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

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NO-TILL GUIDELINES

FOR THE ARID AND SEMI-ARID PRAIRIES

AGRICULTURAL EXPERIMENT STATION
SOUTH DAKOTA STATE UNIVERSITY
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NO-TILL GUIDELINES
FOR THE
ARID AND SEMI-ARID PRAIRIES

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Successful crop production, regardless of the methods used, is a careful piecing together of numerous components into a system. Simply replacing one piece with another is seldom successful. Often, a change in one place requires that other parts in the system also be changed.

For example, we regularly read of farmers who replace gasoline engines in their pickups with diesels. We know that not only the engine has to be changed. The clutch, bell housing, linkages, gauges, etc. also need to be modified.

Similarly, producers who want to switch to no-till techniques must design a no-till farming **system** that fits their situations.

Most of the difficulties that have occurred in the past when producers attempted no-till can be traced to the fact that they tried to change only one component (tillage) of what was a working, conventionally tilled farming system.

The following outline was prepared in late fall 1990 to define the primary components required to design a no-till farming system. We offer **opinions** on the strengths and weaknesses of various options currently available for each of these components. No-till technology—equipment, techniques, knowledge—is changing rapidly. Portions of this document could be out of date quite quickly. The basic concepts and principles outlined, however, should be valid forever.

COMPARISON OF SYSTEMS

No-till farming systems have strengths and weaknesses. Systems based on tillage have strengths and weaknesses. They are not the same.

Unfortunately, with no-till we do not have the over 100 years of organized research and trial-and-error learning experiences that are available in planning a tilled system. So we must start at the very beginning, defining some agronomic and economic factors involved in crop production and evaluating how they are affected by changes in tillage practices. Farming systems containing four different tillage options will be compared. They are:

Tillage Type	*Designation*	*Residue Cover After Seeding* %
No-Till (Zero Till)	NT	80-100
Conventional Till	CT	0-30
Ridge Till	RT	40-70
Minimum Till	Min	30-60

The difference in these systems is the amount of surface residues present **after** planting. Many producers who claim to be using minimum or conservation tillage actually leave less than 10-20% residue cover after seeding. They are, in this analysis, using conventional tillage. Similarly, some "no-till" drills cause sufficient disturbances to leave no more than 30% ground cover. Producers using these seeders have a minimum till system, not no-till.

You will note that yields and profits are not included in Table 1. Their relationships to tillage vary with environment and with how successfully the grower has chosen the components that make up each system.

Table 1 does, however, demonstrate the dramatic differences in no-till and conventional tillage. Ridge till and minimum till systems (with a few exceptions) tend to be intermediate in most categories.

Those unfamiliar with no-till may be surprised that it is rated as equal or superior to other systems in a majority of the categories listed. The producer can capitalize on these strengths but must at the same time develop management strategies that also minimize adverse effects in the categories where no-till is inferior to other systems.

This is where "system" comes into play. Most people realize that minimizing the negatives is important.

Table 1: Comparison of agronomic and economic factors as affected by tillage system.

	NT	*CT*	*RT*	*Min*
Residue in %	80-100	0-30	40-70	30-60
Soil Temperature				
Spring, Noon, 1 inch	Cool	Warm	Warm	Cool
Spring, Noon, 2 inch	Cold	Cool	Warm	Cold
Spring, Midnight ,1 inch	Warm	Cold	Cool	Cool
Spring, Midnight, 2 inch	Cool	Cold	Cool	Cold
Summer, Noon	Cool	Hot	Hot	Warrn/Hot
Soil Moisture				
1 inch	Moist	Dry	Moist/Dry	Dry
2 inch	Moist	Moist/Dry	Moist	Moist/Dry
Deep	Best	Worst	Intermed.	Intermed.
Weed Seeds	On surface	1/2 tillage depth	Cleared from ridge	1/2 tillage depth
Seedbed	Excellent	Excellent to Poor	Excellent	Fair to Poor
Phytoxicity	Potentially High	Moderate to Low	Low	Moderate to High
Trafficability When Wet	Excellent	Poor	Good Excellent	Poor
Organic Matter Tilth	High	Low	Intermed.	Intermed.
Water Infiltration	Highest	Lowest	Intermed.	Intermed.
Snow Catch	High	Low Moderate	Moderate High	Low High
Energy Required	Low	High	Intermed.	Intermed. High
Equipment Costs	Low Intermed.	High	Intermed.	Intermed. High
Timeliness per H.P.	Excellent	Poor Intermed.	Intermed. Excellent	Intermed. Excellent
Herbicide Costs	Moderate High	Low High	Low Moderate	Moderate High
Weed Control	Excellent	Poor	Poor Excellent	Poor Excellent
Importance of Rotation	High	Low Intermed.	Low Intermed.	Intermed. High

Unfortunately, they usually do not put enough emphasis on the other aspect: adopting management techniques that let them utilize the substantial advantages no-till offers.

ROTATIONS: THE PLACE TO BEGIN

There is only one place to start planning a viable no-till program: picking the crop rotations to be used. Crop sequence and characteristics control every other aspect of the no-till system.

Some factors to consider are:

1. Water use patterns
2. Snow catch ability
3. Disease organisms
4. Insect cycles
5. Phytotoxicity
6. Weed control options
7. Ability to rotate herbicide types
8. Potential profitability
9. Equipment needs
10. Optimum row widths
11. Seeding and harvesting dates (work load)
12. Farm program restraints and rewards
13. Marketability
14. Historic rainfall patterns and probabilities

In most of the western corn belt, Great Plains, and prairies, no-till will save enough moisture that you can use rotations not possible with conventional tillage. In fact, recent research in this part of the country indicates that more intensive crop rotations are **required** to maximize profits; aid disease, weed, and insect control; limit phytotoxicity; and efficiently utilize the moisture saved through use of no-till techniques.

The potential crops should be classified according to their type, planting and harvesting dates, snow catch capability, water use, etc, as shown in Part 1 of Table 2.

In Part 2 of the same table, you can see immediately that these crops

vary greatly in the labeled herbicide programs which are available for use with them under no-till conditions. In general, more labeled programs are available for grass-type crops than for broadleaved crops. The exception is soybeans where numerous effective no-till labels exist.

The terms limited, adequate, and many are relative. They are based on the degree of flexibility a grower has in controlling weeds, timing herbicide applications, herbicide modes of action, and cropping intervals. The terms were adjusted somewhat to take into account the most likely broadleaved and grassy weed species that are encountered in the particular crop. For instance, grass control options in spring wheat were rated "adequate to good," since there are several labeled compounds that control the foxtail and wild oats commonly encountered in spring wheat. Winter wheat grass control was given a lower rating of "adequate to limited," since almost no labeled programs are available to control cheatgrass or downy brome which is more likely to be found in this crop.

Remember that this table (Part 2) was prepared in 1990. New herbicides, new rates, new combinations continue to be released; they could change or outdate recommendations we present here.

A crop should not be eliminated at this point simply because few herbicides are available for it. The final determination of suitability will be discussed later.

It is initially helpful to think of the crops in terms of their plant type and water use. Corn and sorghum, for example, are grassy, high water-use crops and could fill the same space in a rotation. Likewise, either soybeans or sunflower could represent high water-use broadleaved crops. The rotation is planned at this point with these options open. Specific crops are selected later utilizing factors such as weed control options, markets, equipment, etc.

Table 2. Crop Characteristics Important in Rotation Planning. Part 1: Physiological and morphological traits.

Crop	Type	Seeding	Harvest	Snow Catch
Winter Wheat	Grass	Sept-Oct	July	Excellent
Spring Wheat	Grass	April	July/Aug	Good
Corn	Grass	April/May	Sept/Oct	Good
Sorghum	Grass	May	Sept/Oct	Excellent
Soybean	Broadleaf	May	Sept	Poor/None
Sunflower	Broadleaf	May-June	Sept	Fair/Good
Millet	Grass	June	Sept	Poor/Good
Flax	Broadleaf	April	August	Fair/Good
Safflower	Broadleaf	April	August	Fair
Canola	Broadleaf	April	July/Aug	Fair/Good
Barley	Grass	April	July	Fair/Good
Oats	Grass	April	July/Aug	Fair/Good
Peas/Legumes	Broadleaf	April	July	Fair/Poor

Table 2. Crop Characteristics Important to Rotational Planning. Part 2: Labeled No-Till Herbicide Programs/Water Use.

Crop	Broadleaf Programs	Grass Programs	Water Use
Winter Wheat	Many	Limited/Adequate	Low
Spring Wheat	Many	Good/Limited	Low
Corn	Many	Adequate/Many	High
Sorghum	Adequate	Adequate/Limited	High
Soybeans	Many	Many	High
Sunflower	Very limited	Good/Limited	High
Millet	Limited	Limited/None	Low
Flax	Adequate	Many	Low
Safflower	None	Limited/None	Low/Moderate
Canola	None	None	Low
Barley	Many	Good/Adequate	Low
Oats	Many/Adequate	None	Low
Peas/Legumes	Adequate/Many	Adequate	Low/Moderate

Producers in dry areas should strive for a mix of high and low water-use crops. Producers in better rainfall areas will include more high-use crops.

A good rotation has diversity in plant types, planting dates, and harvest periods. This diversity spreads work loads and decreases insect, disease, and weed pressure.

The following is a list of potential crop rotations. It is not meant to be

Table 2. Crop Characteristics Important in Rotation Planning. Part 3: Equipment Considerations.

Crop	Preferred Row Width	Harvesting Equipment	Critical Water Use Period
Winter Wheat	6-8"	Straight/Flex	Oct/June
Spring Wheat	6-8"	Straight/Flex	June/July
Corn	22-30"	Corn Head/All Crop	July/Aug
Sorghum	6-15"	Straight/Flex/All Crop	August
Soybean	6-10"	Flex Head	August
Sunflower	15-30"	Pans/All Crop	August
Millet	6-8"	Swath/Flex	August
Flax	6-8"	Flex/Swath	June/July
Safflower	6-8"	Flex/Swath	July
Canola	6-8"	Swath/Flex	July
Barley	6-8"	Straight/Flex	June/July
Oats	6-8"	Straight/Flex	June/July
Peas/Forage Legume	6-8"	Flex/Swath	June

complete but demonstrates factors used in planning good rotations.

Water Use Intensity Index	Crop Rotation
0.66	w. wheat-w. wheat-fallow
0.5	w wheat- fallow
1.0	w. wheat-corn-fallow
1.0	w. wheat-corn-millet-fallow
1.33	w. wheat-corn-millet
1.33	w. wheat-corn-flax
1.33	w. wheat-soybean-s. wheat
1.33	w wheat- corn-soybeans-barley
1.5	w.-wheat-corn-soybeans-s. wheat
1.5	w. wheat-soybeans-corn-flax
1.5	w. wheat- soybeans-corn-s. wheat
1.5	s. wheat-soybeans
1.66	s wheat-corn-soybeans
1.66	s. wheat-soybeans-corn
2.0	corn-soybeans

To make understanding water use easier, we assigned a number to the crops depending on water use. Fallow is assigned a 0, low water-use crops a 1, and high water-use crops a 2. An average water use intensity rating was determined for each rotation. The winter wheat-fallow rotation is 1 + 0 = 1 divided by 2 crops (2 years) = 0.5. Winter wheat-corn-fallow would be 1 + 2 + 0 = 3 divided by 3 crops = 1.

An ongoing study at Akron, Colo., (winter wheat-fallow is the predominant conventional tilled system) has shown greatest profitability with a no-till winter wheat-corn-millet-fallow rotation followed by a no-till winter wheat-corn-fallow rotation. A winter wheat-fallow rotation produced less than half the income of the more intense rotation.

These data from a warm, dry, environment (16-inch annual rainfall) reinforce the results obtained in a recently completed no-till rotation study at Redfield, S.D., where a no-till corn-soybean rotation produced the greatest net profit, followed by spring wheat-soybeans and a corn-soybean-spring wheat rotation. This is during a 4-year period marked by two much drier-than-normal years, one slightly wetter-than-normal year, and one very wet year. (Normal is 18.5 inches)

Normal conventional tillage rotations in the Redfield area contain at least 50% small grain (water-use intensity of 1.5 or less). Rotations with intensities greater than 1.5 are inconsistent at Redfield when tillage is used.

Work by Al Black and Armand Bauer at Mandan, N.D. (also a 16-inch rainfall area) found increased returns with a spring wheat-winter wheat-sunflower rotation when it was no-tilled as compared to the same rotation conventionally tilled and to a less intense rotation (spring wheat-fallow) regardless of tillage method.

It appears that no-till rotations on soils with moderate to good water holding capacity will require a water use intensity rating of **at least** 1, even in very dry areas. Areas with climates comparable to or wetter than Redfield will do best with ratings close to 2.

Good inferences can be obtained from these three studies for other areas of the prairies. The Redfield site received 11.8, 16.7, and 15.3 inches of rain in 1987, 1988, and 1989 respectively. The 1988 and 1989 data should produce a good estimate of what will happen in drier areas during "normal" years. Spring wheat-soybean, corn-soybean, and corn-soybean-spring wheat rotations produced $55, $53, and $42 in net profit, compared to net profits of $11 to $23 produced by less intense rotations. Even in this dry cycle, rotations having intensity ratings greater than 1.5 produced on average over twice the net return as the best rotation having an intensity of 1. The average profit of the three intense rotations was over three times as great as the average profit of the three rotations with an intensity of 1.

The most intense rotation included at Mandan, N.D., had a rating of

1.33. The most intense used by Westphal and Peterson at Akron, Colo., ranks a 1. In both cases, these were the most profitable no-till rotations. If even more intense rotations were included, profitability perhaps would increase even more. The profitability of rotations having intensities approaching 2 would be expected to decline in these environments since crop failures would be more likely when dry cycles are encountered.

