereal or flax. Crop quality is very important in the marketplace. Harvesting must avoid cracking or soiling the beans. New varieties of beans are more upright and are therefore better suited to swathing.

Crops such as alfalfa or perennial grass provide an excellent opportunity to increase diversity and intensity particularly in short growing seasons. Further diversity is gained by including annual crops for use as forage, flexible forage/grain or green fallow. Producers with livestock find it less difficult to diversify rotations.

THREE CROP-TYPE ROTATIONS

These rotations combine a cool season grass, a warm season grass and a cool or warm season broadleaf. Because they contain a warm season grass, three crop-type rotations have been limited to southern areas of the northern plains.

Three crop-type rotations could help solve many of the problems now appearing in mature no-till operations. As crop-types increase, so do management options. This option requires more attention from researchers.

Here are some examples of 3 crop-type rotations in order of increasing diversity.

- *Wheat-canola-fallow*
- *Wheat-corn-canola*
- *Winter wheat-sunflower-millet*
- *Wheat -winter wheat-canola-millet*
- *Barley -w. wheat-corn-sunflower*

Three crop-type rotations can vary in intensity from 1.0 (winter wheat-corn-fallow) to 1.67 (spring wheat-corn-sunflower). They can be made up of 75% cool season and 25% warm season species - reflecting the mix of plant types in natural vegetation in the northern plains.

Using a warm season grass crop like corn or millet breaks weed and disease cycles of both cool season grass and broadleaf crops. Unfortunately, few varieties of corn are available for areas with less than 2500 corn heat units. Research should emphasize the development of corn genetics and herbicide options for the northern plains.

Both winter and spring wheat can be included to spread the workload and provide a two season break between the other crop types. For example, in spring wheat - winter wheat - corn - pea, the risk of disease in the spring wheat, pea and corn is low. Disease pressure in the winter wheat may be high, but it can escape yield loss if it matures early enough.

The pea segment benefits from the three years between broadleafs. Peas could be substituted with sunflower, canola, or field bean. Sunflower following corn is risky in dry areas but this greater intensity may fit in more humid zones. Peas, canola and beans limit the use of atrazine in the corn, causing yield losses. Millet would be a good alternative since it is tolerant to atrazine. New corn herbicides belong to the sulfonylurea family which may also carry over to the next year.

Another alternative for northern areas is to substitute sunflower for corn. Then to avoid back-to-back broadleafs, substitute millet for peas. Thus, the rotation becomes spring wheat-winter wheat-sunflower-millet. The late seeded millet helps control weeds in the cool season grasses. Likewise, the spring wheat-winter wheat years provide sanitation for the sunflower and millet.

Crops and sanitation can be managed effectively with three crop-type rotations. Most seeds from weeds which cannot be controlled in a given crop will germinate within 2 years. During this time, crop types are grown which will allow chemical control of these weeds. When the original crop is grown again with no chemical control, the problem weed population is greatly reduced. This principle is not applicable in non-diverse rotations using tillage. Even some high disturbance 'zero till' systems will move dormant seeds to the surface where they can germinate.

Clearly, many different crop sequences are possible. Personal attitudes toward risk will dictate which one to choose but it is also clear that rotations require the development of warm season grass and cool season broadleaf crops for the northern plains.

ECONOMICS AGAIN!

Crop rotation is the best way to manage risk and improve efficiency. On each farm, diversity and intensity need to be balanced to achieve the desired level of risk and return. High intensity with low diversity (wheat-field bean) offers high risk and potentially high returns until major problems develop. Moderately intense, highly diverse rotations such as spring wheat-corn-canola-winter wheat-sunflower or spring wheat-corn-sunflower are less risky and return less gross per acre. They can spread workload and fixed costs, reduce price and weather risk and reduce weed, disease and insect problems. As a result, these rotations can be profitable. Low intensity with high diversity (winter wheat-millet-canola, winter wheat-corn-oat greenfeed) have lower risk in dry years but less gross returns in good years.

Low intensity with low diversity rotations like wheat-canola, wheat-fallow or continuous wheat have little future in no-till. They have high fixed costs per acre, higher risk and lower gross return.

Crop rotation will depend on a producer's personality and that of the banker, landlord and spouse. Ultimately, though, the future of no-till requires increased emphasis on crop rotation.

An example of the systems approach

The systems approach is complex, but is an important and necessary part of "advancing the art" of no-till. The process is demonstrated in the following example from the northern mixed grass prairie area.

- In this area, drought is more common than excess water
- Spreading the workload is useful for economic, labour and family reasons.
- The rotation is: Winter wheat-millet-sunflower-wheat-corn-canola. Workload is spread over four seeding and harvesting windows.
- A two year interval between crop types gives control of wheat root diseases and four crop types allow a good herbicide rotation.
- A short season corn hybrid is used and millet is grown for birdseed.

The spring wheat can be seeded very early since sunflower stubble is the first to be ready in the spring. However, following sunflower with wheat may be risky in a dry cycle so a cool season oilseed like canola or flax could be substituted for sunflowers. In this case, winter wheat should be substituted for spring wheat since using spring wheat would compromise workload spreading by requiring seeding three spring crops prior to corn planting. Depending on markets, pests, forecasts, and input prices, peas, lentils, or edible beans can substitute for canola. This would force a change from winter to spring wheat because of potentially poor winter hardiness when sown into the low residues from annual legumes. Again, workload spread is reduced but can be partially regained by substituting canola-winter wheat for sunflower-spring wheat. The recovery in workload spread is only partial because sunflowers would normally be harvested well after the other crops.

Growing corn and sunflowers would require modifying a drill or obtaining a row crop planter. A corn head or all-crop head would be needed for harvest. These higher fixed costs may be offset by savings in other areas and by the increased profit potential from a diverse array of crops. Where the risk is too great to justify the equipment expense, millet and safflower can substitute for corn and sunflower respectively. Similarly, in warmer broadleaf areas, sorghum can replace corn. The risk is greatest in short season areas where rotations may shift to alfalfa, sweet clover cover crops or grass to maintain appropriate intensity.

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Advancing The Art ~ SEED and FERTILIZERS

In zero tillage systems, it is important to have good fertilizer placement without sacrificing seed placement. Seeds need to be placed where they will germinate and emerge quickly, and undamaged from fertilizers or herbicides. Fertilizer management and seed placement may change under zero tillage. This component outlines important options in achieving both good seed and fertilizer placement.

Zero till offers a better seedbed for quicker emergence in a moister soil. This advantage needs to be nurtured by good fertilizer management. Extra N fertilizer may be needed to fully optimize the no-till moisture benefit. However, N must be applied away from the seed using one of many techniques discussed.

Uniform chaff and straw spreading is essential in all no-till farming operations. If crop residue is not spread uniformly, the next crop to be planted will have problems. Seeding through thick residue will be hard. Most disc openers will not cut through residues very well and hoe openers or air seeder shanks will cause bunching of the residue as it moves through the soil. Both of these situations will cause problems for the emerging seedling due to the thickness of the matt.

SEED PLACEMENT

Good no-till crops begin with proper seed placement. In fact, in terms of return on your zero till investment, good seed placement is extremely important. All the crop inputs in the world cannot resurrect a crop that is seeded too deep.

The goal of seeding is quick establishment of a vigorous crop that competes well with weeds. Ensuring good seed-soil contact will help achieve this. Zero tilled seedbeds are more firm and moist than tilled seedbeds. This seedbed advantage of the zero till system should be maximized.

Good seed placement gives the seed what it needs; moisture, oxygen and adequate heat. Crop establishment in zero tillage is effected by crop residue, seeding date and depth and fertilizer placement.

CROP RESIDUE

Several no-till manuals explain the absolute need for uniform spreading of straw and chaff. Whether using traditional harvesting equipment or the recently introduced stripper-header, management of residue at harvest-time is a key to no-till farming. Proper residue management allows seeding equipment to operate more efficiently and helps to provide seed-soil contact.

Chaff collection will reduce residue problems and improve zero till crop establishment. In cereals, chaff typically constitutes 13-35% of the residue.[1]

Equally important for good seed placement is rotating high and low residue crops. In our cool northern climate, crop residues decompose slowly. Successive high residue cereal crops may accumulate excess surface residue no matter how well it is chopped and spread.

For optimum seed placement, stubble height should match the residue clearance and soil penetrating ability of the seed opener. Stubble higher than 25 cm (10") is best for low disturbance disc seed openers. Shorter stubbles are better for seeding with hoes or sweeps.

Compounds released by residue-feeding microbes can stop germination and seedling development. This process, called allelopathy, is not well understood.

SEEDING DATE

In most cases on the northern plains, zero tilled crops can be sown on the same day as conventionally sown crops. Usually, the zero tilled fields are slightly cooler. However, zero till places the seeds nearer the soil surface where it is as warm (Figure 1) as the deeper, conventionally-sown seed is placed. With zero till, the soil is also more firm and moist than conventional tilled seedbeds. On similar seeding dates, zero till gives better crop establishment. In fact, many zero till fields can be sown earlier than conventional till fields. This is because zero till soils have better structure and more residue cover which provides improved traffic-ability.

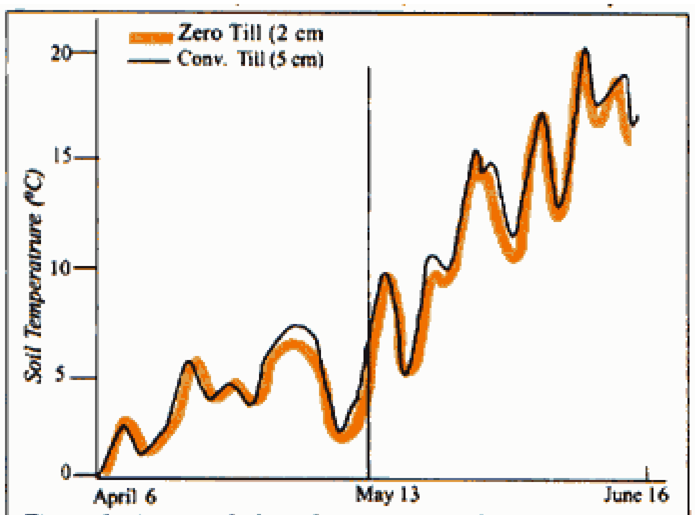


Figure 1: Average daily soil temperatures from 3 sites, Fort Saskatchewan, Alberta[2] (Sown on = May 13/96).

Early zero tillers found that hoe-type seed openers gave better crop emergence in cool soils compared to disc openers. The hoe openers reduced hairpinning, giving better seed-soil contact and faster warming in the seed zone. This knowledge still pays off today. With suitable residue management, zero tilled fields can be seeded early for maximum yield potential.

SEEDING DEPTH

Zero tillers can and should seed shallow. Seeding depths common in tilled seedbeds are not appropriate for no-till seeding. Sowing at 7.5 cm (3") depth in no-till instead of 3.7 cm (1.5") can be a disaster (Figure 2).[3] Increasing seeding depth from 2.5 to 7.5 cm (1 to 3") can delay emergence by three days and reduce yields.Seeding depth with no-till should be 2.5-5.0 cm (1-2") as this promotes quick emergence and allows the crop to get a head start on weeds.

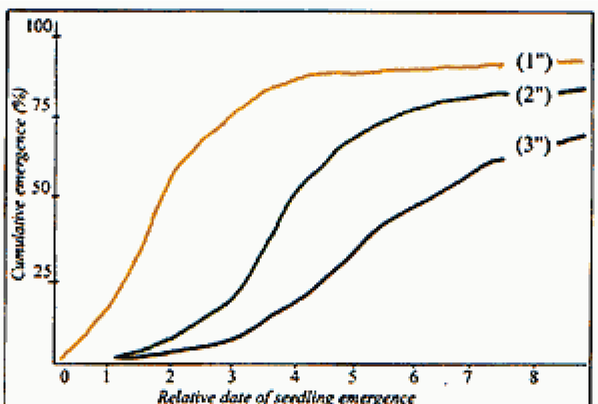


Figure 2: Emergence through time at three seeding depths.[3]

Cereal crops sown too deep have uneven emergence, poor root growth and fewer tillers. Winter wheat sown deeper than 2.5 cm (1") will have poor winter survival because of delayed emergence.[4] Semi-dwarf wheats have short coleoptiles which makes it hard for them to emerge from deeper than 5 cm (2").

Small seed crops like canola, flax and sorghum are very slow to emerge if sown deeper than 2.5 cm (1"). Deep seeding also reduces plant vigour, making the plant more susceptible to diseases such as root rot (Figure 3).[5]

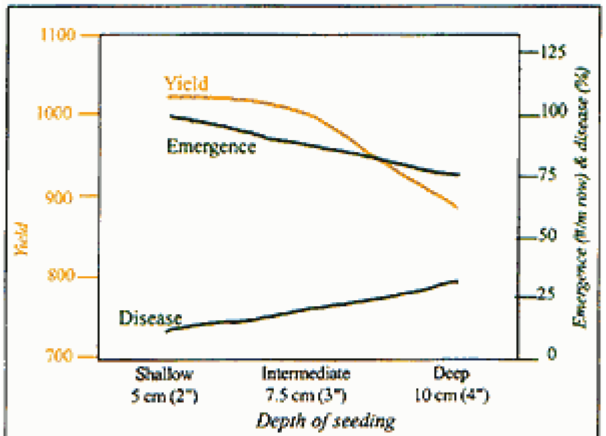
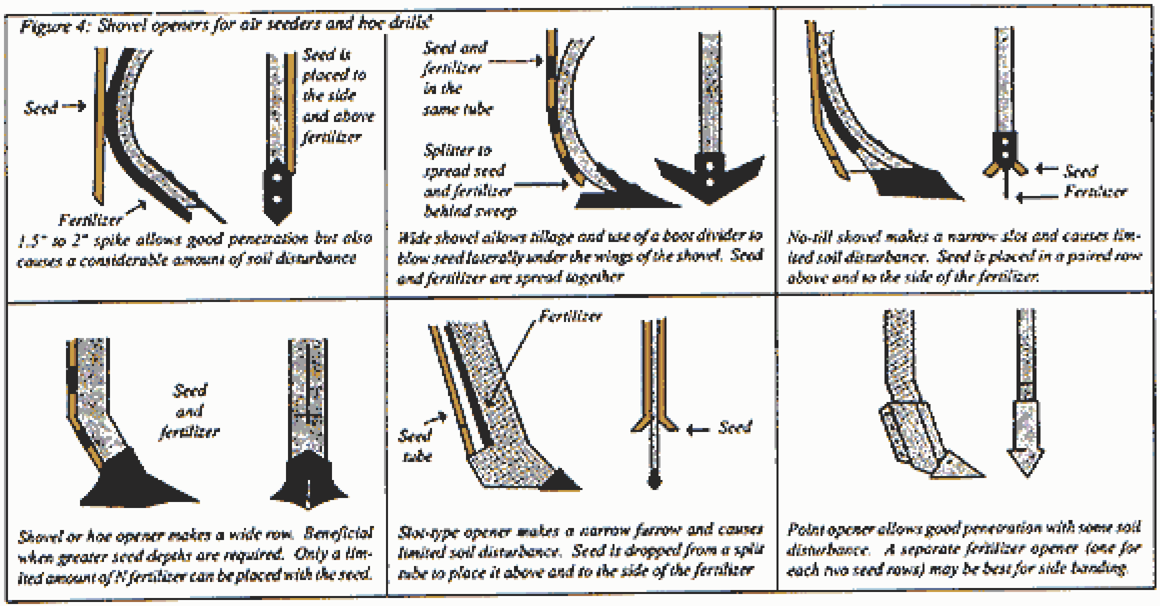


Figure 3: Seeding depth effects on yield (grams/plot) (gold scale) emergence (plants/metre of row) (green scale) and common root rot (% infected) (green scale).[7]

SEEDERS AND PLACEMENT

Many no-till seed openers are now available (Figure 4).[6] Most recent developments focus on simultaneous seeding and fertilizing.

Figure 4: Shovel openers for air seeders and hoe drills[6]



Opener performance varies with soil and environment. No one opener is superior in all conditions. But, most no-till openers are capable of good seed placement if residue is managed properly.

The strength of hoe openers is that they can clear residue from the seed row, allowing heat from sunlight to be absorbed into the seed row. At night, this heat is released, protecting seedlings from frost. In warmer, more arid climates, seed row warming is not so critical. In fact, less soil disturbance conserves soil moisture. In cooler, more humid climates, seed zone warming is more important. But there are trade-offs.

Increasing soil disturbance increases fuel use and weed germination. For these reasons, seed row disturbance is best kept to a narrow band, immediately around the seed.

Disc openers pull more easily and give more precise depth control than hoe openers. They also disturb less soil and therefore stimulate fewer weeds. However, they may hairpin residue into the seed row and require more maintenance than hoe openers.

A newer approach to seeding is to install residue manager wheels or row cleaners in front of the seed opener (Figure

5). These wheels work like a hay rake to clear residue from the path of the opener. This reduces hairpinning with discs, and contributes to seedrow warming with little or no soil disturbance.


Figure 5: Resdidue manager wheels clear residue from the path of the opener and reduce 'hairpinning', particularly in cereal stubble.

Both disc and hoe openers are available on air seeders. Because of their efficiency, air seeders are now common. Most air seeders have shank-mounted openers. Depth control is by a rigid frame linking load carrying wheels in front with press wheels in the rear. Depth control is adequate but can be a bit uneven in rolling terrain due to the distance between the front and rear wheels (Figure 6).[6] On some air seeders, depth can be controlled on individual openers by adjusting a press wheel mounted on the shank of each opener. Having press wheels attached in this way will reduce trash clearance.

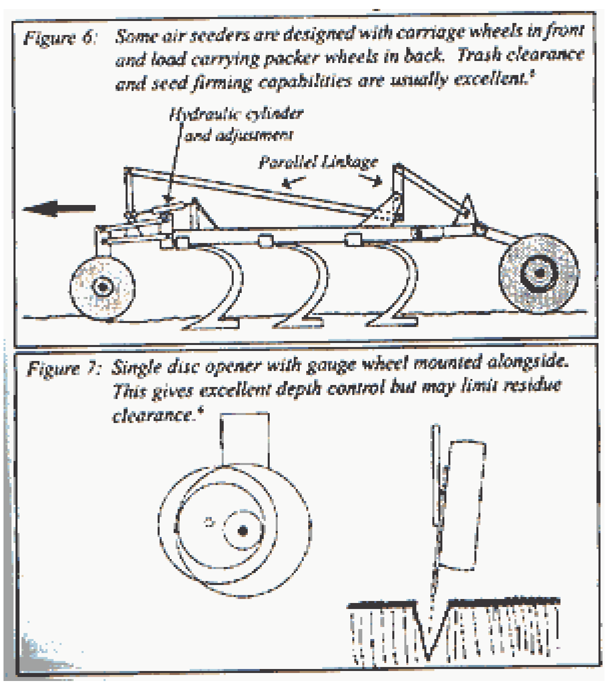


Figure 6: Some air seeders are designed with carriage wheels in front and load carrying packer wheels in back. Trash clearance and seed firming capabilities are usually excellent.[6]

Figure 7: Single disc opener with gauge wheel mounted alongside. This gives excellent depth control but may limit residue clearance.[6]

Depth control on single disc seeders is by a gauge wheel mounted on the side of the disc, or by a press wheel fastened to the framework of the disc (Figure 7).[6] Generally, disc openers with gauge wheels offer more precise depth control.

Press wheels

Press wheels and on-row packing ensure the seed is in contact with moist soil for quick germination. On-row packing also compresses the soil above the seed, reducing seeding depth. For these reasons, on-row packing greatly increases crop emergence and establishment[7] (Figure 8) and is almost a necessity in the northern plains.

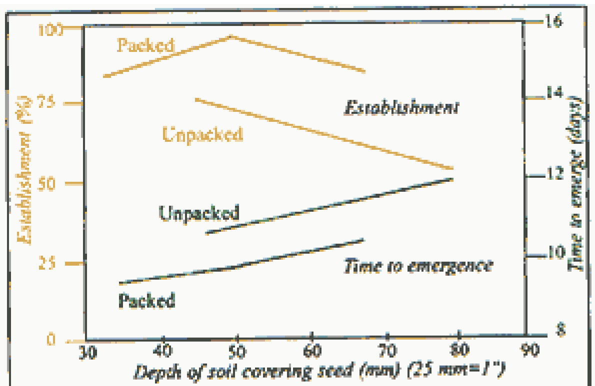


Figure 8: Seeding depth and packing effects on speed of emergence (green) and on establishment of barley (gold).[7]

Both shank-mounted openers and disc openers use press wheels, but in different ways. There is debate over which system is best. On most seeders, the press wheels set seeding depth and perform on-row packing.

The most appropriate packing pressure for press wheels under a range of conditions is probably 22-45 kg (50-100 lbs) of down pressure on each packer wheel.[8] Somewhat less pressure is needed in wet soil; more pressure is needed in dry soil conditions. Because the press wheels carry part of the weight of the machine, packing pressure may be too high in very wet soils. Crusting of the seed row may occur and delay crop emergence.

Most airdrills sold today have packing pressures of about 68 kg (150 lbs) /wheel with one or two approaching 90 kg (200 lbs)/wheel. Packing systems mounted to the back of conventional airseeders have different settings but exert a maximum of about 26 kg (60 lbs)/wheel (20 cm (8") spacing). Shank mounted packers are also adjustable, but can be set at higher pressure than the mounted gang packers.

Row spacings and press wheel width will change the packing pressure of each wheel. Even though machines with wider row spacing are generally lighter, there is still proportionally more weight to bear by each wheel. This may not make a big difference to airdrills, but it improves the rear mounted packers. Here's one manufacturer's example:

- *8" spacing - max 60 lbs/wheel (20 cm spacing - 26 kg/wheel)*
- *10" spacing - max 75 lbs/wheel (25 cm spacing - 32 kg/wheel)*
- *12" spacing - max 90 lbs/wheel (30 cm spacing - 39 kg/wheel)*

Wet soil can cling to press wheels and upset seed placement. A lightly loaded, flat-surfaced, steel, press wheel will pick up more soil and residue than a narrow rubber wheel.

On single disc drills with side-wheel depth control, adjustable pressure press wheels follow immediately behind the disc, setting the seed in moist soil. They do not support the seeder. Instead of a dense, highly packed ribbon of soil over the seed, the seed row is covered by loose soil by a second low pressure closing wheel. Loose soil over the seed allows easier plant emergence.

Most commercially available zero till drills do not always adequately space large seeds such as corn and sunflowers planted at low rates. If these crops are included in the rotation, a zero till row crop planter will do a much better job of seed placement.

Seeding tools which allow optimal seed and fertilizer placement in a range of crops are still needed. Hopefully, farmers and manufacturers will continue to experiment with new concepts in seeding. If made affordable, precision planting systems used in row crop production would improve seeding for zero tillers in the northern plains.

"I'd say for fertilizer placement be flexible; for seed placement be absolutely rigid - get the seed where it needs to be."

*Ron Bell, Birtle, Manitoba*

Straw Management and Harvesting Equipment

The stripper header for harvesting small grains will allow you to harvest 50-60% more acres per hour than straight cut headers. This is due to much faster travel speeds of 8-10 km/hr (5-5.5 mph). Faster speeds are possible as very little straw is put through the combine. Less straw inflow increases harvester efficiency, as very little additional threshing of heads is needed and separation is easy as little straw is inside the combine.

Stripper headers are also excellent for picking up lodged grain, and the straw does not require spreading over the field as it stays in its original position. Seeding the next crop into tall standing stubble has been done successfully with disc drills. If an air seeder is being used, a set of coulters mounted on the front of the seeder has proven successful for direct or no-till seeding.

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Extension Agric. Engineer, Fargo, North Dakota

FERTILIZER

Crop nutrition is foremost on the minds of no-till farmers. Successful zero tillers are constantly experimenting with new equipment and fertilizer products to achieve better returns. What has developed is a sense that seeding and feeding the crop go hand-in-hand. Each must be optimized to make the system work.

Achieving the high yield possible with zero till requires an aggressive fertility program. Current fertilizer recommendations are usually based on conventionally tilled systems. However, zero tillage has more yield potential and, therefore, may require more fertilizer than conventionally tilled crops.

N FORMS AND LOSSES

Nitrogen is our most common yield limiting nutrient. Its sources are the natural breakdown of soil organic matter, N fixation by legumes, and manure and synthetic fertilizer. All forms are used in zero tilled systems.

ORGANIC MATTER

In general, the rate of turnover of N from crop residues is slower in zero till than in conventional till, particularly in the first 3-5 years. It is usually recommended that 10-20% more N be applied in this period. After about five years, a new equilibrium of N release is reached when additional inputs are no longer needed.

Growing legumes in the rotation, with proper inoculation and good management of the residue, will improve the N supplying power of the system. Legume residues release N more quickly than non-legumes. The amount and type of legume also affects the rate of N breakdown and subsequent fertilizer needs. Annual legumes release N more quickly than perennial or biennial legumes.

Legume breakdown benefits are equal in zero and conventionally tilled soils. But when it comes to atmospheric N fixation, recent studies with peas and lentils show that more N is fixed in zero till versus tilled soils (Table 1).[9]

Table 1: Percentage N derived from the atmosphere.(9)		

Rotation	Zero Tillage	Conventional Tillage
wheat-canola-wheat-lentil	68	47
wheat-canola-wheat-lentil	63	50
wheat-canola-wheat-lentil	65	52
wheat-pea-wheat-lentil	72	62
canary seed-sunola-wheat -lentil	75	68
wheat-mustard-canary seed-lentil	72	70
Average	69	47

In a Saskatchewan study, the average yield of spring wheat in a pea-wheat rotation was 986 kg/ha (15 bu/acre) greater than in a wheat-wheat rotation.[10] In addition, the protein content of the wheat seed in the pea-wheat rotation, was 15.4% compared to 13.9% in the wheat-wheat rotation. Decomposing crop residues contributed more N to building grain protein in the pea-wheat rotation than in the wheat-wheat rotation. Most of the yield benefit probably came from disease control as only 6% of the N in the pea-wheat rotation came from the pea residue.

Legumes provide more benefits to following crops than just N. These benefits are not well understood, but include less root disease and better soil structure. Legumes also allow subsequent crops to use more nutrients, perhaps due to increased root growth. Yield increases from having legumes in the rotations require that other nutrients be monitored so they do not limit yield.

"A good fertilizer program is important for many reasons. It is as important to minimizing disease problems as any other management strategy. If you have a crop under stress from nutrient deficiency, it will be susceptible to diseases. You need a good program of fertility."

*Ardell Halvorson, USDA-ARS, Mandan, North Dakota*

MANURE IN NO-TILL SYSTEMS

Information on the use of manure in zero till systems is limited. However, manure should be considered as a soil-building nutrient rather than a waste product.

Applying 25 t/ha/year (10 t/acre) of cattle manure probably is not a problem to zero till seeding, and tillage is not needed to give a yield response from the manure. Fresh or composted manure gives similar yield responses.

Manure spreading will put some viable weed seeds back on the field. Weeds with hard seed coats, like red root pigweed and lambs-quarters, are not affected by animal rumens. In fact, the rumen may break dormancy. Grassy weeds without seed coats, do not usually survive the rumen. Composting manure will also reduce weed seed viability.

Manure from swine and dairy operations can be separated into liquid and solid portions. The liquid could be dribble-banded onto standing forage, or even annual zero tilled crops.

SYNTHETIC FERTILIZER

Fertilizer N can be applied as urea or ammonium nitrate in granular form, or as a blend of these in liquid form. Anhydrous ammonia is also used extensively. In the soil, moisture allows the enzyme urease to convert urea to ammonium. Microorganisms then convert the ammonium to plant-available nitrate.

All forms of N, from organic matter and from applied fertilizer, can be lost if crop rotation intensity is not adequate. Nitrogen can be lost as a gas, leached below the root zone or tied up by soil microbes. In some cases, N leached below the root zone pollutes ground-water. Fortunately, since soil erosion rarely occurs in no-till, contamination of surface water is avoided.

Losses of applied N fertilizers are costly for farmers. Different application methods, formulations and soil conditions affect these losses. For example, urea left on the soil surface is partly lost when urease in the crop residue converts the urea to ammonia gas. Consequently, surface application of urea is not recommended for zero till in the northern plains.

Nitrate is subject to leaching because it is easily carried in the soil water. Any applications of nitrate should occur close to when the crop will use it. Similarly, applications of urea or ammonia fertilizers, which are converted into nitrate in the soil, should occur under conditions that do not favour subsequent N losses.

FERTILIZER PLACEMENT

Good fertilizer placement is critical for economic yields. It can also prevent losses of nutrients to the ground water and atmosphere. But what constitutes the best fertilizer placement depends on crop rotation, equipment, labour and financial resources. However, seed placement should never be sacrificed for better fertilizer placement.

Crops can take up more N, P and K when the nutrients are banded, although the reasons for this vary. Losses of fertilizer are reduced because banding decreases fertilizer exposure to the soil environment and reduces its rate of conversion to a plant available form. This plant available form can be lost by leaching, or by turning into gas and escaping into the atmosphere.

PRE-PLANT BANDING

Banding fertilizer in a separate operation does not run against the philosophy of zero till. Banding can be done in the spring or the fall and the seeding operation can then concentrate on one thing - good seed placement. Some producers can use the same equipment for seeding and banding fertilizers.

Fall banding increases the choices of seeding equipment. Since there are many good seeding equipment options which do not have fertilizer application capability, fall banding removes the need for more costly one-pass seeding equipment. While fertilizer may be less expensive in the fall, fall banding does increase fuel and labour costs at that time of year, and it will disturb the soil. In wetter, colder soils, banding provides soil drying and warming before seeding.

Some fall applied N can be lost before the crop can use it. However, these losses can be reduced by banding in late fall, when the soil is 5-10 C (41-50 deg F). If ammonia or urea rather than leachable nitrate are used at these temperatures, then the N will stay as non-leachable urea, ammonia or ammonium for a longer time.

Nitrogen can also be pre-plant banded in the spring, or it can be injected (nested) into the soil in the fall, near planting or after planting. Spoke wheel injecting of liquid N is useful as it gives even less soil disturbance than banding. As a result, fewer weeds germinate.