When data from the 1988 through 1991 growing seasons at Redfield are averaged, the profitability ranks corn-soybeans as most profitable, followed by soybeans-spring wheat and corn-soybeans-spring wheat. At Redfield more intense rotations are more profitable. The intensity rating for the rotations from most to least profitable over the 4-year period are 2, 1.5, 1.66, 1, 1.33, 1, 1.

The bottom line of this data is that a producer needs to evaluate environment, soils, and financial situation when planning a rotation.

Less intense rotations will be more "safe" in terms of producing a crop in dry years. More intense rotations have more profit potential but may cause increased risk. Soils with limited water holding capacity require more conservative rotations.

Mandan, N.D., producers probably can support more intense rotations on the 16 inches of rain normally received there than can producers with the same rainfall at Akron, Colo., because of the difference in potential evapotranspiration (water use).

One way to find the starting point for planning rotations is this: a producer using no-till should be able to adapt rotations **at least** as intense as those used successfully by conventional tillers (with similar soils and temperatures) that receive 2 to 4 inches more rainfall.

Once a set of potential rotations is compiled (it may be shorter than our example list), the following discussion can be used to determine which ones best fit each situation.

EQUIPMENT

At the very least, every no-till producer needs a no-till drill, a tractor, a sprayer, and a combine.

This equipment (and other pieces you may accumulate) should be designed for a controlled-traffic tram-line system. With this system, all wheel traffic—or of the drill and sprayer at the very least—follows the same path during every operation.

Normally this means the sprayer is three or five times as wide as one drill pass (a 15-ft drill requires a 45-ft sprayer). An odd number of multiples works better, but a sprayer two or four times as wide as the drill pass can work also.

The drill is equipped with electric solenoids which divert seed from the openers falling in the tractor's wheel tracks to those on either side when seeding the center pass of each three-pass set. The tram-lines provide a path which can be easily followed while spraying crop and stubble. This not only assures more accurate spraying (skips and overlaps are eliminated) without the hassle of a foam or dye marking system, but also allows spraying at night.

(Know what you're doing if you're out at night spraying. The winds will likely be calmer and the plants may be more susceptible to post-emergence systemic herbicides, but you want to quit spraying a good 3 to 4 hours before dew formation.)

In most cases, it is difficult to adjust combine tread width to follow normal tractor tread widths. We can do it at the Dakota Lakes Research Farm because the 4400 JD combine allows a 90-inch tread setting, within the recommended range on our 706 IH and 2840 JD tractors. Consequently, header size is set to equal drill size.

With many larger combines, tractor and combine tread width ranges do not overlap. However, you will need to establish some pattern so the combine tracks in the same path each year. This may have to be different than the tractor/sprayer tracks but should be consistent year to year.

All equipment should use tall, narrow tires to minimize the width of compacted soil and limit the size of skip rows in the tram lines.

Combine size and header size are concerns from other standpoints as well. Big combines with large headers need big grain tanks to be efficient. This creates extremely large axle loads which may cause severe deep compaction.

Large combines with wide heads, as now designed, can not adequately spread straw and chaff the full width of the header. A large part of the difficulties encountered in no-till can be traced directly to inadequate spreading of crop residues and chaff. Optional and after-market equipment is available and improves performance somewhat; it should be considered a necessity.

Take time when setting the combine to assure that straw chopper and chaff spreader are set correctly. It could save you substantial time, effort, money, and problems later. Don't forget to check out any custom combiner's machine; it is still not common for custom combiners to use spreaders and choppers.

A spring-tine harrowing perpendicular to the direction of combining is the best alternative if straw spreaders are not available, but it is a poor substitute for proper equipment on the combine. If harrowing is done soon after harvest, straw spread is better but snow catch is decreased.

(Chaff is too fine to be spread well by harrowing.) If harrowing is done in the spring, residue spread is terrible. Proper equipment on the combine will pay for itself the first year.

The type(s) of combine header(s) depend on the crops grown. From Table 2, Part 3, you will see that crops requiring a straight head can also be cut with a flex head. Flex heads with automatic header height control are a must for soybeans.

They may also be used to straight cut some of the other crops instead of swathing. Picking up swaths on good no-till fields can result in substantial amounts of surface residue entering the combine with the swath. This is especially true if corn, sorghum, or sunflower was the previous crop. Decaying small grain straw is not a major problem.

Flex heads are more costly, require slightly more maintenance, and sometimes require slower combine ground speed. The ideal is to own both a flex head and straight table.

If minimizing costs is a concern, a flex head is an adequate substitute for a straight head. On the other hand, a straight head cannot perform adequately in situations where a flex head is required.

Flex heads should be equipped with poly tine reels. If they are to be used in lieu of a straight head, they should have tine covers for unlodged small grain, sorghum, and some other short standing crops.

Obviously, a corn head is the preferred method for harvesting corn. An all-crop head can be used in some situations where combine capacity is large relative to the yield/acre and acres to be harvested.

Residue spreading is a major problem with this system. Semidwarf varieties of corn designed to be drilled in narrow rows and harvested with a straight or flex head are available. They have shown promise but have less yield potential than standard varieties in many situations. There is also limited snow catch in the following winter, and there are limited variety selection options.

Standard sunflower varieties also require sunflower pans, an all-crop head, or some other specialty head for proper harvest.

The mix of crops in your rotation will control your choice of equipment. All-crop heads can sometimes be used for sunflowers, sorghum, and possibly corn. Research from Kansas indicates that corn heads may also do an adequate sunflower harvest in some situations but that pans and all-crop heads are preferred. Semidwarf and miniature sunflowers are becoming available. These may allow use of straight and flex heads for harvesting.

Where lodging isn't a problem, straight or flex heads do an excellent job of harvesting sorghum. All-crop heads and flex heads work best when lodging occurs. Header availability may affect variety and row spacing selection for sorghum.

We discourage using grain carts in no-till fields because their axle loads are extremely large. If you do use a grain cart, it should be one designed to travel in one traffic lane while the combine harvests in the next.

No-tillers need to own a good sprayer and know how to use it. Even if you hire a custom applicator, you need to be able to apply time-sensitive treatments **when they are needed**. Spot spraying for perennial weeds, escapes, etc. also requires the touch of the master's hand to be most successful. With tram lines and a modern sprayer (equipped with a spray controller and/or a direct injection system), it will not be difficult to make accurate, timely, and safe herbicide applications.

You need to evaluate your own time constraints, handling facilities, and dealer service to determine the type of sprayer that best suits your needs. Rigs will vary from an ATV spot sprayer to a self-propelled. A wind shielding device extends spray periods and reduces the potential for off-target drift.

Sprayer swath width should be a multiple of drill width. Odd multiples work best, with sprayers 3 or 5 times drill width being most common. Sprayer tread width should match the tractor's.

Almost any tractor will work in a no-till system. The best results will occur with MFWD and smaller 4-WD tractors equipped with tall, narrow tires and no duals. Tracked vehicles also work well for seeding but are not the most economical spray tractors at this time.

Probably no subject generates more controversy than a discussion of no-till drills. It would be futile to attempt to discuss each drill on the market (even if there were a complete list) and all the options available on each. Consequently, three broad categories will be discussed: hoe drills, air seeders, and disk drills.

The strength of hoe drills is their ability to move residue and soil from the seed row. This reduces root diseases and phytotoxic effects when proper rotations are not followed and also allows producers to "get down to moisture."

The weak points of a hoe drill in no-till include inadequate depth control, poor residue clearance, bunching, and increased residue covering.

In addition, a hoe drill tends to smear and "ball-up" in wet soil conditions. It creates disturbances that can cause crusting. It plants small-seeded weeds such as foxtail, cheatgrass, and kochia. It limits the use of early preplant herbicide pro-

grams. And it precludes row spacing narrower than 10 to 12 inches.

Consequently, hoe drills are probably not right for most no-till situations. Of the rotations listed in our examples, only the winter wheat-winter wheat-fallow and winter wheat-fallow rotations would allow exclusive use of a hoe drill, and then only if it had very good residue clearance.

The winter wheat-corn-fallow, winter wheat-corn-millet, and winter wheat-corn-millet-fallow rotations could also allow use of a hoe drill in conjunction with a corn planter. Residue clearance would be a limiting factor.

Air seeders provide exceptional convenience in transportation, filling, and calibration when larger seeding widths are used.

In general, air seeders are equipped with one of various designs of hoe-type openers or a split boot sweep. The hoe-opener rigs have many of the same limitations of hoe drills, with the exception that air seeders with hoes can be used for crops such as winter wheat (which tolerates wider row spacing) and then changed to split boot sweeps for obtaining narrower rows in other crops. The split boot sweeps, however, cause substantially more disturbance than straight openers and are also prone to plugging.

Use of these machines with sweeps constitutes minimum tillage, not no-till. Consequently, the properties associated with these implements more closely resemble those found under minimum tillage in Table 1 rather than those in the no-till section.

In some instances, air seeders fail to leave enough residue to be considered even minimum tillage by the definitions used in this paper.

Both hoe drills and air seeders with sweeps or hoes tend to move rocks and stones to the surface, causing difficulties with crops such as soybeans.

Only recently have some manufacturers begun to market disk openers designed for air seeders in no-till seedbeds. If good depth control and adequate down pressure can be attained, these machines may offer a viable option for many producers.

The last category of drills is equipped with disk-type openers. Disk openers are becoming the opener of choice for most situations.

There is, however, a wide diversity in disk openers, and, consequently, a large variation in how well they operate in different situations.

In general, newer disk openers offer advantages in terms of lack of disturbance, improved depth control, narrower row spacing options, and much superior residue clearance.

Potential disadvantages, depending on the implement and the crop rotation, include potential hair pinning of residue in the seed slot, increased phytotoxic effects, increased maintenance, higher initial price, and greater down pressure requirments.

Disk opener drills can be divided into two classes in terms of their use in no-till.

The first type uses coulters to cut residue and produce a loosened zone of soil in which conventionally styled seed openers place the seed. Included in this class are several one-piece drills and conventional, mounted drills attached to a coulter cart.

The second type of drill uses a more heavy duty opener designed to both cut residue and place the seed.

Although these drills differ significantly in design concept, the same criteria should be used to evaluate them. A good disk drill meets the following criteria:

1. Minimum to no surface distur bance
2. Minimum to no hair pinning
3. Good depth control
4. Narrow press wheel with adjustable pressure settings
5. Depth control adjustment sepa rate from the press wheel
6. Slot closing mechanism separate from press wheel with individual adjustment
7. Adequate down pressure with easy adjustment

The four types of disk openers can be classed as double disk, offset double disk, single disk, and cross slot.

A traditional double disk opener has both disks meeting at a common point. The offset double disk opener has one slightly in front of the other. The single disk opener has only one disk and a seed placement boot. The cross slot opener is a single disk opener with a seed boot on either side.

In terms of criterion # 1, surface disturbances, one very helpful trick employed by some manufacturers is a depth gauging wheel at the point the opener exits the soil. This prevents soil from lifting and following the disk. In general, the smaller the disk angle in relation to the direction of travel, the less the disturbance. Disk drills which cause substantial surface disturbance have many of the same limitations as drills with hoe-type openers.

Commercially available forms of openers can be ranked from least to most disturbance as follows:

cross slot = single disk < double disk < coulter cart.

Hair pinning of residue into the seed slot is the biggest potential problem with disk opener drills. Adequately spreading both straw and chaff and carefully selecting the rotation will reduce these problems substantially, regardless of opener type used.

Double disk openers **without** an offset tend to be greatly inferior to other opener types in this category. Larger diameter disks are superior to smaller diameter ones.

In all cases, keep the disks **sharp**.

Rating commercially available openers for hair pinning would show, in terms of residue in contact with the seed:

cross-slot = or < single disk < offset double disk < double disk

Hair pinning is a much greater problem when small grains follow each other in a rotation than in other conditions.

Shallow seeding of most crops overcomes the negative impact associated with cold soil conditions in no-till. This is possible since one of no-till's strengths is good surface moisture content.

Soil temperatures at a 2-inch depth are colder in no-till than in conventional till. However, soil temperatures at a 1-inch depth in no-till are comparable to those at a 2-inch depth in conventional till. Seed normally can be placed 1 inch deep or shallower in no-till with adequate available moisture when it must be planted closer to 2 inches deep in conventional till to assure it doesn't dry out.

This is one of the most important reasons to use no-till in the northern Great Plains. It does, however, require exceptionally good depth control capabilities to assure that some seeds are not placed too deep into cold soil and others are not planted too shallow or left on the surface. Depth gauging wheels immediately adjacent to the opener disk where it exits the soil have become the standard on row crop planters and also work exceptionally well on drills.

The drawbacks to the wheels are higher initial and maintenance costs and the increased amount of stubble which is flattened by the wheels during fall seeding operations. At the present time, 4-inch-wide wheels are standard. In good no-till conditions a narrower tire should provide adequate depth control with less flattening. This is not a concern in spring seeded crops.

Openers not equipped with gauging wheels either depend on press wheels to control depth or rely on depth of coulter operation, as in the case of coulter cart drills. These obviously do a much less consistent job.

The importance of precision depth control will depend on the types of crops grown and the local environment.

Producers in humid environments and those with irrigation can err to the shallow side with imprecise openers. Those with longer growing seasons can plant deeper with little adverse effect.

Cold soils are less of a problem for late seeded crops (sunflower) than for those seeded earlier (corn, soybeans). Cold soils are also not a concern in winter wheat seeding. Small-seeded crops, such as flax, canola, and sorghum, require much more precision than larger seeded crops.