Spring banding offers an advantage over fall banding in that fertilizer rates can be adjusted in direct response to spring moisture conditions. On soils where denitrification causes fertilizer loss over winter, spring banding can improve fertilizer use over fall banding. However, spring banding can be disruptive to the zero till seedbed. The first pass fertilizer application tends to loosen residue giving clearance problems for seeding and making uniform seed placement more difficult.

Overall, spring banding is perhaps the least preferred of the fertilizer application systems.

BANDING AT SEEDING

Banding fertilizer at seeding time offers considerable planting flexibility, in that last minute plan changes are not limited by any pre-plant operations. Because the one-pass seeding is the first pass over the field, there are fewer problems with crop residue plugging equipment. On the other hand, some types of one pass openers may disturb the seedbed too much, preventing uniform seed placement. Large amounts of fertilizer may have to be handled at seeding time.

Nitrogen can be side or mid-row banded during the one-pass seeding operation. One-pass seeding saves time and allows earlier seeding with higher yield potentials. This will also allow the full N rate to be applied without seed damage.

Depending on the system, one-pass seeding costs more because of the horsepower needed to pull the equipment, and the number of openers needed to apply the seed and fertilizer. Mid-row banding requires a set of openers dedicated to fertilizer placement. Side banding requires specially designed openers (Figure 4).

To offset the cost of one-pass side-banding openers, row spacings up to 30 cm (12") have been used with no effect on yield.[11] It is possible to avoid the purchase of one-pass seeding openers by dribbling liquid N through hoses on the shank onto the soil surface near the opening. With this system, fertilizer placement is less precise, but seed placement can be optimized.

Seed openers are available for safely side banding anhydrous ammonia. Using this less expensive N helps pay for the one-pass seeding equipment. If anhydrous ammonia is used, it must not be allowed to escape its band and enter the seed row at the time of seeding. Particular caution should be exercised on light textured soils.

Anhydrous ammonia should be at least 4-5 cm (2") away from the seed. Some producers have successfully placed NH_3 at the tip of sweeps and spread seed over the remainder of the sweep width.

Choosing the right one-pass opener can be difficult as there are many on the market. It is difficult to tell at the time of purchase whether seed placement will be sacrificed to get 'one-pass' capability.

In fact, as long as toxicity is avoided, the exact location of the banded N is not critical as there is enough early N movement in the soil for good early crop growth. Any banding technique will reduce soil reactions with the applied fertilizer and, therefore, will limit losses of N from the soil.

SEED PLACED N

Seed placed N is also a form of banding and an effective form of application. However, N fertilizers can be toxic to seedlings if too much is placed with the seed. Because of this, low rates of seed placed fertilizer may have to be supplemented with an additional fertilizer operation to ensure enough N for adequate crop growth.

Toxicity is most common in soils that are light textured, high in salts, low in organic matter, have poor fertility, high pH with free lime, and are cool and dry. Toxicity is also more likely with narrow seed openers, wider row spacings and small seeded oilseed crops. The amount of damage will vary from year to year and with fertilizer type.

The amount of N that can be placed with small grain seed at planting (Table 2) is based on seeder row spacing, seeder and opener type and how much 'seedbed is used' (SU). Seedbed use is determined by the following formula:

% SU = (Seed spread x 100) / Seed Row Spacing

Table 2: Maximum nitrogen fertilizer rates with small grain seed at planting based on seed row spacing, seeder type and seedbed used

Planter Type	Seed Spread		Seeder Row Spacing							
			6" (15 cm)		7.5" (19 cm)		10" (25 cm)		12" (30 cm)	
	(inches)	(cm)	SU	lb N/ac	SU	lb N/ac	SU	lb N/ac	SU	lb N/ac
Double Disc	1	2.5	17%	20-30	13%	19-28	10%	17-23	8%	12-20

Hoe	2	5.0	33%	32-44	27%	27-38	20%	23-31	17%	20-27
	3	7.5	50%	44-58	40%	37-48	30%	30-40	25%	26-34
Air Seeder	4	10.0	66%	56-72	53%	46-58	40%	37-48	33%	32-42
	6	15.0	100%	80-100	80%	66-79	60%	51-55	50%	44-56
	8	20.0					80%	66-83	67%	56-71
	10	25.0					100%	80-100	83%	68-86
	12	30.0							100%	80-100

There is a lot of variation in the amount of N that can be safely spread with the seed across the width of points, even a sweep point. This is due to differences in soil texture (Table 3). Table 4 shows spring wheat yields as influenced by spread width of seed and dry fertilizer behind a sweep. Nitrogen rates can be more safely increased as the sweeps provide space between the N and seed. This works best with dry fertilizer.

Table 3: Maximum estimated seed placed N fertilizer rates with small grains.(12)

				% Seedbed Used		
				10-20	30-50	60-100
	Particle Size			Double Disc	Hoe	Air Seeder
Soil Texture	Sand	Silt	Clay	1" (2.5 cm)	2-3" (5-7.5 cm)	4-12" (10-30 cm)
	Percent			lb N per acre		
Loamy sand	80	10	10	5	10-20	25-40
Sandy loam	60	35	15	10	15-25	30-45
Sandy clay loam	55	15	30	15	20-30	35-50
Loam	40	40	20	20	25-35	40-55
Silt loam	20	65	15	25	30-40	45-60
Silty clay loam	10	55	35	30	35-45	50-70
Clay loam	30	30	40	35	40-50	55-80
Clay	20	20	60	40	45-55	60-100

Table 4: Average spring wheat yield with one-pass seedings as influenced by spreader type and fertilizer rate.(12)

Fertilizer Rate		Single Row	5" (12.5cm) Wide	8-10"(20-25cm) Spread	12"(30cm) Spread
N	P				
(lb/acre)		average bushels per acre yield			
0	0	29.6	31.5	33.5	34.6
40	0	28.5	35.5	42.6	41.8
80	0	24.0	39.3	47.1	48.4
40	17	30.4	38.6	46.7	46.9
80	17	20.8	37.6	44.2	47.7

** Trials were completed using a 24 ft air seeder chisel plow with a 12 inch opener spacing. Seed and fertilizer were delivered through one tube.*

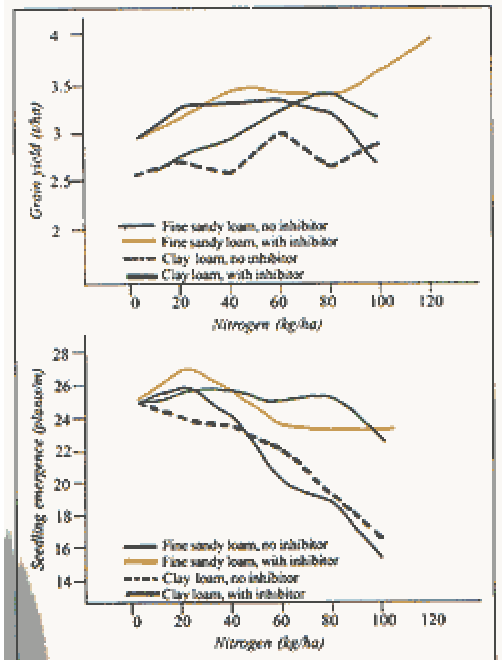

Figure 9 (Bottom) Seedling emergence and (Top) yield of barley both benefitted from use of urease inhibitor with seed-placed urea (1994-96).[13]

UREASE INHIBITOR

Like other forms of N, urea can cause crop damage when high levels are placed close to the seed. Damage from urea conversion during germination increases as the soil dries after seeding. Rain, on the other hand, decreases damage.

A urease inhibitor called n-(n-butyl) thiophosphoric triamide (NBPT or Agro-tainÆ) will reduce urea losses and toxicity. NBPT slows the conversion of urea to ammonium and ammonia to over a 14 day period. This decreases seedling damage and reduces ammonia losses, making more N available for crop growth with less leaching. NBPT will also improve N uptake from topdressed urea.

Field studies in Manitoba showed that NBPT put with seed-placed urea increased both seedling emergence and grain yield in barley on two soil types from 35-90 lb N/acre (Figure 9).[13]

SPRING BROADCASTING

Broadcasting urea is not recommended. However, ammonium nitrate containing fertilizers may be a practical choice for some zero tillers. Broadcasting allows higher rates of N to be applied with minimum equipment, time and labour costs.

Spring broadcasting allows flexibility in application rates at time of seeding. It is also a useful way to apply extra N where one-pass seeding is not used or when growing conditions warrant a higher total N application. It is a technique which can be used from before seeding until after the crop has emerged.

Broadcasting N works better in more humid areas where there is a better chance of a spring rain to wash the N into the soil. Nitrogen should not be broadcast onto thick residues, as surface microbes may tie it up.

Fertilizer N can be applied in-crop, but delaying application will reduce yield potential from applied N. However, applications up to heading or after flowering of wheat may still increase grain protein.

"I don't think there's any question that the best way of putting our phosphorous is either seed-placed or side-banded... dual deep banding is another option, but I don't think it's as good. We may have oversold a specific placement of nitrogen - you can manage your overall system by manipulating source and timing to get around placement

problems."

*Cynthia Grant, Agric. & Agri-Food Canada, Brandon, Manitoba*

POSITIONAL P & K AVAILABILITY

While N and S are mobile within the soil, and will move readily with soil water, Phosphorus (P) and potassium (K) are relatively immobile and remain close to where they are placed. Therefore, fertilizer P and K are most efficiently used when placed near the seed.

Lack of mobility of P and K make it difficult to take representative soil tests and accurately interpret a field's fertility status. Phosphorus deficiency can occur in cool soils when root growth is slow and phosphorus release is restricted.

WEED INTERACTIONS

Fertilizers used to improve crop growth will increase weed growth unless they are placed near the crop and away from the weeds. Consequently, broadcast N may give weeds an advantage while banding N near the seed will give the crop an advantage.

Other practices can also reduce weed competition. Combining N placement with a taller winter wheat variety with higher seeding rates can further reduce weed growth (Figure 10). Each cultural practice, when used alone, will reduce weed growth but the interaction of these practices magnifies their benefit.[14]

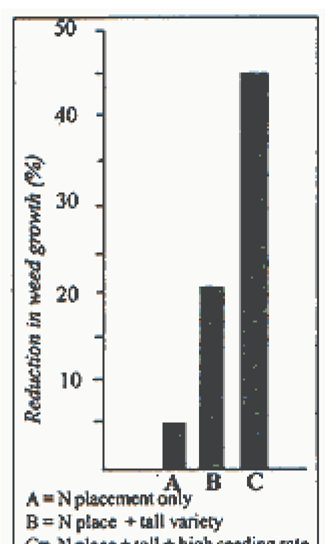

Figure 10: Cultural practices.[14]

PRECISION FARMING

Achieving the higher yields that are possible with zero till means that more fertilizer is needed. On eroded areas, continuous zero tillage will increase the yield potential and improve the uptake of fertilizers. Also, different parts of fields will respond differently to fertilizers and may ideally require varying rates.

Computers and satellite guidance systems allow crops to be produced more efficiently by enabling farmers to better manage small areas of land. It has great potential for zero tillers and others to improve efficiency.

Research is being done to determine if there is an economic benefit to precision farming for small grains. Yield monitors are becoming popular and are a good first step into precision farming. It is interesting to see the variability in crop yield as the combine moves across the field.

For yield data to be useful, a global positioning system (GPS) receiver, along with a memory system and yield data processing software is needed. Remote sensing of the crop canopy can also be used to measure potential crop yields.

For variable rate fertilizer application, a controller is needed for each fertilizer applied. This allows the fertilizer rate to be changed on the go as the applicator moves across the field.

Variable application is desired so that appropriate rates of fertilizer can be applied. The rates are based on topography, soil type, soil tests, soil moisture and the yield goal. Prior to precision farming, all parts of the field received the same fertilizer rate. This was regardless of the productive potential of the various areas within the field. Consequently, some areas would receive too much fertilizer and other areas too little.

FERTILIZER PLACEMENT OPTIONS - PROS(+) AND CONS(-)

FALL BANDING

(+) allows use of the least expensive source of nitrogen (ammonia) and it spreads the work load. This means the spring operation concentrates on seeding. Fall banding saves equipment expenses and increases the choices of seeding equipment available since there are many good seeding equipment options which do not have fertilizer application capability. Fall banding allows the correct amount of fertilizer to be applied for each crop without risk of crop damage. In cooler, wetter areas, fall banding permits the soil to warm quicker and allows earlier seeding the next spring.

(-) requires separate equipment and an additional trip across the field which is expensive in both fuel and labour. The extra fall operation dries the field and it tends to promote volunteer growth and stimulates weed germination the next spring.

SPRING BANDING

(+) offers the same advantages as a fall banding operation with the added benefit that fertilizer rates can be adjusted in direct response to spring moisture conditions. All types of fertilizer, including NH_3 and liquid UAN, can be used in a spring banding application. On soils where denitrification causes losses of fertilizer over winter, spring banding gives more efficient use of fertilizer compared with fall application.

(-) includes the extra expense of the added operation. It disrupts the zero till seed bed and makes uniform seed placement difficult.

SEED PLACED

(+) is generally considered the simplest fertilizer placement system. A one pass seeding/fertilization operation is efficient in time and fuel costs. Many available machines are capable of placing seed and fertilizer together. That fertilizer which is with the seed is used very efficiently by the plant.

(-) fertilizer amounts are limited by the danger of seedling injury. Reduced plant populations which result from excess fertilizer placed with the seed can mean later maturity and/or lower yields. Seed placed fertilizer may have to be supplemented with an additional fertilizer operation to ensure that sufficient nutrient amounts have been provided for the crop. Handling more fertilizer at seeding time slows down seeding.

BANDING AT TIME OF SEEDING

(+) allows the total fertilizer requirement to be placed with one pass at seeding time. Placement is near enough to the seed to offer efficient use of the fertilizer but sufficiently separated from the seed to minimize toxicity concerns.

Because of the proximity to the seed row, side banded fertilizer is most accessible to the seed and least accessible to weed seeds between rows. The single operation is cost efficient in fuel and labour and gives planting flexibility. Because the one pass operation is the first pass over the field, there tend to be fewer problems with the crop residue plugging the equipment. All forms of N can be used.

(-) requires specialized equipment. Some types of side banding equipment may disturb the seedbed and cause problems with uniform seed placement. There may be high horsepower requirements at seeding because of high draft requirements of some side banding drills. Large amounts of fertilizer need to be handled at seeding. Generally, anhydrous ammonia is not used for side banding so overall fertilizer cost may be higher.

SPRING BROADCASTING

(+) allows flexibility in application rates at time of seeding. It is a useful means of applying extra nitrogen when one-pass banding equipment is not available or when growing conditions warrant a higher total nitrogen application. Broadcasting is a fast method of application with a low power requirement which can be used when it is convenient from before seeding until after the crop has emerged. When fertilizer is broadcast before seeding, even zero till seeding will provide some minimal incorporation. Generally, ammonium nitrate (34-0-0) is the most efficient form of broadcast nitrogen. Liquid UAN can be dribble banded on the surface close to seeding.

(-) there is inconsistent fertilizer efficiency in high residue situations and in dry years. Broadcasting also means an additional operation in the spring when time is limited.