The degree of depth-control precision required to do a good job of stand establishment for the crops used and in the environment available is probably the single-most important factor that determines why producers in one area prefer one type of drill and those in other areas another. Producers on adjacent farms using different rotations may have different requirements.

Criterion # 4 is to have narrow (usually about 1-inch) press wheels with adjustable pressure settings. This wheel presses the seed into the firm soil of the seed slot.

Press wheels designed to mold or pinch loose soil next to the seed in conventional seedbeds do not work in no-till. V-type closing wheels on narrow spacing drills also pose considerable problems with residue clearance. (This criterion does not apply to the cross slot seeder since the concept is different.)

Adjustable pressure setting capability is required so little or no pressure is used when the seedbed is very wet. This prevents smearing, compaction, and "balling up."

This brings us directly to criterion # 5, which is related. Openers utilizing the press wheel as a depth control device can cause excessive pressure to occur in many instances.

Reducing this can only be accomplished by reducing down pressure on the opener, which then could cause inadequate and inconsistent penetration by the opener. Controlling depth at a location other than the press wheel is the only solution.

Drills with depth control wheels beside the opener with a separate press wheel are one example of this concept. Coulter drills also employ this concept, since depth of seeding, in reality, is controlled by coulter depth and not by the press wheel. Properly designed coulter cart drills have limitations in terms of depth control precision (# 4) but meet the requirements of criterion # 5 quite adequately.

Criterion # 6 is also related to differences between tilled and no-tilled seedbeds. Loose soil allows closing and pressing operations to be combined. In a no-till seedbed, they must be separated since pressure requirements are also much different.

Some drills are equipped with adequate closing devices. Other drills may require light harrow attachments to perform the closing or covering, as in harrows attached to coulter cart drills.

Harrows almost totally flatten stubble and should not be used for seed-

ing winter wheat where snow catch is desirable.

In reference to criteria # 7, it is comforting to know that most drills sold as no-till drills contain down pressure capability that is more than adequate in all but the most extreme circumstances. It is more common for no-tillers to use too much down pressure than not enough. Correct adjustment of down pressure cannot be over emphasized.

There are still questions about the adequacy of down pressure of the new disk-type openers operating on air seeders.

Don't overlook, in selecting a no-till drill for your particular operation, the other needs you have—transportability, size options, ability to multiple hitch, seed metering capability, and the availability of good parts and service.

Most commercially available drills cannot adequately space large seeds planted at a relatively low rate (corn, sunflowers). If these crops are included in the rotation, a row crop planter or modification of the no-till drill is required.

You can put the openers on row crop planters through the same evaluation. Most modern planters will do a good job of no-tilling if equipped and operated properly. Depth control is excellent on most newer planters. Adequate down pressure can be obtained through use of heavy-duty down pressure springs or ballasting of each unit (sandbags or bags of seed in the insecticide boxes have worked well). Press wheel and closing wheel design is not optimum on some units but creates less of a problem with the large seeds that go through these machines.

Several producers have added row crop planter metering units (IH Cyclo predominantly) to no-till drills (JD 750 series most common) for planting crops like corn and sunflowers. This may be a cost effective method of increasing crop selection flexibility.

Any drill or planter to be used in no-till must be capable of placing starter fertilizer in proximity to the seed. In almost all cases, this may be accomplished by simply placing the material with the seed. Options designed to deep place nitrogen or nitrogen-phosphorus fertilizer combinations are convenient but expensive. At the present time, it does not appear this is a major concern for most producers.

It is obvious that selection of a seeding tool or tools becomes an individual choice based on climate, crops, and producer preferences. There may be several options that will work in each situation. Nothing beats running your plans past some experienced no-tillers with similar conditions to see what they think.

WEED CONTROL PROGRAMS

The common belief that no-till requires much greater use of herbicides, as compared to most conventional systems, is not true, if good no-till practices are followed.

No-till is more dependent on crop rotations, competition, and sanitation to control weed pressure than is conventional till. The herbicide use per dollar of product output is often only slightly greater, and in many cases is much less, than with tillage.

Good no-tillers use herbicides to augment other weed control methods. Most conventional tillage systems use tillage and herbicides as a replacement for other weed control methods.

One of the problems with early no-till farming methods was the belief that herbicides would replace tillage. In reality, good management and proper rotations replace tillage in successful no-till programs; herbicides are only one tool in this scheme.

Crop rotation is one of the most important factors in planning an effective weed control program.

Rotations that contain plants of the same type with similar growth patterns (seeding and harvest dates) will develop weed problems (whether tillage is used or not) from weed species with similar growth habits. Prime examples are cheatgrass (downy brome) in winter wheat-fallow and wild oats in continuous spring small grains.

The more varied rotations possible with no-till reduce problems of this sort. Conventional tillers could also gain from more varied rotations, but as discussed before, it is not possible to economically grow many of these crops with conventional tillage in the drier areas of the Great Plains.

Competition is the second tool which no-tillers use in their weed control programs.

There are several aspects to competition. The most obvious is that the increased cropping intensity necessary to optimize no-till will also increase crop competition with weeds. Low-intensity rotations have more weed problems.

The second factor in competition is that quick establishment of a vigorous crop in narrow rows will produce a complete crop canopy early in the season. All the crops listed in Table 2, with the exception of corn and sunflowers, should be seeded in rows no more than 6-8 inches apart for best results. Equidistant spacing (row spacing equals spacing in the row) occurs in corn and sunflower when row spacing is 15-22 inches depending on plant population.

Harvesting and seeding equipment constraints may limit row space options with corn and sunflowers. Some producers modifying no-till drills to plant corn are using a 22 1/2

inch spacing for corn rows (openers spaced at 7 1/2 inches for other crops). Commercially available corn heads are available to harvest rows as narrow as 20 inches. In some cases, sorghum is also planted in rows wider than 6-8 inches to allow low seeding rates with some drills. Usually, this entails seeding with every other seed opener. Some drills feature options that allow individual sets of seed openers to be locked up.

Narrow row spacing not only aids weed control but also results in better residue distribution after harvest. For some crops (soybeans are an example), it improves yields. Other factors that improve early crop growth and uniform canopy establishment, such as starter fertilizer, seed treatment, high seeding rates, and uniform seeding depth, are discussed elsewhere in this paper. Their importance in aiding weed control may outweigh their direct value to improved yield.

Sanitation is another concept in weed control that should be practiced in conventional tillage systems, but must be used in no-till.

Sanitation refers to any management practice that reduces the amount of weeds going to seed in a field and prevents introduction of weed seeds from sources outside the field. Examples of this concept include weed-free seed sources, cleaning seeding and harvesting equipment between fields, mowing and/or spraying fence lines and waterways to prevent seed formation, and (the most important) practicing good stubble management following harvest.

Waiting too long before applying post harvest burndown sprays is the leading cause of heavy weed pressure in no-till. The stubble must be sprayed before weeds go to seed. This may require spraying before other weed seeds and volunteer grain have germinated.

Fast acting contact burndowns such as Gramoxone should be used if weeds are near seed set. In some cases, a second low-rate application of Roundup or similar product may be required to clean up volunteer grain in late-emerging wheat. Waiting too long in hopes of avoiding this second spray is penny wise and pound foolish. The herbicides and rates generally used are both economical and environmentally safe, especially when compared to the cost of herbicides used in the crop or to the potential loss associated with poor weed control in the subsequent crop.

Timely weed control in stubble also improves water storage and can have dramatic effects on disease and insect pressure.

Another management factor important in limiting weed pressure is proper selection and use of seeding and harvesting equipment.

Spreading chaff uniformly across the full header width also uniformly spreads the weed and crop seeds. This aids weed control in several ways. An unspread chaff windrow produces an environment favorable to weed germination, while at the same time containing sufficient organic matter to limit soil applied herbicide effectiveness at normal use rates. The unspread windrow also limits early plant growth (competitiveness) through increased phytotoxcicity and cooler soil temperatures.

Seeding equipment designed to create little or no surface disturbance aids weed control by leaving weed and volunteer crop seeds stranded on the soil surface. Many of these seeds will rot, be eaten by wildlife, or fail to germinate due to unfavorable moisture conditions.

Seeding practices that cause substantial surface disturbance "plant" weed seeds along with the crop. Hoe drills are the most effective cheatgrass, foxtail, and wild oat seeders available on the market. Some seeders do enough disturbance to plant large seeded weeds such as sunflower and cocklebur.

Use of low disturbance seeding methods eliminates pressure from large seeded weeds and large seeded volunteer crops and reduces pressure from most smaller seeded species.

A couple of years of good weed control will substantially reduce weed pressure in low-disturbance no-till, since weed seeds from past failures are not brought to the surface by tillage.

The final step in a weed control program is to design crop rotation-herbicide programs to control anticipated weed pressure.

There are only two herbicide application methods sufficiently consistent to be used in most no-till situations: early preplant programs and postemergence application.

Early preplant programs are to no-till farmers what pre-plant incorporated and surface incorporated programs are to tillage farmers. Early preplant programs consist of applying all or part of the residual herbicide compounds before crop planting. This increases the probability that sufficient precipitation will occur to activate the herbicide prior to crop emergence.

Applications are generally labeled to be from 30 to 45 days before planting, but with long residual compounds in drier areas, treatment may be even earlier. Compounds with shorter half life may require split applications, with half to two thirds applied early and the remainder at seeding time, especially in wetter regions. The interval between application and planting and the need to use split applications will depend on the compounds used, environment, the amount of surface residue, and weed pressure anticipated. Split applications with maximum labeled intervals are most consistent but entail increased expense due to the additional trip required.

Under heavy residue conditions, soil applied compounds taken up through plant roots are more consistent than those absorbed through shoots. Split applications of shoot-uptake compounds are highly recommended under heavy residue conditions, especially when used alone.

Properly managed early preplant programs have the following strengths:

1. Consistent weed control if prop erly done.
2. Spraying at non-peak work peri ods.
3. Burn down treatments at plant ing are not required in most cases, saving money, herbicide, and time.
4. Less time-sensitive (a larger application window) than post-emerge programs.
5. Less sensitive to short periods of adverse weather.
6. Broad spectrum control available for some crops.
7. Reduced risk of carryover associ ated with long residual com pounds.

Disadvantages of early preplant herbicide programs in some environments:

1. Some long-residual herbicides may not be desirable on land overlying shallow aquifers.
2. Herbicide investment is made earlier in the growing season.
3. Weed types that will be present must be predicted in advance.
4. A risk of carryover to subsequent crops in years much drier than normal (depending on compound and crop sequence).
5. Potential for late-season weed pressure in years much wetter than normal, although split applications and narrow crop rows reduce this risk.
6. High carrier volumes (10 to 40 gal/acre necessary).

Postemergence is the other herbicide application method adapted to no-till systems.

Advantages of postemergence programs include:

1. Spraying decisions can be made after weed pressure is known.
2. Many postemergence herbicides have little or no soil residual.
3. Can be used where residue spreading has been less than ideal.
4. Many compounds can be sprayed with low rates of carrier.
5. Can be used where seeding equipment causes substantial surface disturbance.

Disadvantages of postemergence programs:

1. Burndown treatment is usually required at planting time with later seeded crops.
2. Very timing sensitive (a narrow application window).
3. Performance is sensitive to adverse environmental conditions at or near spray time, and the result may be crop injury or lack of control.
4. Increased chance of cutworm problems due to early season weed growth in fields.
5. Sequential treatments (two sepa rate sprayings) may be required to obtain broad spectrum con trol.
6. If failure occurs, few viable res cue alternatives are available.
7. Yield loss to weed competition may occur prior to spraying.

There are always exceptions to any generalizations, which themselves could change with labeling of new compounds. Some excellent programs consist of a combination of early preplant and postemergence techniques.

With any herbicide program, it is imperative to know what weeds need to be controlled. This means scouting and identification. You might have not seen some of these weeds before; both no-tilling and new and different crops will result in a shift in weed species present.

Large-seeded weeds such as cocklebur and sunflower will become less troublesome within 2 years of starting no-till with low disturbance seeders. Weeds encouraged by mono-cropping, such as cheatgrass and wild oat, also will decline in importance if proper rotations are followed.

Small-seeded weeds which can germinate on or near the surface will be the predominant types present. The amount of pressure from these weeds will depend on the rotation and the efficacy of the previous crop's weed control program. These weeds along with perennial weeds are the ones most likely to require use of herbicides for their control.

Once the anticipated weed spectrum is determined, you can design your herbicide program. The factors that need to be evaluated when selecting herbicides include:

1. Efficacy on weed spectrum present. The fact that a compound is labeled to control or suppress a species does not mean that it will give consistent, satisfactory results in this specific situation. Study research results, test plot results, and Extension publications.

2. Preferred method of application for the weeds to be controlled. Some compounds can be used either early preplant or post but have differing efficacy on certain weeds as affected by application method. For instance, Pursuit gives excellent control of sunflower postemergence but is marginal, at best, early preplant. The same compound is good on lambsquarter early preplant, but marginal when used postemergence.

3. Rotational intervals required prior to seeding following crops in the rotational sequence.

4. Tank-mix or sequential treatment combinations available to control or aid in control of weeds not sufficiently handled by the first herbicide.

5. Limitations on use of other herbicides or insecticides during the growing season.

6. Mode of action/chemical family. Continued use of compounds with similar modes of action could result in development of tolerant biotypes unless compounds with different modes of action are included in the mix or elsewhere in the rotation.

7. Crop safety as affected by application method.

8. Carrier volumes recommended. Are they similar to those for other compounds in the tank mix? Is rate adjustment necessary?

9. Grazing, haying, and residue feeding restrictions if livestock use is a possibility.

10. Soil or environmental factors affecting performance, carryover, or crop tolerance.

11. Other treatments required, i.e., a burndown at planting for postemergence sprays in late seeded crops.

12. Cost of the compound, tank-mix compounds, additives, sequential sprays, and/or burndown treatments required plus application costs.

Perennial weed control in no-till systems is no more difficult and in many cases is more effective than in tilled systems. Failure to conduct an effective perennial weed control program in a no-till system can, however, lead to substantially greater losses than it would in tilled systems.

It should go without saying that sanitation and competition are the two cornerstones of a perennial weed control program. It is especially important to prevent "weeds" such as brome grass from setting seed in fence rows and field borders. Early hay making or at least mowing the edges to prevent seed formation is highly recommended.

Once your weed management program is in place, controlling existing perennial weeds becomes a matter of designing crop rotations that allow spot spraying of effective herbicides, at proper weed growth stages, several times over a 2-year period. Fall applications are most effective for control of perennial plants. For good results, the plants need to be actively growing when sprayed and have sufficient size for good coverage, but should not be allowed to go to seed.

Each perennial weed will have a different control program. One used successfully at the Dakota Lakes Research Farm for field bindweed illustrates this.

The control program starts with a wheat crop. Bindweed patches are spot sprayed with a Banvel application when the crop reaches the proper growth stage. This controls seedling plants and suppresses established plants sufficiently to allow the wheat to become competitive.

Following wheat harvest, the stubble is uniformly sprayed with a light-rate burndown which will suppress growth of the bindweed but not kill it. If volunteer grain and late germinating weeds require a second burndown treatment, bindweed patches are left unsprayed.

Approximately the first of October, the bindweed patches are sprayed with Banvel, Roundup, 2,4-D (3 oz, 16 oz, 16 oz) tank mix. An early maturing variety of corn is planted in late April the following spring. When the corn is in the spike to 2-leaf stage, 8 oz of Banvel is spot sprayed on the patches. The corn is harvested in mid-September, which allows spot spraying of the few remaining plants in the patches again that fall. Generally the bindweed is gone by this time. If not, Roundup can be spot sprayed on the patches prior to seeding soybeans the next spring, and the field enters a wheat-corn cycle the following year.

The same suppress-"set-up"-kill program works with other perennials. Contact burndowns (such as Gramoxone) appear to be better at setting up perennials for the kill by the systemics (Roundup, Banvel, etc.) The advantages of no-till are the increased effectiveness of early season treatments because early weed growth has not been disturbed by tillage, patches are more visible, and the tram-line system assures a better job of spot spraying.

DISEASE AND INSECT CONTROL

As with weed control, the most important factors in good disease and insect control programs are the management choices that **prevent** the problem. Your best choices are rotation and sanitation.

Some diseases and insects can be controlled by proper rotations and some are controlled by sanitation. There are also insects and diseases which are not affected by cultural or management practices.

Diseases which develop directly as the result of residue on the soil surface include the leaf spotting diseases (tan spot and septoria), head scab in small grains, and root diseases. Rotation is the method of choice to control these diseases. Small grain should not follow small grain and wheat should not follow corn. True minimum tillage systems which leave 30-60% residue cover experience comparable disease pressure when rotation is not used and environmental conditions favorable to the diseases occur.

Other diseases are not residue related. They include those carried by insect vectors: barley yellow dwarf mosaic and wheat streak mosaic, carried by the oat bird cherry aphid and the wheat curl mite respectively. These diseases affect both winter wheat and spring small grains. Stubble sanitation is the key to con-

trolling these diseases. The vectors require live grassy plants to survive for any extended length of time. Controlling all grassy weeds and volunteer cereals in the stubble will significantly reduce the population of these insects.

In winter wheat, all grasses should be killed 2 weeks prior to seeding the crop. In this respect, no-till gives you an advantage you can't get in conventional seedbeds: Seeding no-till can be delayed at least 2 weeks longer, since no-till soil cools more slowly in the fall, lush fall top growth is not required to prevent erosion, and winter hardiness is less of a concern. The late seeding decreases the probability that insects from adjoining areas can establish harmful populations in the field after the wheat has emerged and before winter arrives.

Improperly managed no-till fields of winter wheat seeded early into stubble containing living grassy plants will be totally destroyed by one or both of these diseases. Late seeded no-till wheat planted into stubble where no live plants exist will face less danger from these diseases than early seeded wheat on black fallow. Root diseases in no-till winter wheat seeded into cereal residue will also be very severe if host plants are present or have just recently been killed.

Cereal rusts can be considered tillage neutral. Inoculum for these diseases moves in on the wind. Resistant varieties are still the method of choice to deal with rusts.

Some insects—cutworm, grasshoppers, army worms—are controlled primarily by sanitation. Cutworm moths lay their eggs at the base of live plants, and if the live plants are not present, the moth does not lay eggs. Some species lay eggs in late summer or fall (the dingy cutworm) and some in spring (the black cutworm). Knowing when moth flights take place in your area and what species are involved will help you avoid trouble.

The belief got started that "trashy" conditions favor cutworms, but living, green "trash" at the time of egg laying is much different than dead, trashy residue at the same time. Black fields with no plants don't attract moths, and neither do clean no-till fields.

Similarly, grasshoppers will die or move from a field which has no live vegetation. Border sprays to prevent movement from noncrop areas are extremely effective.

Economic infestations of corn rootworm have occurred when corn was planted in small grain stubble. The rootworm beetle is attracted by foxtails and other grassy weeds to lay eggs in the stubble field.

In all these instances an inexpensive, environmentally safe, stubble burndown treatment could have prevented insect problems and the need to use insecticides.

The most common insect pest controlled primarily by rotation is the corn rootworm. Tillage has little effect on its life cycle. Rotations with one year between corn crops work in most areas at the present time.

Extensive use of corn-soybean rotations has favored the development of extended diapause corn rootworms. They wait an extra year to hatch and thus become synchronized with the corn in a 2-year rotation. Extension bulletins define these areas quite well.

Insects which are not affected significantly by tillage include corn borer, sunflower seed weevil, and the head moth. These are managed much the same in no-till as in other tillage systems.

There is some recent evidence that insects which live on the underside of plant leaves are inhibited by light reflected onto these areas from residue covering the soil surface. This is an interesting concept which deserves more investigation. Some evidence exists that long term no-till provides a better environment to support predator species.

Don't overlook the benefits of seed treatment. Good quality, disease-free seed is a must. Fungicide seed treatments are recommended, but more research is needed. Fields which have experienced wire worm infestations in the past may benefit from seed treatment for wire worm.

Seed treatments are cheap insurance, especially for the no-till producer where quick establishment of a good crop canopy is so important.

FERTILITY

At the moment, there is not much research connecting fertility and long-term no-till managed in intense rotations. The following observations are subject to change as more long-term data become available.

Grossly underestimated is the detrimental effect that soil erosion has on soil fertility. Preventing erosion will, in the long run, reduce the amount of fertilizer required per unit of crop produced. Research in Manitoba has shown that even doubling fertilizer rates cannot restore full productivity to some eroded soils.

Changing from low-intensity conventional systems to high-intensity no-till systems builds up organic matter in the soil. It replaces, in part, the tilth and water holding capacity lost since the land was broken from sod.

Building organic matter requires nitrogen. Therefore, during the early phases of no-till, more nitrogen may be required than the crop uses. The cost of this additional nitrogen should be considered an investment. You will be paid back.

The most difficult thing about nitrogen fertilization to determine is proper rate. You are operating with two unknowns when you start no-till: Organic matter levels are rising, and you have only a poor idea of potential yields for many of the crops.

Yield goals for determining fertilizer levels, therefore, need to be estimated from conventional tillage yields. The yield goal is usually defined as the best yield obtained on average once every 5 years. In other words, it is the yield obtained in a "very good" year.

For small grains and other low water-use crops, a no-till yield goal will be equal to or only slightly higher than it would be in conventional tillage. One reason that you should not expect bigger differences in yield goals is that small grains usually follow more closely behind the previous crop in a no-till system than in most conventional tillage rotations. Another reason is that yield goals are based on performance in a "very good" year; the yield advantage to no-till occurs in the not-so-good years with low water-use crops.

For high water-use crops, it's a different story. Depending on the environment, soil, crop, and rotation, you can set yield goals for these no-till crops 20 to 100% above those obtainable with conventional tillage. If good no-till farmers are already growing high water-use crops in your area, talk to them about yield goals. If you're the first no-tiller in your area, use your best judgement.

It is extremely important to use a deep nitrate (2-ft minimum) sampling procedure to establish fertilizer requirements and evaluate the success of the nitrogen program. The fertilizer recommendation based on the yield goal and residual nitrogen will have to be further adjusted to compensate for the immobilization (organic matter building) that takes place during initial phases of no-till.

It is usually recommended that 10 to 20% more nitrogen be applied during the first 3 to 5 years of no-till. This is when the deep nitrate test becomes valuable. If the yield goal is too high or the immobilization rate lower than the 10 to 20% adjustment assumes, the nitrate test will detect this error and allow the excess nitrogen to be deducted from the next year's fertilizer bill. Not using the deep nitrate test leads to overfertilization in many cases, a practice both economically and ecologically unsound.

Now that you know how much fertilizer to use, the next problem is how to apply it. There are numerous acceptable ways of applying nitrogen fertilizer in no-till. From a nitrogen-efficiency standpoint, placing nitrogen into the soil is the best method of application, followed by surface banding techniques, and early season broadcast applications. From an economic standpoint, broadcast application of liquid nitrogen as a carrier for certain herbicides often is quite effective.

Drills that place fertilizers in bands between or along side seed rows are a convenient way of injecting nitrogen and other fertilizers at rates which would be harmful to germination if placed with the seed. Sometimes this option is quite expensive, requires more tender capacity, increases maintenance, and slows seeding slightly due to increased filling time. Other methods of soil placing fertilizers include spoke applicators, "blasters," and coulter knife sets, in separate operations or attached to seeding equipment. The unique design of the cross-slot opener appears, from preliminary data, to allow high rates of fertilizer to be applied in one "wing" and seed in the other.

The value of using soil placement techniques (in terms of potential increased nitrogen efficiency) needs to be weighed against the cost of equipment. Where nitrogen rates are relatively low (90 lb N/acre or less), it may be more economical to suffer some loss in nitrogen efficiency in return for savings in time and equipment. This may be most relevant where nitrogen fertilization can be combined with herbicide applications.

Tram-line systems assure uniform fertilizer application and make it easy to apply part of the nitrogen requirement during the growing season. In some cases this can significantly increase nitrogen efficiency.

The single biggest advantage of soil placement equipment is that it can band nitrogen and part of the phosphorus fertilizer in the same zone. Unfortunately, the conditions under which response to dual placement will occur are not well defined in conventional tillage, and almost no work has been done in long-term, intense no-till rotations. Soil chemical, physical, and biological changes associated with long-term no-till may limit the need to dual-place nitrogen and phosphorus.

The most prudent course at this time seems to be to purchase separate placement capability only if it is most convenient and economical for your operation. Hedge your bets, however. Find equipment you can modify later.

Some drills can be retrofitted easily, others only with great difficulty. Separate trip equipment (knifers, "blasters," and spokes) could also be added to your equipment line at a later date.

In situations where high concentrations of undecomposed surface residue develop, broadcasting nitrogen may speed decomposition but may increase leaching.

The other major fertilizer required on the prairies is phosphorus. Recent data indicate that early concerns about phosphorus availability in no-till environments may have been unnecessary. These concerns were based on the fact that soils are

cooler in no-till and tillage was no longer used to move phosphorus into the root zone.

Newer research indicates that these conditions appear to be more than offset by increased mycorrhizal activity, a decreased rate of phosphorus conversion to less soluble forms, and enhanced earthworm activity. Mycorrhizae live on roots and aid the plant in phosphorus uptake. Tillage (especially fallow) decreases the population of these micro-organisms substantially. Earthworms help to incorporate phosphorus and increase phosphorus available to the root because of elevated phosphotase activity in their castings. Organic acids produced by decaying residues in no-till slow the conversion of the very soluble (available) phosphorus in fertilizers to less soluble (unavailable) forms.

Phosphorus fertilization does not appear to be the major concern in no-till that was once believed if good rotations are used. With poor rotations that lead to root diseases, nitrogen and phosphorus placement becomes extremely important. This is a root health problem, not a fertility problem. With narrow row spacing, relatively high rates of P2O5 can be safely applied with the seed of most crops without harming germination.

Recommendations call for no more than 20 lb of N+K2O per acre for crops in narrow rows and 6 lb of N+K2O for crop in wide rows. This means over 100 lb/acre of 18-46-O and 16 gallons of 10-34-0 could be used with narrow rows and 30 lb and 5 gallons could be used in wide rows. These rates are well within those commonly recommended for the types of yield goals used in many situations. There is evidence that even higher rates may be possible in no-till conditions, due to improved soil moisture. This concept needs more testing.

The most important thing in phosphorus fertilization in no-till is to use part or all of the recommended phosphorus as a starter.

The cold soil conditions encountered in no-till can be partially mitigated by assuring that roots from each germinating seed encounter a soil zone high in available phosphorus as soon as possible. Seed placed (pop up) phosphorus is the most convenient way to achieve this goal.

It appears that there is a minimum amount of fertilizer required to give a continuous band of phosphorus. With less than this critical amount, zones of fertilized and unfertilized soil will result. Research is being performed to answer this question.

In the interim, it appears that as much of the recommended phosphorus as safely possible should be placed with the seed. If all the phosphorus cannot be applied with the seed, the remainder can be included with the nitrogen fertilizer.

The jury is still out on whether seed placing all the phosphorus will be an adequate long-term method of phosphorus management. Some data show deep banding to be the best method, other studies find broadcast to be superior. These differences appear to be related to both environmental and soil factors.