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Advancing The Art ~ WEEDS

Zero tillage relies on herbicides to control weeds. With numerous herbicides available and with new ones being developed, they are and will be, an effective management tool. The trick to managing weeds, however, is to keep their numbers low and to limit their spread. This is done by rotating many things, particularly herbicides and crops. Integrated Weed Management (IWM) means doing things that give the crop an advantage over weeds.

Our ability to continue zero tilling will depend on our skill in successfully managing weeds. Zero tillage can permit cost effective and efficient weed management which makes it an attractive system. However, weeds that are difficult or costly to control might reduce zero tillÌs attractiveness. Integrated weed management[1] will reduce our reliance on herbicides.

Good weed management is preventing a build up of hard to control weeds and reducing yield losses from them. Trying to eliminate weeds is futile and expensive. Attempting it may even encourage herbicide resistance. We need to avoid the over-use of herbicides in zero tillage by integrating a balance of management and technology tools. In short, we need to use integrated weed management.

PREVENT WEED PROBLEMS

By using clean seed and equipment and controlling weeds in field margins, new weeds will be kept out. Controlling weeds in field margins is important for zero tillers as this is the source of problem weeds like dandelion, goatÌs beard and scentless chamomile.

Field weed seeds can be removed by collecting chaff. In many cases, over 200,000 weed seeds per acre have been removed by chaff collection. Most of them can be killed by turning them into silage or compost with livestock manure.

Chaff collection helps reduce weed spread.[2] About 85% of weed seeds entering a combine end up in the grain tank. The remaining 15% are expelled from the combine, up to 140 m (430 ft) from where they were harvested (Figure 1). Collecting the chaff reduces this spread.

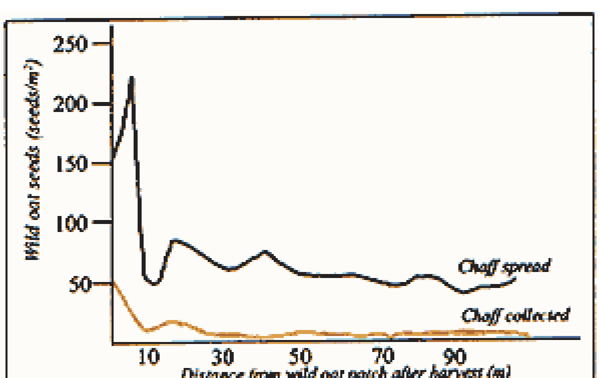


Figure 1: Wild oat seed movement.[3]

This tool along with precision agriculture, where weed patches are mapped and dealt with on a map unit basis, should prove effective when used together.

KEEP WEED NUMBERS LOW

There are six ways to do this:

- *vary seeding dates in a field from year to year*
- *use pre-emergence herbicides in the rotations*
- *encourage quick crop emergence before weeds*
- *spray in-crop weeds early rather than waiting for all weeds to emerge,*
- *seed soon after spraying burn-off treatments*

- *minimize soil disturbance between rows at seeding*

If these techniques are used effectively then occasionally in-crop spraying can be avoided. However, if this option is used, the weeds will need to be watched to ensure that their densities do not build up to difficult levels in subsequent years. A risky technique some use is to spray a "pre-emergent" burn-off after seeding. When it works, it gives good weed control, as newly emerged weeds are killed and the crop can get a jump on later emerging weeds. However, if rain or wind after seeding prevent spraying, weeds will escape control and affect crop establishment.

HELP CROPS CHOKE WEEDS

Give crops the advantage over weeds by using high quality seeds that produce vigourous seedlings and by using competitive crop types and varieties.

Other agronomic tools like high seeding rates and shallow and uniform seeding depth will help the crop emerge quickly and compete with weeds. If a crop has an advantage over weeds then spraying may not be necessary.

KEEP WEEDS "OFF-BALANCE"

Changing weed management techniques in a field year after year makes it hard for weeds to adapt and is a powerful tool. Using different techniques does not allow one type of weed to dominate and will delay the development of herbicide resistance.[3]

Cropping plans should include rotating competitive and non-competitive crops, seeding dates within a field from year to year, herbicides groups, pre and post-emergence herbicides, pre and post-harvest herbicide windows and crops with different life cycles, including perennial and winter annual crops.

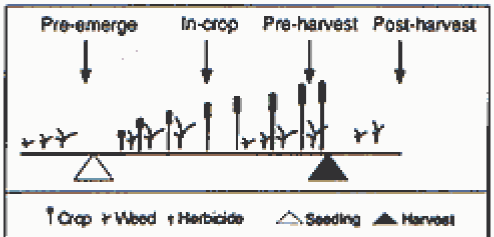


Figure 1: Herbicide application windows in zero tillage.[1]

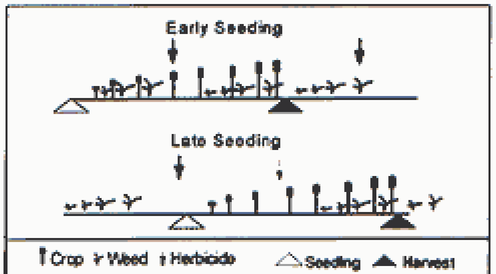


Figure 2: Different herbicide windows in early and late seeding.[1]

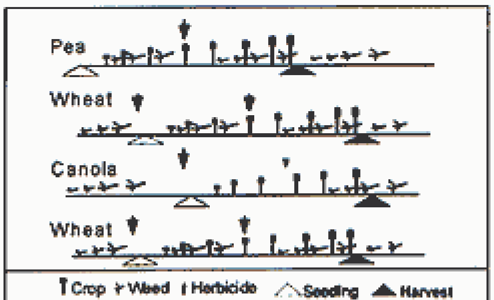


Figure 4: Four year rotation with unbalanced herbicide use.[1]

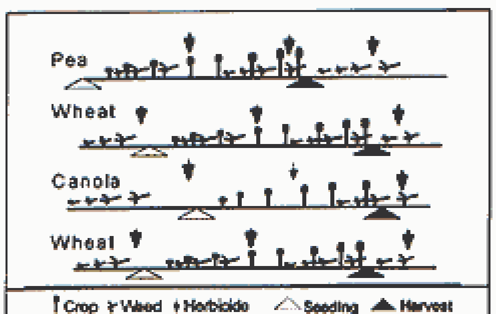


Figure 5: Four year rotation showing more balanced herbicide use.[1]

Herbicides can be applied in annual crops during four windows: before seeding, in the crop, pre-harvest and post-harvest (Figure 1).

Using all four options may not be necessary if crop sequencing is planned (Figure 2).

If weeds are controlled the previous fall, then pre-seeding herbicides may not be needed the next spring. Delaying seeding in some fields allows most weeds to be killed with pre-seeding herbicides. However, with early seeding, in-crop herbicide use is more likely as weeds will emerge with, or shortly after, the crop (Figure 3).

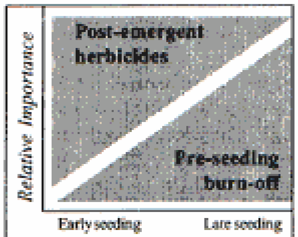


Figure 3: Relative importance of pre-seeding and post-emergent herbicides.

With delayed seeding, in-crop herbicides may not be required, especially in zero tillage where weeds have not been stimulated by tillage. It can be hard to reduce herbicide use during mid-season seeding as both burn-off and in-crop treatments are needed.

A multi-year weed management planner can be used to see how crop rotations and herbicides effect weed communities. For example, a four year pea-wheat-canola-wheat sequence where only pre-seeding and in-crop treatments are applied, will select for Canada thistle, dandelion, or winter annuals that germinate in the crop (Figure 4). Many weeds become problems with this approach.

Perennial weeds like dandelion and Canada thistle, as well as new winter annuals, like cleavers and night flowering catchfly will germinate under a maturing crop and are difficult to control with herbicides the next season.

A more balanced approach is to use all of the windows over several years within a field (Figure 5 above). In this example, pre-harvest herbicides are applied one year in four and post-harvest herbicides are used every year to reduce the build up of perennial and winter annual weeds. Where perennial and winter annual weeds are increasing problems these non-traditional herbicide windows of more than one year in four may be necessary.

Examining your three or four year crop rotation and herbicide use patterns may explain why new weeds appear. Crop rotations which give balanced herbicide windows will suppress weed changes and reduce weed densities.

"With my no-till program, my goal is to use less chemical. I don't spray much in-crop for broadleaves - some, but not much. I'm not paranoid about weeds, I can accept a few out there. The expense trade-off is important. We probably shouldn't be looking at totally weed free fields."


Darrel Oech, Beach, North Dakota

OTHER BASIC ISSUES

Many weed management issues with zero tillage systems have been discussed in the first manual produced by the Manitoba-North Dakota Zero Tillage Farmers Association. New zero tillers would find this information very useful. It covers issues like the need for a good marking system for spraying into standing stubble and gives farm experiences in controlling specific weeds not discussed here.

SPRAY WATER QUALITY

Some herbicides are severely inactivated by poor water quality, especially glyphosate.[4] Calcium and magnesium, in particular, reduce glyphosate activity. Other ions, like sulphate, chloride, sodium, and bicarbonate can cause problems.

It is important to test your water for hardness to see if there is a problem. The hard water problem can be reduced by using full herbicide rates, mixing ammonium sulphate fertilizer (21-0-0-24) to the spray tank before adding the glyphosate and by keeping water volumes low (Figure 6).[5]

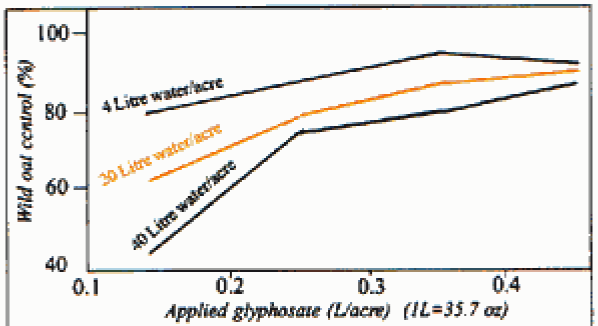


Figure 6: Effect of water volume on glyphosate activity.[5]

HERBICIDE GRANULES

Ethylfluralin, trifluralin and triallate applied as granules work well in conventional tillage, especially in canola. Given their spectrum of weed control and the need to mix herbicides groups to avoid herbicide resistance, they would also be useful in zero tillage.

These granular herbicides are not registered for surface application without incorporation. However, they have been effective in zero tilled field trials without incorporation (Table 1).[5] In a worst case scenario of; early seeding, cool soil and a non-competitive crop, this technique has given 80% control compared to 90% control with post emergent herbicides.

Table 1 Incorporation effects on wild oat populations and efficacy of fall granular herbicides (applied October 1991).(5)

Incorporation Method	Untreated	Triallate	Triallate/ Trifluralin	Trifluralin
	(Wild oat plants/m^2)			
Zero Till	131	8	10	55
Minimum till	371	23	42	95
Conventional till	359	102	63	193
Maximum till	505	166	104	370

Zerotill - no incorporation

Minimum till - one cultivator incorporation (spring)

Conventional till - two cultivator incorporation's (spring)

Maximum till - three cultivator incorporation's (one fall, two springs)

Why should these granular herbicides work without tillage? Incorporation with tillage puts the herbicides near germinating weeds while reducing atmospheric losses. However, with zero tillage, weeds emerge from near the surface. Therefore, these herbicides may not need to be incorporated to get them close to weed seeds. The greatest success with non-incorporated herbicides occurs when they are applied to a field that has been zero tilled for at least three years. In these cases, the weed seeds are near the soil surface. The granules are applied just before freeze up to reduce herbicide losses.

Non-incorporated surface application works just as well as incorporation with harrows. But for best results, use these herbicides with mid-season sown crops, so that early escapes are controlled by pre-seeding burn-off treatments. In low crop residue situations in Australia, the liquid formulation of these products has been very effective when applied at seeding, ahead of narrow point seed openers.[6]

CONTROL OF WINTER ANNUALS

Recommendations for the control of common winter annuals like stinkweed and flixweed are available in most weed control guides and spraying can occur up until freeze up.

The control of "new" winter annuals like cleavers, night flowering catchfly, storkÌs bill, common peppergrass, and blueburr is less well understood, with few recommendations available. These weeds are protected by the insulating layer of snow trapped by zero tillage stubble.

In-crop control methods are recommended for these weeds, but they do not work well for plants that have overwintered in zero tillage. Control of these weeds may require early or late post-harvest use of higher rates of phenoxy herbicides than are commonly used to control other winter annuals or fall use of herbicides normally used in-crop or with glyphosate. More research is required here.

SOIL HERBICIDE RESIDUES

Using 2,4-D or dicamba in the fall or spring can damage following crops. However, in western Canada, zero tilled canola, peas and lentils have not been affected by registered rates of 2,4-D that were used in the previous fall.[7]

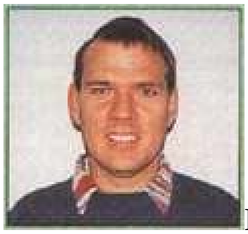
However, fall or spring use of dicamba or spring use of 2,4-D has thinned crops and reduced yields (Table 2). In sensitive crops, residues from chlorsulfuron and metasulfuron may last 1-2 years longer in zero tillage.[8] Some farmers with high pH soils have seen residual problems lasting 9 years. On the other hand, imazamethabenz carry-over effects on canola and wheat were less in zero tillage than in conventional tillage.[9] It is best to be cautious with herbicide residue risks.

Table 2: Effects of soil residues from 2, 4-D and dicamba applied 0 and 15 days prior to seeding on several crops.(7)

Herbicide (oz/ac)	Days before seeding	Yield (check = 100)			
(1oz = 28ml)		Canola	Alfalfa	Peas	Lentils
Check		100	100	100	100
Banvel @ 2	15	105	117	91	32
Banvel @ 2	0	102	105	85	19
2,4-D Ester @ 8	15	84	87	68	30
2,4-D Ester @ 8	0	84	95	50	20
Banvel + 2,4-D E (2+8)	15	89	86	75	9
Banvel + 2,4-D E (2+8)	0	85	10	44	10

For potentially sensitive crops, choose pre-seeding herbicides like glyphosate that have no soil residues.

"Herbicide resistance won't beat us! It can't! We will just have to do creative things and be determined to find new ways around the problem. There are more tools coming available every year. Zero till offers too many benefits for us to just let it go"

Bill Crabtree, West Australia

STUBBLE AND HERBICIDES

Extensive research in standing stubble or with surface residues shows that post-emergence herbicides work just as well with zero, minimum or conventional tillage systems.[10] However, to be sure of good herbicide activity use properly calibrated, good spraying equipment.

Interestingly, crop residues can control or suppress weeds. The residues create a poor seedbed for weeds to establish in and they have a negative chemical effect on weeds. The residues also promote increased pathogens and insects that can feed on weed seeds.

PERENNIAL WEED CONTROL

Controlling most common perennial weeds like Canada thistle, quackgrass, and perennial sow-thistle is almost the same in zero as in conventional tillage. These weeds should be suppressed or controlled at every opportunity. Use targeted measures, such as high rates of clopyralid on Canada thistle, when necessary. Newly registered pre-harvest RoundupÆ works well on these weeds and is an effective part of a perennial weed management system.