Phosphorus requirements per foot of root length are greatest early in the season. Moisture, roots, and available phosphorus must all be in the same location for uptake to occur. With no-till, where adequate surface residue is present, moisture and roots are near the soil surface early in the season. This is not always true in tilled systems.

Likewise, minimum-disturbance no-till systems tend to have more moisture under the mulch later in the season; while tilled systems, ridge-till, and even "no-till" systems where substantial disturbance was associated with seeding will have drier surface layers at this time. In dry environments, surface layers may become dry during the growing season even if low disturbance techniques are used. In these instances, there should be value to having some phosphorus deeper in the root zone. It can be placed there with any of the soil placement methods mentioned above, or result from movement of shallow phosphorus due to biological activity (earthworms, root growth, etc.), or it may be residual phosphorus resulting from previous incorporation by tillage.

Deep fertilizer placement capability is potentially more important to producers in dry areas. Those in humid areas with more frequent rainfall, greater surface residue levels, and more biological activity will be less likely to benefit from deep placement in no-till (ridge-till is a different environment). More research will be required to further define phosphorus placement needs other than the definite requirement to have sufficient phosphorus in proximity to the seed to aid early season growth.

Other fertilizer nutrients may be required in certain situations. Method of application will depend on the characteristics of the nutrients and the materials used to apply them. Advice should be sought if soil tests indicate a need for elements other than nitrogen or phosphorus.

Differential soil testing and fertilization of eroded areas is one other factor in fertilizer management which should be considered if substantial erosion has occurred in the past. Increased infiltration resulting from no-till will allow improved productivity on hill tops and side slopes, if sufficient fertility exists. In many cases, however, erosion has removed enough organic matter and fertility to limit production. Restoring some of the lost fertility (the effects of erosion cannot be fully offset by fertilizers) by sampling and fertilizing eroded and non-eroded areas separately will increase crop growth on eroded areas. This will

improve the amount of surface residue to protect the soil from continued erosion and speed the rate of organic matter increases and return of productivity to the eroded portions of the landscape.

EVALUATION OF THE CROPS

CORN

Corn is one of the primary crops in many no-till programs. Varieties are available for use throughout the prairies as far north as southern Canada.

Corn is a high water-use crop which responds readily to the increased moisture available in no-till. And several excellent broadleaved weed control programs are available to fit almost any situation where no-till corn will be grown. Options for grass control are very good in most situations.

No-till corn should be planted 1-1 1/2 inches deep and at least as early as conventionally tilled corn. Where surface residues are very heavy, varieties should be chosen that are 5 to 10 days earlier in maturity than what would be considered full season for the area.

Desirable traits to look for in the variety are good early season vigor, adaptability to high plant populations, lack of tillering (suckering), high yield potential, good root growth, and other properties desirable for the area.

Corn can be planted with any of the new style corn planters as long as the opener disks are sharp and the planter is equipped with heavy-duty down-pressure springs (ballasting the units with weight in the insecticide boxes has also been effective). Planters with offset double disk openers work well. Performance of non-offset openers can be improved with notched openers designed for no-till use.

"Trash-whipper" attachments that clean both residue and soil from the row area are not recommended. A trash whipper could lead to problems with crusting, weed control, delayed seeding, and "balling up." Creating these shallow furrows also encourages severe soil erosion if rows are not perfectly on the contour.

New attachments use brushes or fingers to move trash but not soil. If these devices move part of the residue from the row area, they may be useful to producers in cool or humid environments with large amounts of residues (following wheat, for example). This is especially true if straw spreading is less than perfect. These devices reduce phytotoxic effects, limit hair pinning, and allow the row area to warm more quickly in the spring.

In drier areas with good chaff and straw spreading, proper rotation, good seed openers, and starter fertilizer the only case where it is absolutely necessary to move residue from the row area is when corn follows corn. And that's not a recommended no-till rotation in most circumstances.

Plant populations should be increased **at least** 10 to 20% over those used in conventional tillage to take advantage of increased yield potential. Normal row widths will work adequately, but consider using rows as narrow as 20-22 inches, especially if you are modifying a drill to seed corn. Narrow rows and high plant populations may not increase yield directly but will improve late season weed control and create a more uniform distribution of crop residue. Commercially available corn heads will harvest rows as narrow as 20 inches.

Varieties which **do not tiller** are essential since this trait is encouraged by cool, moist soil conditions and pop-up fertilizer programs.

No-till corn should not be cultivated. Cultivation causes severe root pruning in no-till since feeder roots are shallow.

SORGHUM

Grain sorghum is traditionally grown in the warm, dry areas of the Great Plains because it possesses better heat and drought tolerance than corn. Sorghum does have some advantages and disadvantages, compared to corn, in no-till systems. Disadvantages include:

1. Lower market price for cash grain.
2. Less yield potential in "good" environments.
3. Fewer herbicide programs avail able.
4. Not as well adapted to cool areas.

The advantages of grain sorghum are:

1. Little or no modification needed to seed with a good no-till disk drill (seeding rate adjustment can be difficult).
2. Small-grain equipment can be used for harvest with few modifi cations.
3. Better competition with late sea son weeds (narrow rows, more plants).
4. Less concern with diseases in small grains in the rotation.
5. Better ability to withstand heat and drought.
6. Lower seed cost.

No-till sorghum should be planted shallow (approximately 3/4 inch) roughly 2 weeks earlier than is common in conventional tillage. Varieties with similar maturity to those commonly used should be planted in narrow rows (15 inches or less) at seeding rates higher than commonly used in wide row, conventional till production. Increasing seeding rates 40-80% to discourage tillering is recommended. Tillering will be encouraged by the cool, moist soil conditions and seed placed fertilizer. Tillers develop later than main stems, increasing the potential for harvesting and quality problems.

Varieties with excellent standability are recommended. The availability of saftened seed greatly expands the herbicide programs available.

SOYBEANS

More than any other crop, soybeans depend on no-till to be an economical and environmentally sound crop. The limited residue left after soybean harvest, however, can lead to significant soil erosion unless both the soybean residue and residue from preceding crops remain undisturbed on the soil surface.

Like corn, the large soybean acreage in the U.S. has led to the development and labeling of numerous herbicide programs for soybeans and assures that efforts will continue in the future. In fact, currently available no-till herbicide programs for soybeans offer a degree of efficacy, safety, and flexibility not available for any other crop.

Use of no-till has allowed soybean production to move west of the crop's traditional growing areas. Where this migration will end is not certain at this time, but the profitability of rotations including soybeans at Redfield, S.D., indicates more movement may be possible.

Soybeans, like many broadleaved crops, are more tolerant of phytotoxic compounds than many grass crops. Soybeans have few insect and disease problems when properly rotated and are a legume crop which produces its own nitrogen needs and reduces the nitrogen required for subsequent crops. Soybeans are marketed in the oilseed/meal market, and the price will vary roughly with other oilseeds (sunflower, canola, safflower, etc.).

Soybeans are sensitive to heat, drought, and high soil temperatures during the growing season. Good soil cover is essential to production in hotter regions. Flower abortion is common during hot, dry periods, but the long flowering period associated with indeterminate varieties used in northern growing regions improves the chances that favorable weather conditions will occur to allow sufficient pods to form. It is believed that the surprisingly good yields attained with soybeans in dry years at Redfield resulted from the ability of full-season varieties to wait out hot periods and compensate when cooler weather came. Early maturing varieties have shorter flowering periods, and they failed to perform as well in hot years.

Soybeans require use of flex heads or floating cutter bars for harvest. Rocks or stones on the soil surface can cause substantial difficulty when harvesting. Use of straight heads to combine soybeans should never be considered because crop loss is excessive even in the best conditions.

Numerous excellent early preplant herbicide programs are available for soybeans and are highly recommended in dry areas where postemergence herbicide performance is more variable. In more humid areas, postemergence programs have been very successful as have some EPP programs. Sufficient programs are available to tailor one to each specific circumstance.

No-till soybeans should be planted earlier than those in conventional tillage. Seeding rate should be 180,000 live seeds/acre in rows no wider than 8-10 inches. Soybeans will be shorter in dry areas, so seeding rate is not decreased. Varieties should be full season for the area, narrow in plant type, and have good emergence scores. Later planting and early varieties decrease flowering period and consequently their ability to "avoid" drought. Soybeans should be seeded shallow (approximately 3/4 to 1 inch).

A seed placed pop-up fertilizer with soybeans is usually not recommended in **conventional tillage** due to potential germination problems. With narrow row spacings in no-till environments, use of high phosphorus (low nitrogen and potassium) fertilizers with the seed has been successful. Until more research or negative experiences indicate otherwise, pop-up fertilizer placed with the seed should be considered a viable management practice.

In no instance should soybeans be no-tilled in wide rows. Both yields and late season competitiveness with weeds will be lost.

Producers with high pH soils will need to use varieties with resistance or tolerance to iron chlorosis. On fields where soybeans have not been grown before, the seed should be carefully inoculated with the proper strains of inoculum. All seeds need to be coated, and the interval between treatment and seeding should be relatively short (less than 4 hours).

Inoculation is recommended where soybeans have been grown before, but the need to do an excellent job is not as great.

The biggest concern about soybeans at this time is that, although they will grow in drier regions, they may not be economical. Consequently, their use in many areas will be "high risk" until more information is available.

The other major drawback to soybeans in dry areas is that they leave absolutely no stubble after harvest. There will not be the snow catch that is so important to moisture management in dry areas.

Development of stripper heads for soybeans (and other crops) would eliminate this concern. Leaving strips of standing stubble would help substantially, but it requires discipline to sacrifice the yield.

On the positive side, soybeans and other legume and oilseed crops provide an excellent tool to break the insect, weed, and disease cycles

found in cereal based rotations. Soybeans also provide a seedbed for subsequent crops which is mellow, warm, and very conducive to fast, uniform emergence.

WINTER WHEAT

Winter wheat received the most emphasis in early no-till programs on the plains. Much of the effort was directed at continuous winter wheat or winter wheat-fallow rotations using no-till techniques.

This approach led to spectacular increases in costs, weeds, diseases, insects, and frustration while showing advantages over conventional production only in dry years or when winter kill was a problem.

It is unfortunate that these bad experiences convinced many producers that no-till does not work, when in fact all it proved is that no-till without rotation doesn't work.

Winter wheat has unique management adjustments in a successful no-till program.

First of all, cold soil conditions at seeding are not a concern in winter wheat, but adequate soil moisture and the need to use a drill which leaves sufficient stubble standing to catch snow are.

The most difficult part of designing a no-till rotation containing winter wheat is determining if the preceding season should be fallow, a cover crop/fallow, or a crop.

This decision will depend heavily on a producer's individual situation. Unfortunately, insufficient research under no-till conditions is available to answer the questions he will have.

What is available indicates that the benefit to fallow ranges from a high of 10 bu/acre in dry years to no difference most years. The 10 bu/acre difference produces increased gross return of $20-$40 per acre in the dry year in no-till situations, depending on wheat price. That barely pays the land costs.

Consequently, if a crop can be grown that will pay all costs including land costs and post harvest stubble treatments minus what it would cost to fallow the land, in a dry year the producer will break even. In years with more moisture he will make more money continuous cropping.

This simplistic approach does not consider such things as government payments, but it does point out the need for each producer to do a complete crop budget (including land costs) when making this decision.

The to-fallow-or-crop decision is made more complicated by the fact that including fallow in the rotation may allow use of inexpensive, long residual herbicides in the crop preceding fallow. The best example of this is the use of atrazine in a wheat-corn-fallow rotation at rates precluded in a wheat-corn-flax rotation.

Once the decision is made to crop at least part of the land destined for winter wheat, the normal disease, weed, and insect considerations and three additional ones must be evaluated.

These new ones are:

1. Is the interval from harvesting to seeding adequate to assure moisture for stand establishment?

2. Will sufficient residue exist on the soil surface to prevent it from drying out or cooling down too rapidly?

3. Will sufficient stubble be left standing following seeding to assure good snow catch.

Answering yes to the first question is easier if the preceding crops leave substantial residue, since less moisture is required where good surface residue is present. Once a field has been no-tilled for several years, surface residue levels should be sufficient even behind low residue crops. This is not the case in early phases of no-till.

The snow catch question is one of the most important you must answer. Good moisture must be present to have continuous winter wheat. The drill used will also affect the amount of residue remaining upright. Some drills, with 4-inch-wide depth gauging wheels located on the side of the opener, flatten most of the stubble. Wheels this wide are not required in no-till and should be replaced with 2-inch wheels if substantial amounts of winter wheat will be seeded.

In early phases of no-till, small grain crops will produce better surface residue conditions than other short-season crops preceding winter wheat. Once good surface residue conditions have been established, short-season legume and oilseed crops provide significant advantages in breaking disease, insect, and weed cycles. Millet is a viable option if seeding and harvest are early and prices are favorable. Peas, lupines, and lentils for grain, or peas for forage, have tremendous potential in winter wheat production if they can be grown economically. With all but lupines, snow catch will be limited under present production techniques. Newer practices becoming commercially available will substantially improve snow catch capabilities.

No-till winter wheat can and should be planted substantially later than winter wheat planted in black seedbeds. There is no need to develop a large plant for erosion control or increased winterhardiness in no-till. Good residue cover also slows the cooling of the soil, allowing wheat growth to continue later into the fall.

Later planting provides no-till winter wheat with significant advantages in

terms of avoiding problems with the insect-transmitted diseases wheat streak mosaic and barley yellow dwarf mosaic. The other important way to avoid these diseases is to make sure volunteer small grains and grassy weeds are killed in the stubble 2 weeks prior to seeding. This provides time for the insects to die before the new host (the winter wheat) emerges. Volunteer control is also essential to limit root diseases.