Dandelion: can be effectively controlled with pre-harvest glyphosate (Figure 7). Fall applied 2,4-D at normal rates for winter annuals improves dandelion control, especially several years after the application of pre-harvest Roundup(R). Pre-seeding and post-harvest glyphosate use are also registered for dandelion control.

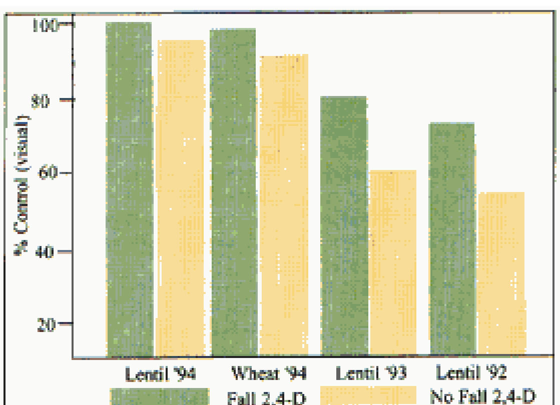


Figure 7: Dandelion control ratings (spring 1995) one year after pre-harvest glyphosate (1L/a) application to wheat and one, two and three years after application to lentils.

Foxtail barley: seedlings can be killed with pre-seeding glyphosate which will also suppress established plants. Using pre or post-harvest glyphosate gives better control than pre-seeding. Other useful tools include using higher seeding rates and banding rather than broadcasting fertilizer.[11] A multi-year approach is required to manage this weed in conservation-tillage systems. If densities become too great tillage may be required.

Yellow toadflax: is an increasing weed problem for no-till farmers in parts of Alberta and Saskatchewan. Yellow toadflax can be controlled by the use of pre-harvest RoundupÆ. Increased crop seeding rates also helped suppress toadflax.[12]

SNOW SEEDED CROPS

Canola sown during fall freeze-up, will germinate in the spring and develop normally.[13] Using this technique with glyphosate and glufosinate resistant canolas is a useful new weed management tool. Since the crop emerges early in the spring it helps to keep weeds off balance by effectively competing against them. The canola crop can finish flowering before the summer drought sets in. True winter-type canola does not survive in the northern plains.

HERBICIDE RESISTANCE

Prevention is the best cure. Since zero-tillage farmers have a greater reliance on herbicides, following good IWM practices by rotating herbicide groups and applications among all herbicide windows and avoiding the over-use of any one herbicide is important. Remember, herbicide resistance could occur to any product.

TILLAGE

Some zero tillers have used some tillage to control foxtail barley or dandelion. At times this may be necessary, but watch your weeds the next year. In wet years, some growers have used light tillage to help dry out wet areas. However, they have often found that weeds that had not been major problems since they stopped tilling, such as green foxtail, were back in high numbers. These weeds can be controlled with herbicides but quick management changes may be needed.

YIELD LOSS DUE TO WEEDS

Recent research determining if yield losses from weeds are with equal with all tillage systems.[14] Where the weeds were removed and no herbicide used, zero tilled wheat and lentils gave higher yields than conventional tillage in most years.

This could be due to fewer and also later emerging weeds and vigourous crop competition due to more soil moisture in zero tilled field. This work may help explain why yields from zero tilled fields are generally higher than conventional tillage, despite the presence of similar numbers of weeds at harvest.[15]

FALLOW IN ROTATION

Fallow is not a neutral force on weeds. Wild buckwheat can increase in rotations with tilled fallow, wild tomato can increase in minimum-tillage fallow (tillage and herbicides), and dandelion and foxtail barley may increase in chemical fallow.[16] Chemical fallow should be minimized and not relied on to avoid the build up of hard to control weeds, higher herbicide use and herbicide resistant weeds. Chemical fallow is difficult to sustain as weeds that survive may set many seeds.

FERTILIZER PLACEMENT

Banding fertilizer greatly reduces the density of green foxtail, especially in zero tillage.[17] With similar wild oat densities in a flax crop, banded nitrogen reduced yield loss.[18] High soil disturbance at seeding also increased yield loss.

HERBICIDE RESISTANT CROPS

These crops allow the use of broad spectrum herbicides from different groups and give new weed management options. For example, early planting of crops resistant to these herbicides could mean that pre-seeding burn-off treatments are not needed. Herbicide resistant crops that volunteer the following season may require special attention.

REDUCED HERBICIDE RATES

Why will reduced rates work in some situations and not others? Herbicide rates are registered to work in average environmental conditions and cropping situations. If conditions favour herbicide activity, or if the crop has a competitive advantage over the weeds (IWM) then reduced rates can work. However, there is not a 1:1 relationship between herbicide rate and weed control. In other words, a 20% reduction in rate does not necessarily mean 20% less weed control. It could mean no weed control difference, in good conditions or 50% less weed control. Experience is required to make this approach work consistently. Be aware that reducing rates leaves you without company support.

FUTURE

Cropping systems in the northern plains are moving toward less soil disturbance with efficient use of herbicides and fertilizers.[19] Successful weed control in zero tillage will require multi-year IWM strategies. Future good weed control lies not in a new "silver bullet" but in a systems approach.

Spraying Equipment

Pesticides should be applied efficiently, at the right time and with minimal spray drift. The nozzle is probably the most important part on the sprayer. It controls the flow rate, produces the spray pattern and uniformly directs the chemical to the sprayed surface. Nozzles wear so they need to be replaced regularly. For good results operating pressure should be uniform over the boom, nozzle spacing should be uniform and the boom should operate at the proper height above the sprayed surface for the nozzle being used. It should also be operated at a constant speed, unless using a spray controller. Even then, speed changes should not exceed the capabilities of the controller.

On occasions, pesticides will drift and cause damage to susceptible nearby crops. It is not possible to eliminate all drift but it can be reduced. Using new low drift nozzles, lowering the boom, increasing application rates and using spray shields and drift control agents will help. Spray shields are becoming popular and they can reduce drift by 50%. Spray shields will not stop all drift so caution is still sensible when spraying near susceptible crops.

A new type of sprayer is being introduced in the northern plains. It is the air assist sprayer that uses a high velocity air stream to help carry chemical to the sprayed surface. Limited information shows more spray is carried into the plant canopy but there may also be more spray drift than conventional sprayers.

Vern Hofman, Extension Agric. Engineer

Fargo, North Dakota

"Competition, sanitation and rotation are my three cultural practices. Herbicides to me are only something that aids my crops competitiveness - we're not going to eradicate all weeds. What I'm out there to do with a herbicide, when I need it, is to give my crop the competitive advantage"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Advancing The Art ~ DISEASES

Three factors are needed to produce a plant disease: a susceptible variety or host, a favourable environment, and a virulent pathogen. These three elements constitute a plant disease triangle and a disease develops only when all three factors are favourable. The best way to reduce the risk of plant disease in zero tillage is to eliminate one of them. In most cases this involves using management practices that reduce the pathogen carryover. Good crop rotation is the most powerful way to reduce plant diseases.

ZERO TILL CONSIDERATIONS

Techniques to control plant disease are similar regardless of tillage system. However, a few aspects of zero till make adopting these techniques even more important.

Crop residues on the soil surface may influence the incidence and severity of plant diseases. Residues have little influence on diseases such as wheat stem or leaf rust which can come from spores carried long distances in the wind and not from the stubble. Unfortunately, many plant pathogens that cause leaf diseases, stem infections, and root rots can overwinter and survive on the crop residue left on the soil surface.

DECOMPOSITION IS ESSENTIAL

Survival of residue-borne diseases is closely correlated with residue decomposition. Tillage promotes residue decomposition by fracturing the residue. This increases access by residue-decomposing microorganisms. In comparison with conditions at the surface, the soil environment is better for sustaining decomposition because the soil microorganisms are protected from drying out.

Populations of *Fusarium graminearum*, the fungus which causes crown rot and head blight in wheat (scab), decline rapidly with tillage.[1] However, in zero tillage it may take two or more non-scab years before it is significantly reduced.

Conditions in the root zone of zero till fields protect crops from drought and heat stress and, consequently, from some diseases.[2] Root rot in cereals and peas has been less severe under zero till.[3]

The microenvironment of the soil and duff layer will affect the types of diseases present, the dynamics of the pathogens, and the risks associated with growing similar crops in close rotation (Table 1).

Table 1. Impact of surface residue and zero tillage on crop diseases in the norther plains

Crop	Disease	Plathogen lives in	Surface residue disease risk	Diesease trends with no-till	Suggested interval between similar crops
Cereals • wheat • oats • barley	Common root rot	residue, soil	medium	decrease	2-3 yr
	Pythium (browning) root rot	residue, soil	medium	no change	4 yr
	Take-all	residue	medium	varies	1-2 yr
	Leaf spot disease	residue	high	increase	1-2 yr
	Fusarium head blight (scab)	residue, soil	high	increase	2-3 yr
	Rusts	living plants	none	no change	not applicable
	Loose smut	seed	none	no change	not applicable

	Common bunt	soil, seed	none	no change	not applicable
	Ergot	soil	none	slight increase	1 yr
	Seedling blights	residue, soil	medium	increase	2 yr
Oilseeds • canola • sunflower • mustard • flax	Blackleg	residue	high	increase	3 yr
	Sclerotinia diseases	soil	low	decrease	3+ yr
	White rust	soil	none	no change	3 yr
	Alternaria leaf spot	residue	high	increase	2-3 yr
	Pasmo (flax)	residue, seed	high	increase	3 yr
Pulses • peas • beans • lentils	Flax wilt	residue, soil	high	increase	3 yr
	Mycosphaerella blight	residue, seed	medium	no change	3-4 yr
	Ascochyta blight	residue, seed	high	increase	2 yr
	Anthracnose	residue, seed	high	increase	3-4 yr
	Sclerotinia stem rot	soil	low	decrease	3+ yr
	Damping off, root rot	soil, residue	medium	increase	3+ yr
	Botrytis stem/pod rot	residue, seed	high	increase	2-3 yr
	Powdery mildew	residue	medium	no change	3-4 yr

Burning crop residue is not recommended for controlling diseases in zero till and is a poor environmental practice. Burning will also not be hot enough to eliminate root stubble on which some pathogens can survive in the field. The buildup of cereal diseases can be predicted. However, we still have a lot to learn about diseases in oilseed and pulse crops in zero till.

DISEASES CAN BE REDUCED BY:

- *using good crop rotation*
- *using tolerant or disease resistant varieties*
- *using pathogen-free seed with high germination*
- *eliminating volunteer plants that can harbour diseases*
- *planting at recommended seeding times and rates*
- *using proper fertilizer balances, especially nitrogen*
- *monitoring your fields and making strategic use of fungicides.*

CROP ROTATION

Appropriate crop rotations lengthen the time between crop types so pathogen populations have time to decline. Crop rotations take advantage of the fact that plant pathogens important on one crop may not cause problems on another crop. For example, common disease problems on cereals will not affect oilseed, peas, or bean crops, and vice versa. Thus, by rotating among crop types, pathogens on the residue from previous crops in the field will not cause a disease problem on the crop being grown. Advancing the art of zero tillage by developing appropriate crop rotations is discussed in component 3 .

Soil and residue borne diseases

For persistant diseases, a long period between susceptible crops would be the best solution, but it is neither easy nor practical for most growers. Rotation is critical for some diseases, but for others it is less important. The level of risk depends on the shortest interval between crops with similar diseases. Diverse rotations reduce the risk of catastrophic losses caused by diseases, but flexibility is needed to take advantage of market opportunities.

Disease severity and yield losses are higher with crop monoculture than with more diverse rotations. For example, compared to continuous wheat production, the following four diverse rotations yielded 11-28% more grain and reduced root and leaf diseases of wheat.[4]

- *wheat-canola-wheat-lentil*
- *wheat-peas-wheat-lentil*
- *wheat-sunola-canaryseed-lentil*
- *wheat-flax-winterwheat-peas*

Yield losses of up to 20% resulted from tan spot and septoria blotch in continuous wheat crops, compared to when wheat followed non-cereal crops.[5]

Sclerotinia

Sclerotinia stem rot has a wide host range including canola, mustard, lentils, sunflower, potato, sweet clover, dry beans, buckwheat, and faba beans. It does not affect cereals and grasses, and has a limited ability to affect alfalfa. Shortened rotations with susceptible crops greatly increases the risk of this disease.

Sclerotinia stem rot of canola has increased by 39% when grown after a rotation with peas and beans compared to a rotation with potatoes and beans.[6] The use of peas in a rotation increases sclerotinia stem rot in succeeding susceptible crops. This disease is difficult to detect in pea crops and may not cause reductions in pea yield. However, numerous sclerotia (small hard resting bodies of the fungus) are released to the soil during harvest. Sunola is another crop that can contribute numerous sclerotia to the soil. Flax is a better alternative for rotations. A more open canopy lowers the risk of airborne infection and subsequent development of sclerotia.

Leaf diseases

Similar crops types, like wheat, barley, other cereals and grasses usually have similar diseases. A short break of 1-2 years usually gives adequate management of cereal diseases.[7] Fungal spores causing tan spot of wheat may be recovered from weathered straw after two years, but their recovery is greatly reduced compared to spore production on straw the season after harvest.[8] A rotation interval of one year between wheat crops is sufficient to lower disease levels of septoria leaf blotch when conditions do not favour the disease. A longer interval is needed when conditions are favourable for the disease.[9]

In general, if cereals are planted more than two years in a row, do not grow the same type of cereal crop each year. Use a range of cereals such as wheat, winter wheat, barley, triticale, oats, and rye. Wheat and barley have more similar disease problems than oats and rye. Grasses and canary seed carry diseases similar to cereals. Growing wheat or barley after grasses or alfalfa-grass mixtures may increase the risk of root diseases.

Root diseases

Crop rotations are an effective way of reducing root diseases such as common root rot. Following 0 and 5 years of nonsusceptible crops, common root rot severity declined from 28 to 13%, respectively.[10]The decline of common root rot inoculum in soil is slow, and a long rotation gives effective control. To lower inoculum levels and reduce the risk of root diseases, almost any annual oilseed, pulse crop, or perennial forage legume can be used. Cereals, canary seed, and wheatgrass forage species should not be used as the fungus sporulates on the crowns of these crops and inoculum levels will therefore be maintained or increased.

Blackleg

For some diseases, the rotation interval is a critical factor for the long-term success of plant disease management. Virulent blackleg is widespread on canola in the northern plains. Losses of over 50% may occur in severely infected crops. Crop rotation is recommended for control of blackleg, although it may not always succeed since airborne spores can travel up to 8 km (5 mi.). However, the largest numbers of spores are produced on two year or older residues.[11] Therefore, the residue from the canola crop grown in year 1 of a rotation will start producing the largest number of spores in years 3-4, so the risk of blackleg infection will be highest in those years from inoculum coming from older stubble.

Ascochyta blight

Unfortunately, crop rotation may have less impact with some diseases like ascochyta blight of peas. Survival of this pathogen is reduced when pea residue is buried, but it can survive for long periods as a saprophyte in soil. In fact, *Ascochyta pinodes*, which causes the disease, has been isolated from soil 20 years after the last pea crop. This pathogen also produces airborne spores that can easily move to adjacent fields. Consequently, growers in areas where peas are commonly grown should expect to see this disease irrespective of rotation or tillage.