No-till winter wheat should be seeded 2 to 4 weeks later than considered normal for black fallow. (In South Dakota this would mean seeding sometime between September 20 and October 20, depending on location). Use of narrow (less than 8-inch) row spacing and increased seeding rates (20 to 40%) is encouraged to provide good competition to weeds in the spring. Seeding depth should be approximately 1 inch.

Phosphorus starter should be placed with the seed at planting. Nitrogen can be deep placed with the drill, but some data suggest increased efficiency with early spring injected treatments. Top dressing nitrogen with the herbicide also works in some situations.

More latitude is available in variety selection from the standpoint of winter survival, which is an advantage of no-till in some areas. When the rotation calls for seeding wheat after another small grain, varieties with tolerance to the leaf spotting diseases should be used.

When winter wheat must be seeded into small grain stubble the following considerations are important. Snow catch is best with wheat stubble, followed by barley, then oats. Disease problems from tan spot and sceptoria will be worse in wheat stubble. Consequently, producers in dry areas may feel increased snow catch is more important than avoiding potential disease problems. Those in moist areas will have more problem with disease than drought. Obviously, broadleaved crops such as flax, canola, and safflower provide a better option. Root diseases are encouraged when wheat follows other small grains. Your best bet is to use a rotation that avoids conditions favorable to root diseases. Openers which produce some disturbance help mitigate effects of root diseases but cause other problems.

One option which is being studied at this time is dormant seeding of winter wheat.

In this practice, winter wheat seeding is delayed to the point that the plant does not emerge in the fall; it only has time to swell or sprout. That is sufficient to allow the crop to vernalize over winter in the soil and begin reproductive growth in the spring.

Work on this at Redfield indicates that good stands of vernalized winter wheat can be obtained by seeding as late as February, if conditions are favorable. Late November to early December would be more normal. Yields were equal to or better than spring wheat and less than winter wheat planted at normal times in years when early maturity was important.

If dormant seeding proves reliable, it may allow a producer to attain some of the early maturity benefits of winter wheat without having to fallow or grow a short-season crop the previous year. Money lost on fallowing or growing spring cereal reduces the profitability of winter wheat rotations significantly in many cases.

Even where short-season crops are profitable, this technique may be valuable in the extremely dry years when sufficient moisture for stand establishment is not available in the fall.

Snow catch ability is extremely important in situations where dormant seeding would be used, since subsurface soil moisture will be very low going into the winter. Consequently, use of this technique behind crops such as hay or soybeans would require harvesting methods that allow good snow catch (leaving strips, for example).

The type and amount of herbicide used for weed control in winter wheat will differ little in no-till as long as good rotations, sanitation, and competition practices are followed. The one major difference is that much more consideration needs to be given to selecting compounds which will not carry over to damage rotational crops.

Winter wheat, because of its excellent competitiveness, is also a good place to select an herbicide which differs in mode of action from other herbicides in the rotation, since such a herbicide prevents development of tolerant biotypes. (Herbicide rotation is covered elsewhere.)

If rotations are used that may favor development of leaf spot diseases under favorable conditions, tram lines greatly enhance the ability to apply fungicides for control of these diseases.

In dry areas, winter wheat produces the best environment for row crops to follow, because of its tall stubble and large amounts of residue. It is extremely important to do a good job of spreading the straw and chaff.

SPRING SMALL GRAINS

The most important thing in production of spring wheat, barley, and oats is to establish a uniform, thick stand early in the season. Seed placed starter fertilizer, good depth control, uniform residue distribution, and shallow planting all are important.

Preceding crop (residue type) also plays a role in determining how quickly the crop emerges. The dark colored residue that follows oilseed and legume crops will speed soil warm up in the spring. This, along with low level of phytotoxicity to

small grains, mellow soils, and decreased surface cover characteristic of these crops all lead to excellent early season stand establishment.

Spring cereals seeded into small grain stubble can face severe phytotoxicity problems along with cooler soil conditions in many situations. If the other steps mentioned have been taken, the small grain will outgrow these problems and produce excellent yields (as seen in results from the rotation study at Redfield).

In most cases, however, seeding of spring cereals into small grain stubble is not recommended. It is a tremendous waste of an extremely valuable resource. The moisture stored because of the late summer "fallow" period, excellent snow catch, and good surface residue are better utilized by full-season, high water-use crops.

It is true that small grains planted in small grain stubble will out yield those following full-season crops, but they cannot come close to matching the economic advantages gained by using this stubble for crops that can respond better to the favorable environment it creates.

Barley is more tolerant of cool soil temperatures than wheat, with both being much better than oats. With this in mind, a good seeding order would be malting barley, wheat, feed barley, then oats.

The primary disease concern for small grains following row crops is the potential for head scab. This fungus also produces stalk rot and ear rots in corn. Producers in areas where warm, moist conditions could occur during small grain flowering should at least avoid seeding wheat on corn stalks. Due to morphological and physiological differences, wheat is more affected by this disease than either barley or oats; although they are also susceptible. Most grass species can serve as an alternate host for the fungi, but corn stalks contain much higher populations of the inoculum than sorghum or millet residues.

Oilseed and legume crops pose little disease concern for succeeding small grain crops. Drier areas may be able to grow small grains after corn, but the producer should be aware that there are no varieties resistant to the disease, no fungicides that are effective to treat or prevent it, significant yield losses can result, and the grain may be both unsellable and unfit for livestock feed.

The other concern for spring small grain producers is avoiding damage from residual herbicide used in the preceding crop. Wheat and barley are more tolerant of atrazine and DNA (Treflan, Prowl, Sonalan) than is oats, but all can be damaged. The best bet is uniform application of the residual herbicide following label directions, good chaff and straw spreading, and starter fertilizer with the seed. A good tram-line system will greatly reduce the amount of overlap related carryover damage.

No-till spring small grains should be seeded shallow (3/4 to 1 inch) as early as possible in the spring. Seeding rates 20 to 40% over conventional tillage should be used to establish quick crop canopy and limit tillering. Tillers develop later than main stems which increases the probability hot weather will be encountered. Cool, moist soil conditions in no-till encourage excessive tillering if seeding rates are too low. Row spacing should be as narrow as possible (less than 6 inches is preferred). Few commercially available no-till drills allow ideally narrow row spacings. In no case should rows wider than 8 inches be used.

Herbicide programs for no-till spring small grains will differ little from those used in conventional tillage, except that the soil incorporated grass control programs are excluded. Proper rotation planning, optimizing crop competitiveness, and minimizing disturbance will limit the need for grass control in many situations.

The other difference is that a broadleaved weed control product that allows spraying at very early crop development stages will be utilized. No burndown is generally used at seeding time, since few weeds have begun to grow at this time. When weeds reach proper growth stage, the herbicide is applied and the crop out-competes any late-coming weeds.

In some rotations, grass pressure may warrant use of a postemergence grass control product. These work quite well, unless the weather is hot and dry. In that case they should be sprayed in the late evening (roughly between 8 pm and 1 am). This is an easy task if tram lines are present. Postemergence grass herbicides are not available for oats, so selection of a good rotation is more important.

FLAX

Flax may have a significant fit in many no-till production systems and, like all oilseed crops, may show improved demand as crude oil prices escalate. Of the non-legume oilseeds, flax has the best spectrum of herbicide options for no-till production.

Flax is seeded and harvested later than spring cereals but earlier than full-season crops, making it a good choice for spreading work loads. When straight cut (or hopefully soon, harvested with a stripper head) it leaves good stubble for snow catch.

Flax is an excellent way to break disease, insect, and grassy weed cycles in rotations predominated by grass-type crops. From an agronomic standpoint, it provides an excellent crop to precede winter wheat in the rotation. The questions remaining to be answered include finding where it can be grown consistently and profitably and determining if

sufficient moisture occurs to allow winter wheat seeding to be successful in these areas.

Flax is less tolerant of frost than small grains and, consequently, should be seeded slightly later (but not much). An early maturing variety should be used where late season heat is a concern. Flax has small seed and must be planted shallow (1/2 to 3/4 inch). Seeding rates should be high to improve the competitiveness of the crop. Seeding depth must be very uniform, rows narrow, and starter used. The weed control philosophy, in most cases, will be similar to that used in small grains with no burndown at seeding and early applications of postemergence herbicides. Some DNA herbicides (Treflan family) are being evaluated for use early preplant in flax to improve late season grass and broadleaf (pigweed, lambsquarters) control. Preplant incorporated treatments similar to this are available for conventional tillage and are effective and economical.

Flax has traditionally been swathed prior to harvest, but straight cutting is becoming more prevalent. In some cases this may require preharvest desiccation or post harvest aeration. This is preferable to the reduced stubble height and danger of swath blowing associated with laying the crop down. Flax suffers few insect or disease problems in most rotations.

CANOLA

Canola is another spring seeded oilseed crop that may have substantial potential. Canola is a name given to rapeseed varieties which are low in euricic acid and produce meal low in glucosynolates. The edible oil produced from canola is very low in saturated fat (healthy) with good cooking properties.

Canola, like flax, should be seeded immediately following spring cereals. It needs to be seeded shallow in narrow rows. Recommended seeding rates (6-8 lb/acre for no-till) require use of grass seed attachments or low-speed gears on some drills. Coated seed (which is available) makes attaining proper seeding rate easier. Winter canola types are available, but have winter hardiness characteristics which limit their use to very mild climates at this time.

Canola is a very good competitor with weeds when established. There are, however, no labeled herbicides for no-till production of canola in the U.S. (Treflan preplant incorporated is all that is available in conventional tillage). Similarly, few good insecticide programs are labeled for flea beetle control in the U.S. Flea beetle is a significant pest in canola which can lead to total crop loss. In Canada where a considerable acreage of canola is grown, excellent seed furrow insecticide treatments are labeled, as are numerous no-till herbicide programs. There are even triazine tolerant varieties available that allow some use of triazine programs (atrazine, Bladex, Sencore/Lexone) for weed control in Canada.

Two types of spring canola, Polish and Argentine, are available. The Polish type is very early, probably maturing earlier than spring barley. The Argentine canola will mature slightly later than spring wheat. Argentine types possess better yield potential in good environments. Canola is not tolerant of hot weather during flowering; consequently, the Polish types may do better in dry areas, Argentine types in cooler areas. Like flax, canola has traditionally been swathed, but straight cutting is becoming quite common. When straight cut, it leaves an excellent stubble for seeding winter wheat, corn, or sorghum.

No-till canola production in the U.S. is severely limited by the lack of labeled pesticide programs. The availability of these programs in Canada may speed labeling. Once they are available, canola may find a niche in rotations very similar to the role of flax, i.e. a short-season broadleaf with good stubble. Market considerations, production costs, and crop adaptability will determine which is used in each situation.

SAFFLOWER

Safflower is another short-season oilseed. Planting and harvesting dates are slightly later than flax and Argentine canolas. It ranks between flax and canola in competitiveness to weeds. There are no insect pests specifically associated with safflower. Safflower is more tolerant of hot temperatures during flowering than canola. Hybrids have demonstrated increased yield potential over older inbred lines.

As with many of the other oilseeds, there is an almost total lack of labeled no-till herbicide programs for safflower. A limited number of preplant incorporated programs are available for conventional tillage utilizing DNA herbicides. Consequently, no-till production of safflower in most cases will depend on the development and labeling of herbicide programs for no-till.

Safflower can be straight cut or swathed. Stubble will generally be shorter and less dense than canola or about the same height as flax. Surface residue will be less than with the other two. Once herbicide programs become available, safflower could occupy the same niche in a rotation as flax or canola. Its superior heat tolerance may affect the area where safflower is preferred.

Safflower will root deeper and mature later than flax. This may limit water for a wheat crop that follows in the rotation.

SUNFLOWER

Sunflower is a high water-use, full-season, non-leguminous oilseed (or

edible seed) that fits a niche similar to soybeans in the rotation.

At the present time, only a few labeled herbicide programs exist for no-till production of sunflower; consequently, management designed to maximize crop competitiveness is more important in sunflower. Rows should be narrowed to provide more equidistant plant spacing (row width approximately same as spacing in row). This will mean 15- to 24-inch rows in most cases since seeding rate should be increased 10% to 20% to provide more plants. Metering units on most no-till drills are not adequate for sunflowers. Modification of drills with IH cyclo drums should work well (15 feet = 8 rows 22 1/2 inches wide). Standard row crop planters can be used by doubling back, which works only on limited acres since everything is covered twice. Most row crop planters can be modified to plant as narrow as 15 inches. If both corn and sunflower are included in the rotation, modification of either the drill or row crop planter is highly recommended. Use of semi-dwarf or dwarf types with high seeding rates in narrow rows may be a viable option in the future.

Currently available no-till herbicide programs for sunflower will provide good to excellent grass control. Broadleaf control is limited in spectrum and inconsistent.

The best approach at this time appears to be an early preplant program that provides grass control plus as much spectrum as possible on broadleaved weeds that germinate late in the season (pigweed, lambsquarters).

Seeding should be delayed until early season broadleaved weeds (kochia, russian thistle, etc.) emerge. The emerged weeds should be killed with a burndown prior to planting sunflower. This program will work in many situations, but attention to detail is essential. No rescue is available if a mistake is made.

Late planted sunflower should suffer less insect pressure from stem weevil and head moth. The crop will normally have to be treated at least once for seed weevil control.

Sunflowers are harvested with pans attached to a straight header or with an all-crop or other specialty head. To some extent, harvesting equipment will dictate row width choices.