Rotations will, however, reduce powdery mildew and other diseases of peas making a healthier crop to fight off aschochyta blight.

A long-term investment

Crop selection for minimizing disease risks should be thought of as a long-term investment. A rotation should be comprised of 50% grass species, including winter cereals, with the remainder divided among pulse, flax, and other oilseed crops. The shortest rotation interval would be 2 years, but 4-6 gives better disease control. Another way to reduce diseases is to extend the rotation more by including a cycle of forage production. Disease risk levels vary with different crop rotations (Table 2).

Table 2: Disease risks associated with different crop rotations in the norhern plains

Rotation	Greater Risk of	Lesser Risk of
canola, barley, flax, durum, wheat	leaf spots (cereals) fusarium head blight, scab (cereals) common root rot (cereals) take-all (cereals)	blackleg (canola) sclerotinia (canola)
wheat, canola (flax), barley, field peas (flax)	fusarium head blight flax wilt (flax)	ascochyta (pea) leaf spots (cereals) root rots (cereals)
wheat, peas, oats/barley, canola/sunflower	sclerotinia (pea, canola, sunflower) fusarium head blight	blackleg (canola)
wheat, peas, winter cereal (rye or wheat) canola/sunflower	sclerotinia leaf spots fusarium head blight	none!
canola, lentils, wheat	none!	most diseases
conola, peas, wheat	sclerotinia	most diseases
canola, lentils/peas, flax, cereal, canola, forage, forage, forage, cereal,cereal	leaf spots	sclerotinia, blackleg ascochyta (peas, lentils)

INTEGRATED PEST MANAGEMENT (IPM)

IPM is the combined use of biological, cultural, mechanical and chemical techniques to reduce pest risk. These techniques include: using resistant cultivars, appropriate crop rotations, using a trap crop, considering economic thresholds, banded pesticides, targeted application of crop protection products and fertilizers, use of biological control for insect pests, and the protection of natural predators. Field scouting helps make an IPM program successful. It gives early identification of pest problems, determination of economic thresholds, and evaluation of the usefulness of a management strategy.

Using IPM has many advantages. It increases management choices and gives the most cost effective strategies. IPM advocates using pesticides only when needed and delays the development of resistance. It improves the timing and efficiency of crop protection and prevents unnecessary losses. Finally, an IPM program reduces hazards and offers protection to the environment and producer.

USE TOLERANT VARIETIES

Always use disease tolerant or resistant varieties when they are available. Even though disease symptoms are present on a tolerant variety, the detrimental effect of the disease on yield is greatly reduced. A susceptible host is necessary for a disease to develop, so the use of a resistant variety will greatly reduce the risk of that disease becoming a serious problem.

If complete resistance is not available in a variety, using one with moderate resistance will give some protection. In addition, the effect of the resistance will be carried over to the next season because there will be less inoculum produced on the stubble.

USE PATHOGEN-FREE SEED

Pathogens may be introduced into a field on seed that has seed-borne disease organisms. Poor quality or disease infested seed may also affect the stand or plant population density, particularly under cool, wet conditions. Some diseases, such as common bunt or loose smut, are easily controlled with fungicide treatment of the seed.

In addition, poor quality seed presents a disease concern because it will not germinate and emerge as quickly as would high quality seed. This makes it more susceptible to soil-borne diseases.

ELIMINATE VOLUNTEERS

Volunteer plants can harbour diseases. Insects that carry virus diseases can move from volunteer plants to a newly emerging crop. For example, wheat streak mosaic virus is spread from wheat crop to wheat crop by the wheat curl mite. Barley also is susceptible to this virus.

While tillage systems have no direct effect on virus infection, the presence of volunteer wheat or grasses in a no-till system does increase the risk of infection. These volunteer plants are reservoirs for both the virus and the mite. The mites can only exist and live on green plant tissue. The volunteers serve as "green bridges" and allow the mite to move from these plants into winter cereals in the fall, or into spring cereals in the spring. In the process of feeding, the mite transfers the virus.

To reduce the risk of wheat streak mosaic virus in a no-till system, use the following steps:

- *Control volunteer cereals and grasses with herbicide within the field to be planted and in adjacent areas, at least two weeks prior to planting.*
- *Avoid planting winter wheat early in the fall adjacent to spring wheat crops*
- *Plant spring grains early. The wheat curl mite is most active in warm temperatures. Virus infections that establish early in a cropÌs development are most damaging.*
- *If available, use tolerant cultivars.*

PLANT AT BEST TIMES AND BEST SEEDING RATE

Early planting of spring wheat reduces the risk to foliar diseases that build up during the growing season and reduces the risk of exposure to heat stress at the 4-5 leaf stage, which adversely affects yield.

High spring wheat plant populations have high yield potential. This can produce dense canopies that increase the humidity which favours the development of foliar diseases, particularly in higher rainfall areas. To compensate, wider row spacings may be which creates a less humid environment with greater air circulation between the rows. Also, wider rows may be more desirable for handling larger quantities of the crop residues occurring with zero tillage.

In drier areas, if plant populations are too high in relation to the amount of water available to sustain good growth rates, the plants can become stressed and more susceptible to some root rot diseases. However, with zero tillage in semi_arid areas, common root rot and take-all diseases of wheat have been reduced with higher seeding rates, wider row spacings and adequate seed placed phosphorus.

BALANCE FERTILIZERS

In high rainfall areas, excess nitrogen fertilizer can produce lush growth with dense canopies. That may increase the canopy humidity, again favouring foliar diseases. In drier areas, increased levels of foliar diseases on spring wheat have been associated with inadequate levels of nitrogen. An unstressed plant is more resistant to disease than a plant stressed by low fertility or other factors. In a long-term tillage study, the severity of leaf spot diseases on wheat was, at times, higher in zero till than conventional till at low nitrogen levels. At adequate N levels, the severity was similar.[12]

Chloride, applied as potassium chloride, has reduced foliar and root-rot diseases of small grains when chloride levels were low (less than 30 lb/ac).[13] These results vary and depend on cultivar, soil types, location, and/or the year.

MONITOR YOUR CROP

Regularly check or monitor your fields for the presence of disease so you can make appropriate decisions for fungicide use. If foliar diseases are present and yield potential is high, applying a fungicide might be useful.

Each year wheat producers struggle with the decision on whether or not to use foliar fungicides to protect their crops against tan spot and septoria leaf diseases. Reference materials for plant diseases and decision aids for foliar fungicides have been developed by various organizations.[14-17]

The decision guide (Table 3) here was prepared by plant pathologists in the northern plains.[18] This can be used at three crop growth stages. As with all aids, this one is only a tool to help make the decision easier. The aid has no hard and fast rule, and other factors not listed, such as development of head scab, may affect the decision.

Table 3: *Foliar Fungicide Decision Aid For cultivars susceptible to Wheat Leafspot Diseases*			
Factor		Suggested Points	Value in your field
1) Market price/bu	$2.00 - 2.50.............. $2.51 - 3.00.............. $3.01 - 4.00.............. $4.01 - 5.00.............. $5.01 >	1 3 5 6 7	
2) Previous Crop	Wheat with stubble..... Wheat w/o stubble..... Barley....................... Other........................	4 2 1 0	
3) Tan spot or Septoria leaf spot development			
Feekes Growth Stage	# of leaves from top of plant free of disease		

6 - 8 (jointing to early flag leaf emergence)	4............................. 3............................. 2............................. 1............................. 0.............................	0 1 2 3 4	
9 - 10 (early flag to boot)	3............................. 2............................. 1............................. 0.............................	1 3 4 5	
10.1 - 10.5 (heading)	3............................. 2............................. 1............................. 0.............................	Don't Spray 2 3 *4	______
4) Yield Potential **	<30 bu/ac 30-35 bu/ac............ 35-40 bu/ac............ 41-50 bu/ac............ 51-60 bu/ac............ >60 bu/ac...............	Don't Spray 0 1 2 3 4	______
* don't spray if flag leaf heavily diseased ** don't spray fields heavily stressed or damaged due to factors other than disease (such as heat, drought, hail).			
5) Climatic conditions: based on past 2 weeks and a one week forcast. Select from one below that mostly closely resembles average conditions. Temperature should be average daytime temperature.			
Temp	Moisture and Rel. Humidity		
(°F)	Dry --Avg.--Wet		
<60 60 - 70 70 - 80 >80	0........0........0 0........1.......3 0........2........4 0........1.........2		______
TOTAL OF 5 FACTORS			______

Recommendation If Total Is:
A. <14 Points .... Do Not Spray
B. =14 - 16 Points .... Spray may be beneficial
C. > 16 Points .... Spray fungicides (4 oz/ac Tilt at Feekes Stage 8 or 2 lbs/acre mancozeb at Feekes 10-10.5). If applying mancozeb, re-asses field 10 days after first application and determine point value. If below 16, do not apply second spray.

FUTURE CONTROL METHODS

Biodiversity of soil microorganisms increases with zero tillage. There are more fungi, actinomycetes, bacteria, and denitrifying microorganisms. The diversity of soil life matches the diversity of the crop rotation.

Changes in the microflora and greater microbial activity may lead to future disease control methods. Microorganisms that can compete with, or antagonize, plant pathogens may be found in the soil or residue.

Biological control methods may give protection from plant pathogens in the future. With these methods, a natural antagonist of a pathogen is applied to the crop. In winter wheat, microbial populations in the rhizosphere can increase by 50% with zero tillage and 95% of these may antagonize the fungus causing take-all.[19] Mixtures of bacteria that suppress take-all have increased crop yield when applied as "living seed treatments".[20] Their effectiveness varies with location and further research is needed before being used commercially.

Fusarium head blight (scab)

Scab is caused by several fungi that overwinter and persist in residue of small grains, corn, and other grass hosts. The fungus invades the crop if prolonged dew periods and high humidities occur at the time of flowering. Head blight infection can be severe with losses in yield, test weight, seed quality, and other quality factors, and the possible presence of mycotoxins. The disease is most damaging in areas of high rainfall and low diversity cereal based rotations.

Manage with:

- *Choosing good crop rotations; plant wheat andbarley crops into non-host residue; planting wheat or barley into corn resi-due is a very high risk for scab!*
- *Using the most tolerant cultivars available.*
- *Planting early (very early in the case of winter wheat) and staggering maturity dates of cultivars, so that all of the crop isnÌt flowering at the same time.*
- *Considering the use of fungicides at flowering*

"Disease management takes a whole new set of skills and a whole new encyclopedia of knowledge, especially for root diseases. Diverse crop rotations can not only help manage diseases on the surface but also in the root zone."

Daryl Domitruk,

Manitoba Agriculture, Carman, Manitoba

What is take all root rot?

Take-all is a fungus root rot which causes a dark, shiny black discoloration of roots, crowns and lower stems of wheat and barley plants. This, in turn, leads to premature whitening and death of the plant. The bleached white heads of affected plants contain little or no grain. Symptomatic plants may appear scattered, in patches, or across large areas of the field.

The fungus, called *Gaeum-annomyces graminis* survives between susceptible crops in undecayed crop residue, on grassy weeds, and on volunteer wheat. The disease is favoured by very moist soils, and is most commonly seen in irrigated wheat, but has been observed in dryland wheat production under moist soil conditions particularly in Australia. Take-all of wheat is more severe in winter wheat than spring wheats, with Canada Prairie Spring cultivars being more susceptible than hard red spring or durum types.

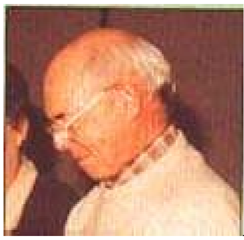
Studies on the effect of zero till production on take-all have shown varied results. Studies in northern plains states of the United States show reduced tillage produce cooler and wetter soils, which favour the fungus. In semi-arid environments take-all of winter wheat can decrease with zero tillage in contrast to moister coastal areas where the disease becomes more severe with this practice. This shows the importance of understanding a disease and its environment.

Manage with:

- *Crop rotation of three years or more between susceptible crops (wheat, barley, rye, some grasses). This can be accomplished with 3 crop-type rotations.*
- *Maintaining balanced fertility. Ammonium forms of nitrogen fertilizer suppress take-all compared to nitrate forms. Take-all is more severe under high alkaline conditions.*

- *Control volunteer wheat and grassy weeds, which may harbour the fungus.*
- *Use more tolerant varieties.*
- *Some fungicide seed treatments suppress take-all.*

"The best disease control method available is a healthy plant. Optimal fertilizer levels, seed placement, rotation and soil moisture will make a healthy plant which can resist diseases."

*Lyle Samson,*

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Advancing The Art ~ FORAGES

There is a lot known about forages in the northern plains, but little of this relates to zero tillage cropping systems. Farmers often view forages as separate from annual cropping although this does not have to be so. Generally, farmers in the northern plains recognize the benefits of forages in rotations, in particular better yields and weed control.[1] But perennial stands are often kept longer than is needed to replenish soil with N. Annual and perennial forage crops improve many soil and weed factors and are probably an under-used tool for our region. Forages add diversity and intensity to crop rotations which benefit zero tillage more than conventional tillage systems.

Most forage producers agree that annual crop yields are higher when planted after a perennial forage crop than after an annual crop. Research shows yield benefits from forages can last 9 years.

Even on a farm where there are no livestock, forages could be beneficially included in zero till rotations. There is a market for the forage and the soil and nutrient benefits for the subsequent annual crops are significant. In a Manitoba study, zero till field pea yields improved when grown in an alfalfa-alfalfa-wheat-wheat-pea rotation compared to when they were grown in a wheat-pea-barley-wheat-pea rotation.[2] The alfalfa was removed with herbicides. The year after the peas were grown, wheat yielded 500 kg/ha (7.5 bu/ac) more in the alfalfa rotation compared to the no alfalfa rotation.

The yield advantage of having forages in the rotation occurs for several reasons.

DEEP WATER USE

Deep-rooted alfalfa is one of the best ways to manage salinity. However, if the soil is too salty for alfalfa, then more salt tolerant grasses may have to be used.

Alfalfa can also retrieve deep-leached nutrients. A new stand can retrieve nutrients from 120 cm (48") and by the third year, nutrients can be retrieved from 210 cm (84").[2]

AlfalfaÌs deep roots effectively allow more water to infiltrate and increase the soil's ability to store water. This is because alfalfa root pores are continuous to the surface and they resist collapse. The pores can remain open for many years.

This"biological tillage" improves the root growth of subsequent crops, increasing their use of subsoil water and nutrients, as their roots are easily able to follow the old alfalfa root channels.

FORAGES REDUCE WEEDS

In general, fewer weeds occur in crops following forages as compared to following grain crops. However, weed reduction from short-term perennial stands will only be achieved by killing stands with herbicides - not by tillage (Figure 1). This is partly because tillage promotes germination of many weeds, particularly wild mustard, lamb's quarters and red root pigweed. Weed seeds left on the surface can be eaten by beetles and other small creatures which thrive in alfalfa and low disturbance zero till soils.

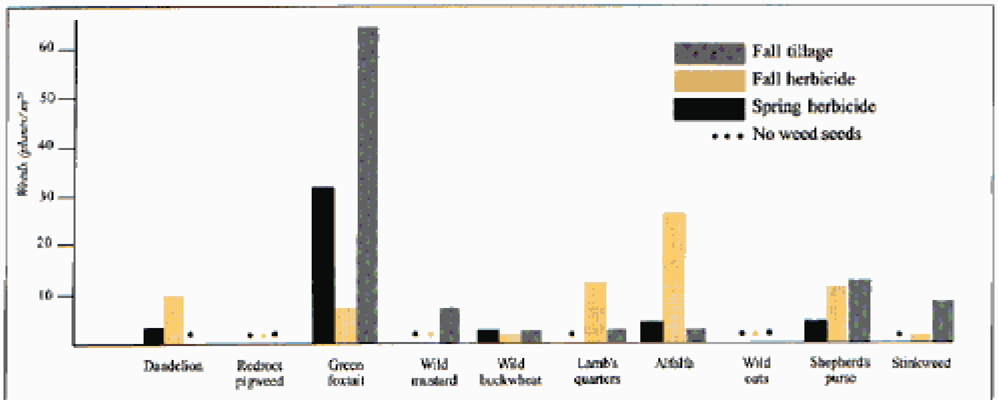

Figure 1. Weeds in wheat (June 18) sown after alfalfa which was killed with fall tillage or herbicides in the fall or spring before seeding spring wheat.

FORAGES CHANGE WEED POPULATIONS

Forages reduce some weeds more than others. Wild oats and green foxtail are greatly reduced by having alfalfa in the rotation (Figure 2).[3] The effect is large enough that wild oat numbers in following crops may not require controlling. Often, wheat crops grown after alfalfa have almost no wild oats. Small-seed broadleaf weeds are less affected by having alfalfa as the previous crop.

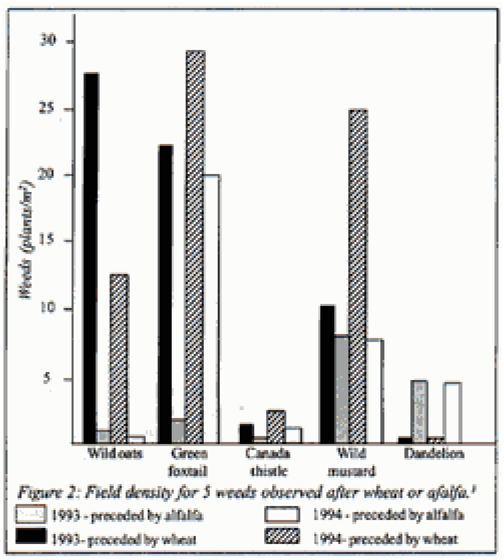

Figure 2: Field density for 5 weeds observed after wheat or afalfa.[3]

Alfalfa is especially good at reducing Canada thistle. Roots of Canada thistle can be reduced by 60% as the alfalfa out-competes thistles for water and light. Control is helped by repeated cutting.

While alfalfa will reduce Canada thistle populations, it may allow dandelions to increase. Dandelions can be suppressed by killing the alfalfa stand before it gets gappy and over-run. Reducing alfalfa stand length to less than 4 years and fertilizing stands with adequate P, K, and S also reduces dandelion invasion.

The shift in weed composition by growing alfalfa reduces the risk of selecting for herbicide resistant weeds. For example, crops sown on wheat stubble must compete with weeds like wild oats, green foxtail and wild mustard (Table 1). However, crops sown in herbicide-killed alfalfa have to compete with wild buckwheat, wild mustard, lamb's quarters and dandelion.

Table 1: The ten most abundant weeds in each field type.

Rank	Previous Crop	
	Alfalfa	Wheat
1	wild buckwheat	wild oat

2	volunteer alfalfa	green foxtail
3	wild mustard	wild mustard
4	lamb's quarter	wild buckwheat
5	dandelion	smartweed species
6	green foxtail	quackgrass
7	quackgrass	lamb's quarter
8	stinkweed	Canada thistle
9	smartweed species	cleavers
10	wild oat	bluebur

Cutting sweet clover and cereal crops for feed effectively reduces annual weeds, especially wild oats.[4] Avoiding an in-crop herbicide in these forage crops helps in rotating herbicides. Similar to perennial systems, annual forages are better at suppressing weeds when used in conjunction with zero tillage rather than with conventional tillage.

NITROGEN FROM ALFALFA

A three year stand of alfalfa is probably optimal for maximum N fixation. After this, the N simply cycles with little more being added to the soil. Pure alfalfa and alfalfa/grass mixtures will give equal N benefits, provided alfalfa is at least 50% of the mix.

Typically, 250 kg/ha (223 lb/ac) of N is released to the soil in the first two years after stand termination. However, this is affected by the size of the stand, and the soil's moisture and temperature when it is killed. One year of non-dormant ÎNitroÌ alfalfa yielding 3.8-6.3 t/ha (1.5-2.5 t/acre) of hay has added 120 kg/ha (107 lb/acre) of N to the soil.[5] About half of this N was available to the following crop. Alfalfa residues typically supply most of the N required for two following crops.

When soils are cultivated in warm and wet conditions, a lot of N is released in the first season, leaving less N for following crops. If the stand is killed with herbicides rather than tillage, then N release will be slower giving more N to following crops for up to 5 years. This slower N release is better timed to the needs of subsequent crops, much like a split N application. This also improves N use efficiency.[6]

In a dry year, total N release from killed alfalfa may be greater in zero tillage as there is more moisture in the surface soil to help mineralize the N.

Another reason to avoid tillage when removing alfalfa, particularly in sandy soils, is that tilling increases nitrate levels below the root zone of annual crops. This nitrate can then leach into the groundwater.

If alfalfa is terminated with herbicides just before planting a spring crop, then N availability to this crop will be lower than if the alfalfa was sprayed in late-summer of the previous year. Some applied N fertilizer may be needed for new legume crops sown into freshly killed alfalfa. When alfalfa is sprayed in late-summer of the previous year, little or no extra N, above "starter-N", is needed for the cereal crop.

When changing from forages to grain crops, a soil test is useful! Forage hay crops remove 2-3 times more P, K and S than grain crops. Crop failures after Îforage-breakingÌ are often blamed on dried-out soil, when a lack of nutrients is a more likely explanation.

FORAGE ESTABLISHMENT

Establishing a forage stand is the most challenging phase in forage production. A no-till seedbed is better than a conventional one for establishing forages, as it is firm and moist, and the small forage seeds can be planted shallow.

A Manitoba study showed that in a dry spring, establishment of alfalfa and meadow bromegrass can be more successful under no-till compared with tilled soil.[7] In this study, the moist zero tilled soil helped the crop survive a 30 day drought after seeding.

Work in North Dakota also shows the best alfalfa stands are produced by no-till systems.[8] Early season alfalfa establishment under no-till is better than later-season establishment. With late-seeding, tilled seedbeds work better probably due to more weeds under zero till at this time.

Many farmers lack specialized forage seeding equipment so they often have to adapt their other equipment. With such a small seed, good depth control is vital. Disc seeders give the most precise depth control and can be adapted to seed forages. Baling the cereal straw before seeding improves crop establishment.[8] Some farmers save time by broadcasting the seed and harrowing afterwards. Farmers in moist areas of Uruguay regularly broadcast forage legumes (clovers) and drill the forage grasses along with the cereal companion crop.

COMPANION CROPS

Even though 85-90% of producers use a companion crop to establish forages, companion crops do reduce stand establishment. Zero till establishment techniques give many of the benefits of a companion crop, like shading and reduced soil temperature. This occurs without their being competition with the forage seedlings.[8]

Without a companion crop, it is possible to take two hay cuts in the year of establishment. In some years, a third cut can be taken in mid-late October. Alfalfa stands are much more hardy in the first year of establishment, therefore a late-season third hay cut in the establishment year is possible.

TERMINATING ALFALFA IN A ZERO TILL SYSTEM

Direct seeding annual crops into chemically killed perennial forages works well if the stand is less than 4 years old. This keeps dandelions in check and reduces holes made by gophers. Alfalfa can be killed with glyphosate alone but control is improved by adding 2,4-D, or dicamba, at recommended rates. Extra glyphosate may be needed if the stand is grassy.

The alfalfa should be at least 20 cm (8") tall and close to flowering at the time of spraying. This improves the kill, much like pre-harvest RoundupÆ controls Canada thistle and quackgrass. Pre-harvest Roundup on hay crops allows an extra cut to be taken in the year the stand is killed. This greatly improves the economics of short term forage stands.

INTEGRATING GRAZING AND NO-TILL SYSTEMS

Integrated farming systems elsewhere in the world often have 1-2 years of forage then 1-2 years of grain crops. Farmers in New Zealand, Uruguay and Australia commonly use this "ley-farming" system. Ley farming is a system of alternating between legume-based pastures and grain crops. This provides more organic N to the grain crops.

Integrating these systems is not popular in the northern plains. However, some farmers have reduced their costs, improved animal performance and made their soils more productive by integrating grazing and annual cropping. This system is most effective under zero-tillage!

Adopting these management practices could improve beef production on marginal soils, and at a lower cost than grain-fed cattle. This will also recycle nutrients while maintaining the other rotational benefits of forages. However, soil compaction on heavy wet soils, and erosion on sandy soils, can sometimes reduce the systems attractiveness.

In North America, grazing and zero till tend to be integrated where alfalfa and alfalfa/grass hay crops are rotated with annual crops. However, other than sending cattle out to clean up crop residues after grain harvest, there are few operations where pastures and grain crops are rotated on the same piece of land. In some cases, marginal lands could support both annual crops and forage crops if zero till is used to minimize soil erosion, salinity problems and leave rocks in the ground.

Alternative grazing systems are viable. However, current grazing systems require minimal management, so there needs to be a clear economic benefit to encourage changing to a new system.

Management systems involving high-producing legume and grass species, regular fertilizer and rotational grazing would make pastures more economical on higher quality land.

" We're seeding more alfalfa on our farm. We don't raise any cattle but I can still sell the alfalfa to someone who does. Farmers are so focused on production that we don't look at marketing. We're going to have to develop markets - work at adding value to what we're raising. We're so used to just taking our production to the elevator or our calves to market in the fall and giving up ownership for what they're willing to pay us. That's the thing that has got to change"


Darrel Oech Beach, North Dakota

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3. Ominski P and Entz (1994). U of Manitoba
4. Schoofs A (1997). U of Manitoba (M.Sc. Thesis)
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Advancing The Art ~ INFORMATION SOURCES

Advancing the art of zero tillage depends on a willingness to ask questions. Zero till has grown because producers have asked themselves, other no-tillers, and agricultural scientists "why" and "how".

When the answer wasn't readily available, they looked for the answers. They encouraged researchers to work on zero tillage in their studies. They became involved in directing research through research department advisory committees. They did their own on-farm research and, in cases such as the Area IV Research Farm at Mandan, North Dakota and the Manitoba Zero Tillage Research Association Farm at Brandon, they created their own organization to develop farm-scale zero tillage research programs.

Information, ideas and opinions are important ingredients in each zero till farmers search for their appropriate production system.

Below are listed the information sources which will be good first contacts in the search for answers to your zero tillage questions .

CONTACT NAMES AND ADDRESSES (1997)

U.S.A.

Dakota Lakes Research Centre

Box 2, Pierre, South Dakota, 57501

Telephone (605) 224-6357 Fax (605) 224-0845

Contact: Dwayne Beck

USDA - Agriculture Research Service

Area IV SCD-ARS Research Farm,

Northern Great Plains Research Laboratory

P.O. Box 459, Mandan, ND, 58554

Telephone (701) 663-6445 Fax (701) 667-3054

Current contact: Ardell Halvorson

Email "halvorsa@mandan.ars.usda.gov"

NDSU - Extension Service

Morrill Hall Room 315

Box 5626, Fargo, ND 58105 U.S.A.

Telephone (701) 231-7240 Fax (701) 231-1008

Current contact: Vern Hofman

Email "vhofman@ndsuext.nodak.edu"

USDA - Natural Resources Conservation Services

220 East Rosser Ave,

P.O. Box 1458 Bismark, ND, 58502-1458 U.S.A.

Telephone (701) 250-4425 Fax (701) 250-4778

Current contact: Alan Ness

Email "alan.ness@nd.nrcs.usda.gov"

Canada

Manitoba Zero Tillage Research Farm

Brandon Research Centre

Box 1000A RR#3, Brandon, R7A 5Y3

Current contact: Ron Gares or Doug Derksen

Email "derksen@em.agr.ca"

Agriculture and Agri-Food Canada (PFRA)

Brandon Research Centre, Box 1000B RR#3, Brandon, R7A 5Y3

Current contact: Bob Bradley Email "bbradley@em.agr.ca"

Ag-Quest Inc. - Conservation Productivity Centre

Box 144, Minto, MB, Canada R0K 1M0

Telephone (204) 776-2087 Fax (204) 776-2250

Contact: David Rourke Email "agquest@agquest.com"

Indian Head Experimental Farm

Research Branch, Agriculture and Agri-Food Canada,

Box 760, Indian Head, SK, S0G 2K0

Telephone (306) 695-2274 Fax (306) 695-3445

Current contact: Guy Lafond Email "lafond@em.agr.ca"

Manitoba Agriculture, Soils and Crops Branch

Box 1149, Carman, MB ROG OJO

Telephone (204) 745-2040 Fax (204) 745-2299

Contact: Daryl Domitruk Email "soilcrop@gov.mb.ca"

Ducks Unlimited Canada

Box 1160, 1 Mallard Bay, Hwy 20, Stonewall, MB, R0C 2Z0

Telephone (204) 467-3000 Fax (204) 467-9028

Contact: Bill Poole Email "webfoot@ducks.ca"

USEFUL PUBLICATIONS:

Zero Tillage Production Manual (1991) and *Integrated Insect Management on Zero Till Fields* (1994)

Manitoba-North Dakota Zero Tillage Farmers Association

Available from Manitoba and North Dakota addresses

No-Till Farmer Newsletter,

Frank Lessiter Publishers

P.O. Box 624, Brookfield, WI 53008-0624,

Telephone (414) 782-4480,

Fax (414) 782-1252,

Email "Lesspub@aol.com"

Direct Seeding Manual (1994)

Produced by: PAMI and Saskatchewan Soil Conservation Association

Indian Head, Saskatchewan

No-till Guidelines for the Arid and Semi-Arid Prairies,

South Dakota State University and USDA

Available from Dwayne Beck at Pierre (see above)

Conservation Tillage Systems and Management,

Mid-West Plan Service #45,

Agriculture and Biological Engineering

Dept., Box 5626, North Dakota State University,

Fargo, ND 58105

Conservation Farming Guide and *Conservation Tillage News*

Alberta Conservation Tillage Society,

Box 326, Carbon, Alberta, Canada T0M 0L0

Contact: Russ Evans Fax (403) 572-3600

Email "acts@telusplanet.net"

Seeding on the edge Alberta Newsletter

Alberta Agriculture, Food and Rural Development,

Conservation and Development Branch, Provincial Building,

Box 159, Fairview, Alberta, Canada T0H 1L0

Current contact: John Zylstra, Fax (403) 835-3600

Email "zylstra@agric.gov.ab.ca"

Pacific Northwest Conservation Tillage Systems Handbook

Washington State University and University of Idaho.

Conservation Farming Manual

Wimmera Conservation Farming Assoc., Victoria, Australia.