As compared to soybeans, sunflowers require nitrogen fertilizer; they leave taller stubble and will catch more snow; and ground cover is not as complete (consequently, residue from preceding crops is important to limit soil erosion). Sunflower is more tolerant of heat and drought than soybeans, and harvesting is not affected by surface stones. Insect control will be necessary most years with sunflower, seldom with soybeans.

Improved herbicide programs for no-till sunflowers would make them a viable crop alternative in many areas.

MILLET

If prices are good, millet may play an important role in no-till for some producers.

Labeled herbicide programs are limited for no-till millet. The big difference between it and some other crops is its substantial tolerance to atrazine carryover. This allows producers to position it in the rotation behind corn or sorghum which have received relatively high rates of atrazine and gain some weed control benefit from the carryover.

No-till millet would be planted in early June, with burndown and post emergence broadleaf options if necessary. Maximizing crop competitiveness is extremely important. If winter wheat is to follow millet in the rotation, it is strongly suggested that the millet be harvested for seed with the straw left in the field.

PEAS, LENTILS, LUPINES, AND FORAGE LEGUMES

Field peas, lentils, lupines, and a host of unexplored early-season legumes that can be used for either grain or forage production may have tremendous potential for no-tillers in more arid regions. These crops are planted early in the spring and are harvested prior to the hot part of the summer. They therefore fill a niche similar to safflower, canola, or flax.

The advantages of these crops are their ability to fix atmospheric nitrogen and their potential use as a protein supplement and a high quality forage. They appear to be especially suited to livestock producers since the grain from many of these crops can be used as a protein supplement without heat processing.

Disadvantages include lack of information on adapted varieties and growing practices, the need to use nontraditional marketing channels, and, in some cases, limited snow catching ability of the stubble. Many herbicide programs currently labeled for soybean production are either labeled or could be labeled for use on these crops if production becomes sufficient for companies to develop the necessary data.

ALFALFA

Alfalfa fits no-till situations very well. It should be seeded into clean wheat stubble about 6 to 8 weeks before killing frost is expected. This will produce an excellent stand and a very productive crop the following season.

When coming out of pure stands of alfalfa, you must kill the crop in the fall or sooner. In dry areas it is best to harvest the first crop and spray the regrowth early in the summer to allow sufficient soil moisture recharge to produce a crop the next year. Where grasses or grassy weeds are present in the stand it appears to

be better to use a systemic grass control herbicide (Poast, Fusilade, or Roundup) to kill the grass and then follow the program outlined above for pure stands. One good program uses atrazine to aid weed control during this "fallow" period and during a subsequent corn or sorghum crop.

The excellent soil tilth and structure developed under long term no-till is already present to a certain extent in alfalfa. Don't screw it up by doing tillage.

ROTATIONS AGAIN

This discussion of no-till systems began with rotations and will end with rotations. They are the key.

The list of potential rotations is repeated here to show how the information presented interacts in creating successful and unsuccessful no-till programs. Since these interactions will depend on local environment, central South Dakota (Redfield to Pierre) will be used as the location.

The rotations are:	*Water Use Intensity*
winter wheat-fallow	0.5
winter wheat-winter wheat-fallow	0.67
winter wheat-corn-fallow	1.0
winter wheat-corn-millet-fallow	1.0
winter wheat-corn-millet	1.33
winter wheat-corn-flax	1.33
winter wheat-soybean-spring wheat	1.33
spring wheat-soybeans	1.5
winter wheat-corn-soybean-barley	1.5
winter wheat-corn-soybean-spring wheat	1.5
winter wheat-soybean-corn-flax	1.5
winter wheat-soybean-corn-spring wheat	1.5
spring wheat-corn-soybeans	1.67
spring wheat-soybeans-corn	1.67
corn-soybeans	2.0

Most producers will use more than one rotation or will combine two short rotations into a longer one.

The winter wheat-fallow and the winter wheat-winter wheat-fallow rotations are both extremely poor. They lack intensity and will cause weed problems and increased disease pressure. They also concentrate the workload for seeding and harvesting, thus requiring a large machinery investment per acre or use of custom services.

The winter wheat-corn-fallow rotation (ecofallow) has been a dependable rotation with well-defined management parameters and economical herbicide programs. Sorghum can replace corn where desirable.

This rotation will probably be used extensively by winter wheat/fallow producers beginning to make the transition to no-till. Results with this rotation are well defined; it is quite safe (even in the drier areas), and fits crop bases of many producers. It is not intense enough to maximize profits in many areas when no-till is utilized. Workload is spread somewhat, but significant acreage will still require substantial horsepower.

Winter wheat-corn-millet-fallow does not increase intensity over the ecofallow rotation but does serve to spread workload over another crop. This rotation will utilize slightly higher rates of atrazine during the corn crop, with carryover controlling weeds in the millet and helping during the subsequent fallow. Grass pressure from foxtails is more of a concern in this rotation than in the three-way rotation. Good stubble and fallow management is important, as is use of low disturbance seeding to minimize volunteer corn (or sorghum). The short season crop (millet)-fallow sequence is inefficient in terms of water use.

The winter wheat-corn-millet rotation turns the intensity up a notch to 1.33. Weed control in the millet will be a concern, since atrazine rates in the corn will be lower to prevent carryover to the wheat crop. The relatively late harvest date for millet presents some concern in terms of winter wheat stand establishment in dry areas. Grass control (foxtail) will be the major concern in terms of weeds.

The viability of rotations containing millet depend on millet prices.

Winter wheat-corn-flax is a rotation that may have substantial potential if flax yields are adequate. The flax crop will limit use of atrazine during the corn year, entailing slightly higher expense with no increase in yield. The flax does, however, offer a crop where grass control options are excellent. Harvest is earlier than for millet, increasing the chance for good winter wheat stand establishment. Snow catch in the flax stubble will also be better than with millet and will be excellent where stripper heads are used for harvest.

Canola or safflower are other oilseeds which will fit this rotation when herbicide programs are available and the environment favors their use. Short-season legumes such as field pea, lupine, or lentil are also viable options in this rotation.

The winter wheat-soybean-spring wheat rotation (sunflower could be used also if weed control options are available) presents opportunities and potential difficulties. It has been the most profitable rotation in the studies of Al Black at Mandan, N.D. (sunflower is used there).

Two years of small grain allow broadleaved weed competition to be down significantly when going into the broadleaved crop. The broadleaved crop allows good grass control. The concerns involve potential disease pressure (tan spot, septoria, and root disease) in the winter wheat from the spring wheat stubble. This is less of a problem in dry areas and can be controlled somewhat by fungicides, but it is a concern.

Snow catch of spring wheat stubble is excellent for the winter wheat. Snow catch following soybeans is almost nonexistent unless strips of stubble are left standing. (Sunflowers catch more snow). Seeding environments for all crops are close to ideal.

When soybeans are used, care must be taken in herbicide choices to prevent development of tolerant biotypes. A sulfonylurea type herbicide program could be used on all three crops (i.e., Harmony, Pinnacle, Harmony respectively). Even if Pursuit were used on the soybeans, the modes of action are similar. The two stubble periods make it unlikely that such tolerant biotypes will develop, but using a program with a different mode of action (perhaps Bronate) during one of the wheat crops (preferably winter wheat) will assure that no problems arise.

The intensity of this rotation is not very high. This, along with the disease concerns, will probably limit it to drier areas of the plains. Workload is spread well in the rotation unless winter wheat seeding and soybean/sunflower harvest overlap.

The next series of rotations turns the intensity up a little more to 1.5. The winter wheat-corn-soybean-barley and winter wheat-corn-soybean-spring wheat rotations are similar to the previous rotation with corn added. Sorghum and/or sunflower could also be used where the situation warrants.

Adding corn makes avoiding herbicide tolerance more automatic, but you should be aware that the new postemerge grass herbicides for corn are also in the Harmony family. Workloads are spread even better with both rotations.

Good snow catch capabilities of corn/sorghum will help to offset the fact that two high water-use crops are grouped in the rotation. Since soybean/sunflower crops reach critical water-use periods late in the season, there is more chance for rains.

In dry years, the soybean crop will be expected to yield less than when it follows wheat, but in normal or wet years little differences is expected. When yield differences are averaged over years and compared to the cost of stubble maintenance (where they follow small grains), profitability will favor these more intense rotations in many locations.

The rotations containing barley will reduce disease concern slightly and may fit some producers' crop bases better. Barley stubble produces less snow catch than spring wheat stubble. The price of barley in relation to spring wheat has limited the profitability of barley in the rotation.

The winter wheat-soybean-corn-flax and winter wheat-soybean-corn-spring wheat rotations have the same intensity as the previous rotations but put the soybean/sunflower component in a more favorable position for soil moisture and create a warmer seedbed for the corn/ sorghum component. These rotations are better suited to cooler, moister areas where moisture for corn is not as critical as early season growth.

Devising methods to improve snow catch behind the soybeans would be important. Areas where this rotation works (cool, moist) would most likely be well adapted for flax production, but there may be considerable concern about using a spring wheat-winter wheat sequence since disease pressure could be severe in this environment. The increased moisture could also dramatically increase the potential head scab problem with spring wheat following corn.

Consequently, the winter wheat-soybean-corn-flax rotation may find a home much more easily than the rotation with spring wheat. Substituting barley or oats in the rotation would decrease (but not eliminate) disease concerns and could make this rotation profitable in certain situations. Short-season legumes or other oilseeds could be substituted for the flax depending on market and climatic conditions.

The other rotation listed as having an intensity of 1.5 is soybeans/spring wheat. This is similar to Al Black's rotation except that winter wheat has been dropped to increase intensity. As with any short rotation, workload is not spread as well as in longer rotations.

Herbicide tolerance could develop unless care is taken to rotate herbicide programs. Bronate/Pinnacle, Harmony - Sencore/Lexone, Harmony/Basagran sequences rotate mode of action, if weed control is adequate. A Harmony/Pinnacle sequence is, in reality, using the same herbicide. This rotation is shorter than desirable and could potentially lead to disease, insect, weed, and nematode problems, although corn-soybean rotations have been successful for years in many areas. This is a better rotation from an agronomic sense. Sunflowers would not replace soybeans well due to disease concerns.

The strengths of this rotation include very low nitrogen fertilizer requirements due to a legume being present half of the time, an excellent seedbed for both crops, excellent weed control options, and need for only a drill and flex head. Improving snow catch following the soybeans would be very helpful.

This rotation was the most profitable at Redfield in the dry year and stayed competitive with more intense rotations in good years. At the end of the study, weeds were more of a problem than in the longer rotations with soybeans.

The spring wheat-corn-soybeans and spring wheat-soybean-corn rotations raise intensity to 1.67 by adding corn to the previous rotation. This again reduces concern with herbicide tolerance, diseases, and insects, except that the second rotation where wheat follows corn should not be considered in most situations because of potential head scab problems.

The spring wheat-corn-soybean rotation has been among the most profitable at Redfield every year, and it spreads workloads very well.

Sorghum and sunflower substitutions could be made in this rotation where warranted. Improving wheat yields by increasing snow catch following soybeans would make this the most practical rotation for many producers because of the increased acres that could be covered with improved spreading of workload.

The last rotation is corn-soybeans. This is again a short rotation, but it has been used for years in the corn belt with few problems.

The potential to develop populations of nematodes and extended diapause corn rootworms cannot be ignored. Workload is more concentrated with this rotation than in the previous one. Corn is aided by warm seedbeds in the spring but in most areas of the Great Plains will yield less than when it follows wheat due to moisture differences.

This rotation, surprisingly, has been the most profitable at Redfield when averaged over years. It has never been worse than second even in the very dry years. A five-way rotation (corn-soybeans-corn-soybeans-wheat) would be excellent at Redfield.

This economic analysis does not attempt to adjust for differences in economy of scale which result from better workload spreading in more diverse rotations. The reasons this rotation looks good economically is that there is no need for post-harvest stubble spray operations, since winter takes care of that; a legume in alternate years reduces nitrogen requirements; and both crops take full advantage of the moisture savings associated with no-till.

In most cases three- and four-way rotations will fit better on the Great Plains than the shorter rotations. The better-than-expected performance of this very intensive rotation in a relatively dry environment does demonstrate the absolute need to increase rotation intensity when switching to no-till.

CONCLUSIONS

Several aspects of no-till have not been discussed in this paper. This is mainly because insufficient research has been conducted on the prairies. The two most important areas are:

1. Determining the management factors required to allow a no-till system to be grazed by livestock.

2. Defining the changes, interactions, and importance of earthworm and other soil organisms in a no-till system.

Livestock are an integral part of most prairie farming systems. For no-till to be universally accepted, methods of furnishing forage and bedding for livestock need to be incorporated into no-till systems. The most simple solution is to mechanically harvest material and transport it to the livestock. It may also be the most economical, but we don't know that for sure.

Livestock (including buffalo) have grazed the prairies forever without permanently damaging the environment. However, the soil structural changes resulting from tillage make soils prone to damage by livestock. When no-till returns soil structure and organic matter to levels closer to those present under native conditions, it may be possible to graze livestock without harm to the soil.

Management of the grazing process may be required however. Brian Jorgensen, a no-tiller who grazes livestock, has offered some advice: planting crops in narrow rows to discourage waste and trails, cutting perimeters and landings to accommodate electric fencing and high intensity rotational grazing, keeping water sources and loafing areas off grazing areas, removing livestock during wet periods and thaws, no supplemental feeding in the grazing area, and no grazing of land that has already been treated with an early preplant herbicide program.

Two cautionary notes should be added. Allowing weeds to grow (after small grain harvest for instance) for use in grazing is penny wise and pound foolish because of the poor value of the feed and the weed seeds that are allowed to develop. Also, supplementing hay or concentrate sources that contain weed seeds is an excellent method of introducing unexpected weed pressure to a field. Supplementing may be unavoidable, but take care to obtain clean feed sources and scout the field very carefully. Hoof traffic will increase large-seeded broadleaved weed pressure.