Contact: Peter Berg, Telephone 011 61 53 811-255 Fax 829-388

WANTFA Newsletter

Western Australian No Tillage Farmers Association

Current contact: Bill Crabtree Fax 011 61 90 83-1100

Guide to Crop Protection and related publications

Manitoba Agriculture, at any local office.

Weed Control Guide (W-253), *Field Crops Fungicide Guide* (PP622), and *North Dakota Field Crop Management Guide-Insects* (ER-22)

NDSU Extension Distribution Center, Box 5655, North Dakota State U., Fargo, ND, 58105 Email "dctr@ndsuext.nodak.edu"

Crop Residue Management to Reduce Erosion and Improve Soil Quality

and *CTIC Partners* magazine

Conservation Technology Information Centre

1220 Potter Drive, Room 170 West Lafayette, Indiana

Telephone (765) 494-9555 Fax (765) 494-5969

Email "ctic@ctic.purdue.edu" or see "www.ctic.purdue.edu:"

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Advancing The Art ~ CHALLENGES

Zero till farmers recognize that, as a crop production system, zero tillage is not perfect. There have been, and continue to be, many challenges as they attempt to find the answers to the questions which continually come up. One of its strengths, however, is economics.

With the economics and crop production I'm seeing from zero till, it's just a matter of time before people are going to be looking across the fence and recognizing that it's the way they're going to have to go. It's a question of straight economics. At present, we have a lot of good conventional farmers who are still doing a good job ... but they're doing it with old dollars or old investments. As land starts to change hands and moves into a new generation, I believe the economics are going to drive people to zero till in the same way that economics drove people to continuous cropping.


Jim Nevin, Rapid City, Manitoba

When I came home to farm in 1982 with my dad, we were nearly half summer fallow. We had erosion, that was one of our main reasons for going to no-till. The other thing I saw was the amount of money we were spending on that fallow ground. Most of the time, in my opinion, it was dollars gone. Before we could take out the problems chemically, summer fallow had a purpose, but I don't feel it does anymore. I didn't take on another acre of land and I feel I doubled my farm.


John Raisler,Beach, North Dakota

While the business of farming demands that economics be a prime consideration, no-till farmers also point to very visible changes which they see around their farmland.

Healthy wildlife indicates healthy land - if you've got pheasants and deer and other wildlife around your land, that means you're doing something right. You're providing the habitat and in the process of providing that habitat and cover, you're creating a system to grow things in. I'm not a tree-hugger - but I am an environmentalist. I think all of us are concerned with taking care of the environment.

John Raisler, Beach, North Dakota

Zero tillage requires a systems approach to crop production. There is no single formula that works. As conditions vary from district to district - and even from farm to farm - no-till farmers have discovered that they must develop the system which fits their local conditions.

You could take a group of very experienced zero tillers, put them in a field and ask them 'are you satisfied with the seeding depth on this crop' .... you'll get half a dozen different answers. The answers will all be well thought out but you'll have different responses because each of them has been successful in slightly different conditions.

*Bob McNabb, Minnedosa, Manitoba*

Farming is like an art - a lot of farmers can do a lot of things in different ways and get the same end results.Jerry Presser, Turtle Lake, North Dakota

Finding what works best requires a continuing quest for the answers to the questions "how?" "why" and "what if".

Everyone approaches zero tillage a little differently. That's why it is important to share ideas. The Association workshops are like continuing education. You learn different chemical combinations and you learn ideas about equipment - about how to treat different soils, how to convert a field to no-till, about rotations....and then you get into what can we expect as earthworms move in, as the soil physics change, as the soil chemical composition changes - what can we expect when we see the microbial activity change?

*Michael Faught, Absaraka, North Dakota*

One of the greatest challenges faced by the early zero tillers was to develop seeding equipment that could place the seed properly in the ground. The 'new' seeding conditions which they faced demanded a system which could cut through the straw and trash, and provide uniform seed placement and safe fertilizer placement. With the equipment which is available today, the equipment decision is still a critical one for the no-till farmer.

I tried all kinds of drills and the first one didn't have banding capabilities. Well, I never had luck spreading fertilizer. If someone were buying a no-till drill without banding capability, I'd tell them to simply forget it - it's that important. It puts the fertilizer where the crop needs it, you're not fertilizing all the weeds - you're placing the fertilizer where the roots can grow into it.

*Jerry Presser, Turtle Lake , North Dakota*

From the beginning, it has been an accepted fact that zero tillage means the use of herbicides to replace the tillage. In particular, glyphosate made no-till farming possible. It must be borne in mind that the age old conflict between crops and weeds continues. In recent years, we've seen the development of herbicide resistance in weeds. While conventional farmers might look to more tillage, many zero tillers are using more diverse rotations and considering new herbicide approaches.

Certainly all of us have had to change our views about weed control because of the resistance problem. Now we are doing things we wouldn't have considered just a few years ago. For example, I've been using a surface applied pre-emergence herbicide which I hadn't thought of using before. Even though I know they aren't going to work 100%, I still rationalize it by saying that's better than having a resistance problem.

*Jim McCutcheon, Homewood, Manitoba*

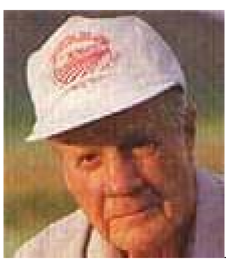
Willingness to alter patterns has become a 'trade-mark' for zero-tillers. Some foresee that there may be a greater need to adapt in the future.

I guess I feel we could lose our herbicides. We could lose them for two reasons. Either they won't control the weeds properly anymore or we'll lose them for environmental reasons. So we would have to adapt and take a different approach. We'll demand that we have a good winter wheat or we may mix in more forages. Even if I'm not doing that right now, that doesn't mean that I can't or won't be in 5 years.

*Robert Stevenson, Oak Lake, Manitoba*

Along with weeds, successful no-till crop production requires attention to plant diseases. Crop rotations play an important role in breaking plant disease cycles - but other zero till attributes have a bearing as well.

I know we have disease on the old stubble that could infect the new crop but it doesn't seem to do it. One plant pathologist said it was because you don't get any splashing of water up from the ground - because the ground is covered with straw. The spores from those leaf diseases have to get mixed up with water and dirt and splashed onto leaves in order to sprout. If your ground is 100% covered by straw, the rain doesn't splash up - so we haven't had many outbreaks.

*Bob Ekre, Beach, North Dakota*

Crop rotation is just one of many tools used by no-till farmers in their production system. There are many reasons for including a wide range of crops in the rotation, but no matter what the added benefits are, the decision to include any crop in the rotation depends, in part, on markets.

Ultimately, farmers are only going to grow this diverse bunch of crops if it can be profitable. The farmers' job, with the help of other people, is to figure out how to make them profitable - how to grow them. Just the fact that someone is willing to buy lentils or some other crop - that's not the driving force. Take peas, for example, I don't think we've got the big acres of peas now because all of a sudden a market developed. I think there was always a market there for a protein crop and people wanted to grow peas as a rotation.

*Garth Butcher, Birtle, Manitoba*

Many thought that zero till was a system which would be unable to find a place in a more diversified, livestock operation. However, the inclusion of legume forages in rotations creates new opportunities. For some no-tillers, the forage crop simply represents another cash crop - one with a ready market among neighbouring livestock producers. Others have diversified their operations into livestock in various ways to take advantage of their own forage production. The livestock operation can benefit as well from supplementing rations with chaff collected at harvest time.

Feeding 140 cows over winter takes a lot of hay and straw. Of course, baling straw removes excess residue but the biggest benefit is chaff collection. The cows licked up the barley and lentil chaff like it was crushed grain - the wheat chaff they didn't like as much. Apparently, ammoniating will improve the palatability and the nutrient level. We'll be doing some research.

*Stan Rampton, Oak Lake, Manitoba*

Adopting a zero till system depends upon a willingness to change and adapt. This is made easier by the fact that there is no single set of guidelines to follow in order to be a successful zero tiller.

Zero till changed the rule - there weren't any rules any more. Today I see people doing things you once would have said 'you can't do that'. I think we have to take a different look at the resources we have available. I think we desperately need a good valuable winter crop whether it's winter wheat, or fall rye or winter canola. We'll continue to learn more about herbicide use, fertilizer placement - 10 years from now we won't recognize what we're doing. I look back 10 years and while we had the same technology, our yields were lower - 10 years from now, even with similar technology, we'll be at some different point. Robert Stevenson, Oak Lake, Manitoba

There are many questions which still need answers. Zero tillage still faces many challenges, but it is clear from the successes already achieved, that the answers can be found. Positive answers can be adopted - negative ones will stimulate more inquiries. However, it is certain they'll be addressed as they emerge, for we believe it is important to advance the art of no-till.

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Advancing The Art
MANITOBA-NORTH DAKOTA ZERO TILLAGE FARMERS ASSOCIATION RECOGNIZED

The efforts of the Manitoba-North Dakota Zero Tillage Farmers Association to establish a better, more "environmentally friendly" crop production system have been recognized by government leaders on both sides of the border.

In 1991, when the Association published the *Zero Tillage Production Manual*, the North Dakota Health Department, Division of Water Quality was a major sponsor. Using Section 319, Clean Water Act funds, which they manage for the US Environmental Protection Agency (EPA), their participation made it possible to make a second printing of 50,000 copies. Again in 1996, when the production of *"Zero Tillage - Advancing the Art"* was under discussion, the endorsement of the North Dakota Health Department and EPA Section 319 funding of publication costs were received.

In 1994, the Manitoba Round Table on Environment and the Economy singled out the Manitoba-North Dakota Zero Tillage Farmers Association for a "Sustainable Development Award of Excellence". The award honours people or groups who exemplify the principles of sustainable development. The award recognized the Association as a "Non-Government Organization" that makes a significant effort to educate farmers about the advantages of sustainable agriculture practices.

Whether in the form of financial support for the Association's efforts or in the form of public recognition, these governmental endorsements represent an important acknowledgement by society that zero tillage has potential to significantly contribute to maintaining environmental quality of soil, air, water, and wildlife while improving the long term sustainability of our crop production systems.

The Manitoba-North Dakota Zero Tillage Farmers Association acknowledges the individual contributions of these North Dakota Soil Conservation Districts (SCD).

Adams County SCD

Arnegaard-Alexander SCD

Bowman Slope SCD

Cass County SCD

Cavalier County SCD

Central Stark County SCD

Divide County SCD

Eastern Grand Forks County SCD

Golden Valley SCD

Morton County SCD

Mouse River SCD

North Central SCD

North McHenry County SCD

North Mountrail SCD

Oliver SCD

Pierce County SCD

Richland SCD

South McLean SCD

Turtle Mountain SCD

Ward SCD

West McLean County SCD

Western Stark SCD

Wild Rice SCD

Williams County SCD

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Advancing The Art ~ ACKNOWLEDGEMENTS

The Manitoba-North Dakota Zero Tillage Farmers Association is grateful for the financial support and encouragement received from our sponsors and contributors in the development of this publication.

The Manitoba-North Dakota Zero Tillage Farmers Association

US Environmental Protection Agency

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- Monsanto - USA
- Canada - Manitoba Agreement on Agricultural Sustainability
- Monsanto - Canada
- Ducks Unlimited Canada
- AgrEvo

Additional printing and distribution of the manual was made possible through contributions from the following:

- North Dakota Department of Health - Division of Water Quality
- North Dakota Association of Soil Conservation Districts
- North Dakota State Soil Conservation Committee
- Manitoba Conservation Disticts Association
- Flexi-Coil
- USDA
- North Dakota Chapter Soil & Water Conservation Society

Informing the public about the availability of the manual was made possible by the following media sponsors:

- FarmLife
- Grainews
- Farm & Ranch Guide

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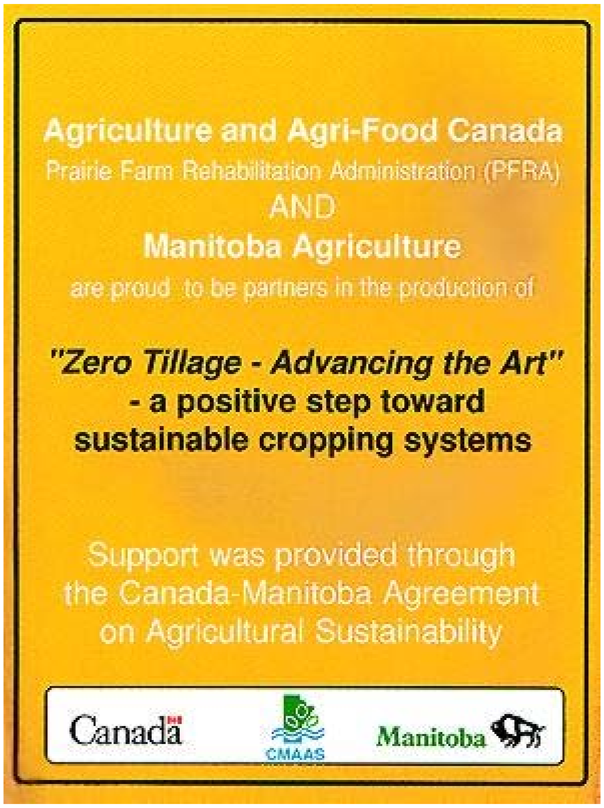
Agriculture and Agri-Food Canada
Prairie Farm Rehabilitation Administration (PFRA)
AND
Manitoba Agriculture
are proud to be partners in the production of

"Zero Tillage - Advancing the Art"
- a positive step toward sustainable cropping systems

Support was provided through the Canada-Manitoba Agreement on Agricultural Sustainability

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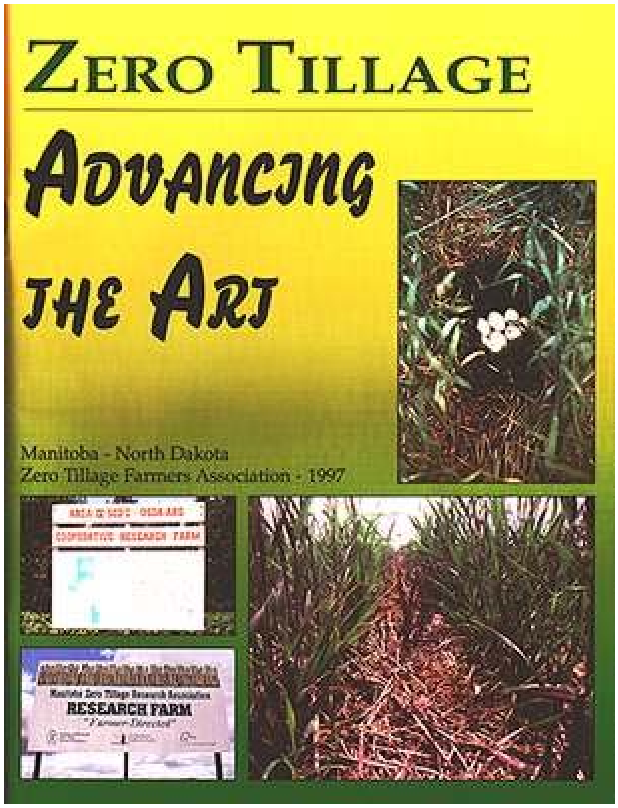

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