Earthworms have been proven to be very important to stopping runoff in no-tilled situations in high rainfall areas by researchers such as Bill Edwards in Ohio. They are also suspected to be the major cause of the extremely high infiltration rates which developed under long-term no-till at the James Valley Research Center at Redfield. Research projects are presently being conducted in an attempt to determine what amount of the high infiltration rate is directly attributable to earthworm holes and what part is the result of surface residue and soil structure improvement.

If, as we expect, the holes are found to be the more important, it will still not be clear what environment/soil type combinations will support earthworm activity, which species are important, and what amount of disturbance can be tolerated without harming the worms or negating their benefit.

The tremendous differences noted in soil "tilth" after a field has been no-tilled for a period of years defy description. Simply stating, for example, that organic matter increases does not fully capture the differences which are immediately evident to any seasoned farmer when he has a chance to walk out

and dig in the soil. Anyone who feels that good no-till systems are not sustainable or are not ecologically sound has never taken the time to study a properly conceived system or to walk into one of the fields and examine both the soil and the biological activity it supports under a no-till environment. There is no system that more closely mimics the prairie than a diverse no-till farming system.

Good resource stewardship is the goal of every producer. However, he still needs to make money. References have been made throughout this paper to a no-till rotation study at Redfield, S.D. The authors feel the completion report for that study, which follows, speaks for itself in terms of the profitability of intense no-till rotations in the period of 1988 through 1991.

No-Till Rotation Systems for Wheat Production

Dwayne Beck

Objective: Determination of the most profitable rotations for no-till production of wheat.

Duration: The study began with a uniform crop of wheat in 1986. Rotations were established in 1987. Pertinent data were collected from 1988-1991.

Narrative: The no-till crop rotation study, jointly supported by the South Dakota Wheat Commission and the SDSU Agricultural Experiment Station, was designed to provide much needed research verification and also meet the need of producers in the area to witness no-till techniques applied on a field-scale basis.

The study area, 5 miles east of Redfield on the north side of highway 212, covered an L-shaped 80 acres of land. Everything at the site was done no-till, meaning only a drill, a sprayer, and a combine were used for all field operations.

Seven different crop rotations were tested. They included: Spring Wheat-Soybeans; Spring Wheat-Corn-Soybeans; Spring Wheat-Barley; Spring Wheat-Winter Wheat; Barley-Winter Wheat-Corn; Winter Wheat-Corn-Fallow; and Corn-Soybeans. Each rotation was replicated four times in different parts of the field. This resulted in plots which are just slightly less than one acre in size.

All field operations were performed with standard equipment, including a JD 752 no-till drill, a corn planter, a 4400 JD combine with either 13-foot flex header or a five-row corn head; and a 25-foot field sprayer. Yields were determined using a 250-bu grain cart equipped with scale. Use of these techniques helped to assure that yields and input costs are the same as those a farmer can expect.

Each rotation in this study was managed as if it were a commercial production field employing techniques presently available for farmer use. The ultimate goal was maximum return. Herbicides were chosen on the basis of cost and effectiveness; fertilizers were applied according to soil tests; etc.

This approach had two major advantages. The first was research verification, a fancy way of saying it allowed SDSU scientists to examine how current best management practices being recommended for no-till fit together and work in field-scale situations; and it let them know where more small plot research is needed to better define these techniques. The second advantage is that it provides producers interested in adopting no-till with both a highly reliable set of input cost and yield figures.

The study was begun in 1986 when a uniform crop of wheat was planted on the field. In the 1987 growing season (fall 1986 for winter wheat) the proper crops were planted in each plot to establish the rotations. The 1988 growing season was the first year that each crop followed the proper sequence in each rotation. The study was ended following harvest in the fall of 1991 when emphasis switched to a similar study west of the Missouri River.

Substantial improvement in soil physical properties were becoming evident after this period of time in continuous no-till. Work has begun to document these changes. No earthworms are present in this study at the present time, most likely due to the lack of a native earthworm source.

Rainfall recorded for the years of the study is shown in Table 1. Some of these years were very dry. The last 2 years were very wet. Rainfall received at the Pierre airport over the same period was included in the table as a means of comparison. This does not mean that yield levels would be similar at Pierre to those obtained at Redfield. The environment and soils are quite different. It does point out that there is not a large difference in rainfall between the Pierre airport and the old research farm at Redfield.

Table 1. Rainfall received at Redfield and the Pierre airport, 1987-1991.

	4/1-9/1		1/1-12/31	
	Redfield	Pierre	Redfield	Pierre
1987	5.93	9.98	11.82	16.57
1988	10.69	9.96	16.73	13.80
1989	7.99	11.35	14.66	16.75
1990	18.70	13.10	21.31	17.16
1991	22.40	17.79	25.88	23.13
Normal	13.12	13.88	18.51	18.08

Results: The results obtained from the study in the 1988-1990 period

Table 2. Yields for the Wheat Commission Study.

1988

Rotation Number	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Corn		67			66	68	66
Soybeans	31	24					24
Barley			51		39		
Spring Wheat	23	24	28	18			
Fallow						xx	
Winter Wheat				32	30	40	

1989

Rotation Number	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Corn		92			91	94	79
Soybeans	33	28					29
Barley			71		48		
Spring Wheat	31	31	35	31			
Fallow						xx	
Winter Wheat				44	53	53	

1990

Rotation Number	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Corn		138			140	139	113
Soybeans	47	49					48
Barley			47		47		
Spring Wheat	44	46	53	51			
Fallow						xx	
Winter Wheat				34	36	40	

1991

Rotation Number	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Corn		100			106	104	101
Soybeans	53	55					56
Flax			18	15	15		
Spring Wheat	39	40	39				
Fallow						xx	
Winter Wheat				26	35	34	

1988 through 1991

Rotation Number	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Corn		100			102	101	90
Soybeans	41	39					40
Barley			56*		45*		
Spring Wheat	35	36	39	33*			
Fallow						xx	
Winter Wheat			34	39	42		

presented some interesting insights into the effects of crop rotations under no-till conditions. The surprisingly good yields obtained with some of the rotations in two consecutive dry years (1988 and 1989) give us substantial confidence in the data for dryer-than-normal conditions at Redfield. It is also interesting to see how these results compare to yields obtained in 1990 and 1991 which were wetter than normal.

Several items stand out in the yield data. One of the most dramatic is the 5 bu/acre average reduction in yield for winter wheat experienced when it was grown following spring wheat and the 6 bu/acre reduction on average when spring wheat followed winter wheat as compared to the same crops following barley.

Based on snow catch and available moisture, winter wheat following spring wheat and spring wheat following winter wheat would be expected to yield at least as much as when following barley. The fact that they are much lower yielding demonstrates the importance of the "rotational effect." Disease is probably one of the main culprits along with phytotoxic effects.

The 3 to 4 bu/acre reduction in spring wheat yields when following soybeans as compared to barley appears to be primarily a moisture effect since the soybeans use more water and leave no standing stubble to catch snow. This trend occurred the first 3 years but not in the wetter-than-normal 1991 season.

The 11 bu/acre increase in barley yield following spring wheat as opposed to that behind corn is probably also a moisture effect. Similar moisture differences increased yield of soybeans in wheat stubble compared to those grown in corn stalks in dry years. The yield difference was 7 bu/acre in 1988, a very dry year. There was no difference in 1990, and in 1991 the wetter environment appears to have decreased yield slightly.

Fallowing prior to growing winter wheat did not increase yields in 1989 or 1991 as compared to wheat "stubbled into barley." Based on the moisture patterns that occurred, that is not surprising. Fallowing for winter wheat at Redfield produced only an

average yield increase of 3 bu/acre. Corn is the crop which has responded the most consistently and dramatically to the increased moisture found in wheat stubble. It has produced on average 11 bu/acre more than that grown following soybeans. A poor variety in 1988 limited yield differences, or they would have been even more apparent.

It was surprising that corn following wheat produced 26 bu/acre more than that following soybeans in 1990 until the timing of the rainfall is analyzed. The corn in wheat was able to avoid detrimental effects from early season dryness and take advantage of late rains. The corn following soybeans had already been hurt some by the time rains fell. The rains came early in 1991, consequently no differences occurred. A higher plant population and more nitrogen fertility in 1991 may have increased yields substantially.

Profitability: The profitability of each rotation was calculated using actual costs of land, seed, chemicals, fertilizers, etc.; harvest time market prices for each commodity; and custom rates for all field operations and transportation.

Based on previous experience in production fields, it was known that the soybean-spring wheat rotation produced very good returns in normal to wet years in the James River Valley; it was a surprise to see it beat the field in profitability in 1988 and finish second in 1989, two dry years.

Good market prices for soybeans in 1988 and wheat in 1989 helped, but two other factors play a role here: the cost savings in nitrogen fertilizer allowed by growing a legume, and the reduction in herbicide costs associated with this system as compared to where soybeans follow corn or spring wheat follows another small grain.

Table 3. Profitability for the No-till Rotation Study.

Net Profit (or Loss) in Dollars/Acre

1988							
Rotation Number	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Corn		16			9	27	27
Soybeans	133	78					78
Barley			(23)		(37)		
Spring Wheat	0	4	(7)	(48)			
Fallow						(41)	
Winter Wheat				3	(3)	35	
Net Profit ($/acre)	**66**	**32**	**(15)**	**(20)**	**(10)**	**6**	**52**
1989							
Rotation Number	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Corn		59			56	73	46
Soybeans	76	57					67
Barley			38		5		
Spring Wheat	26	35	42	27			
Fallow						(56)	
Winter Wheat				61	92	99	
Net Profit ($/acre)	**54**	**50**	**40**	**44**	**51**	**39**	**57**
1990							
Rotation Number	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Corn		112			111	115	71
Soybeans	158	180					175
Barley			(33)		(24)		
Spring Wheat	29	34	31	24			
Fallow						(45)	
Winter Wheat				(33)	(28)	(8)	
Net Profit ($/acre)	**93**	**109**	**(1)**	**(5)**	**19**	**21**	**122**
1991							
Rotation Number	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Corn		68			81	81	79
Soybeans	174	190					195
Flax			(28)	(39)	(32)		
Spring Wheat	13	13	(6)				
Fallow						(45)	
Winter Wheat				(51)	(28)	(67)	
Net Profit ($/acre)	**93**	**90**	**(16)**	**(45)**	**7**	**5**	**136**
Four-Year Average Profitability	**76**	**71**	**(10)**	**(7)**	**17**	**18**	**92**

The biggest surprise in the study was the relatively strong showing of the corn-soybean rotation in the dry years. It was anticipated that this rotation could be profitable in good years and very unprofitable in bad years since it has the highest input costs. In 1989, 1990, and 1991, it had the highest net returns and fin-

ished a close second in 1988. It produced the greatest average return over the life of this study.

The corn-soybean-spring wheat rotation finished in a strong position for third place in the average and was number two in profits in 1990. This longer rotation has some definite advantages in spreading workload and risks. The economy of scale associated with being able to produce more acres of crops with the same machinery using a wider variety of crops as compared to rotations 1 and 7 could very well make this rotation more profitable than it appears in this analysis.

The less water-use intensive number 3, 4, 5, and 6 rotations did not fare well in any year or in the average. Although both 1988 and 1989 were dry years, the more intense rotations were more profitable even in those years.

The profitability of the less intense rotations varied little when the good years (1990 and 1991) came along because they could not take advantage of the better moisture conditions, even if we discard the number 3 and 4 rotations which are very poor. The number 5 and 6 rotations have produced less than a fourth the profit of the more intense number 1 and 2 rotations and less than a fifth the profit of the very intense corn/soybean rotation.

These results are sensitive to commodity prices and were gathered during a period of wheat prices usually less than $3/bu. Increasing wheat prices while holding the other commodity prices stable would have improved the relative profitability of the low intensity rotations but not enough to equal the profitability of the more intense rotations.

Even adding one dollar to the wheat price over the life of this study (keeping corn and soybeans the same) will only bring the profitability of rotations 5 and 6 up to a third of the number 7 rotation. The improved wheat price would also make the intense number 1 and 2 rotations more profitable, approximately equal to the number 7 rotation, again at least three times more profitable than the less intense rotations.

The bottom line of this research so far seems to indicate that in order to take the moisture savings that occur with no-till and turn it into profit, wheat producers may have to utilize rotations which are more intensive than they would commonly grow using conventional tillage. This may or may not affect wheat acreage slightly but will substantially increase the diversity and profitability of the wheat producer.

It is true that Redfield differs in soil type and climate from Pierre, or Gettysburg, or Winner, or Presho. The principles documented by this research should, however, have application over all areas where rainfall is in short supply during some period of the growing season.

It is uncertain at this time what rotations will work best for producers in areas farther west adopting no-till. It is almost certain that they will be less intense than the best ones at Redfield and they may contain different crops, but they will be more intense and more diverse than those that are common when conventional tillage is used.

Consequently, a similar rotation study was slated to be initiated in the fall of 1991 at a site south of Ft. Pierre, S.D. This study will encompass approximately 280 acres and is located on an Opal-Promise soil series. These are heavy clay soils typical of the West River winter wheat growing areas. Seventeen rotations will be included in this study varying in intensity from a Winter Wheat-Fallow to Corn-Soybeans. New crops to be included are safflower, field peas, and lentils. It is hoped that within 4 or 5 years there will be information for rotational planning in the dry areas of the west as good or better than the information provided by the Redfield study. The Wheat Commission sponsorship of both of these studies is sincerely appreciated.

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