TITLE: Rotational Systems: The Key to Successful No-till

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INTRODUCTION:

Prior to discussing the subject of rotations, it might be valuable to furnish some background information. The techniques and data to be presented were developed at the James Valley Research Center located near Redfield, South Dakota (approximately 130 miles south, and 65 miles west of Fargo, North Dakota). This facility, at the time it was closed on December 31, 1989, consisted of a 200 acre main station plus a quarter and an eighty of additional land in the vicinity. Soils in this area are developed in lacustrian sediments left by the glacial lake Dakotah. This makes them similar to those in eastern North Dakota and Manitoba that developed in the remnants of Lake Aggassiz, with the exception that the soils are lower in organic matter due to the warmer, drier, environment. The soils are medium to heavy in texture (silt loams, silty clays and silty clay loams), show slow permeability when conventionally tilled, have good water holding capacity, and are prone to wind and water erosion. Primary crops grown in the area include wheat, barley, rye, oats, corn, sunflowers, sorghum, and soybeans. Soybeans are relatively new but have become quite popular. Acreage of soybean in Spink County has grown from 1,900 acres in 1979 to over 100,000 acres in 1989. Sunflower acreage has shown dramatic declines during this period.

The station normally receives slightly over 18 inches of precipitation annually although this has not been the case in the last few years. Table 1 and Table 2 present in detail the weather experienced during the last three growing seasons at Redfield and compares them to the dry part of the 1930's. Approximately 100 acres on the main station was irrigated; all other land at Redfield and the three quarters at the new Dakota Lakes Research Center near Pierre were dryland in 1989.

The role played by research station personnel in South Dakota includes small plot research trial support; field scale research; and uniform production farming demonstrations. The stations are not well equipped to plant or harvest small plot trials, but station staff assist researchers from the main campus and USDA laboratories when they plant or harvest. We also perform almost all site preparation, plot maintenance, data collection, and treatment application duties. Although these small plot trials covered only about 100 acres in 1989, they consumed the majority of the labor resources available.

The equipment used for the almost 900 acres of cropland at the Redfield and Pierre stations in 1989 is extremely meager as compared to that used by research centers of comparable size in other states and provinces or by farmers. All field operations are performed by two 75-85 hp tractors. One is a 1967 model 706 IH, the other a 1980 model 2840 JD. Other frequently used equipment includes a 12.5 foot no-till drill, a row crop ridge-planter, and a high residue row crop cultivator. We also own some old tillage implements such as an 8 foot chisel (digger), a 15 foot field cultivator, a 16 foot tandem disk, and a 5 bottom plow. These are used only rarely for land preparation and treatment application in small plot studies. Spraying is handled with a home made pull type sprayer covering either 37.5 or 25 feet depending on the job to be performed. Harvesting is done with a 4400 JD combine, a 250 bu. grain cart equipped with a scale, and a small semi tractor and trailers. We employ two full time technicians. These two people and I perform almost all field work and a substantial portion of the research operations at the stations. College students are hired during the summers to help with data collection, plot maintenance, and groundskeeping.

The field scale research portion of our program primarily involves replicated strip trials. Strips are normally 25 to 100 feet wide by 350 to 1300 feet long. This is sufficient to allow use of standard sized farm equipment for all field operations. Harvesting is done using the 4400 combine with the grain being weighed in the 250 bu. grain cart. My staff and I are solely responsible for planning and conducting these trials.

The final portion of our duties involve uniform production farming demonstrations. There are three aspects that enter into this part of the operation. The first is to uniform the fields for research to be conducted in the future. The second is to serve as a method of integrating the knowledge and practices gained from small plot and field scale research projects into a "real world" environment to see how they hold up. And the last is to do what all farmers must do to remain in business; to make a profit. Well over half of our operating budget now comes from profits as compared to under five percent prior to 1983. In two years we expect to be generating about 80% of our operating budget.

Comments regarding the importance of crop rotations to no-till farming will be almost entirely based on field scale research and experiences with uniform production farming. This is not meant to downplay the importance of small plot research or researchers (a resource used extensively to select treatments for trial in field scale studies); but rather stems from the realization that most producers, before adapting new technology, like to have the tires kicked a little harder than is possible in many small plot trials.

You probably have gathered by now that South Dakota State Univ. is in the process of closing the James Valley Research Center at Redfield and opening the Dakota Lakes Research Center at Pierre. The reasons for this go beyond the scope this discussion, but include the issues of land ownership, future irrigation development, and dryland research needs. The preference was to operate both stations, but the unwillingness of the present owner at Redfield to sell us the present site and the belief that resources were not sufficient to develop two new sites simultaneously, led to concentrating efforts at Pierre while maintaining some of the work at off station Redfield locations.

TABLE 1 and 2: Precipitation Data for the James Valley Research Center Redfield, South Dakota

TOTAL PRECIPITATION IN INCHES

	1987 Monthly	**1988 Monthly**	**1989 Monthly**	**Long Term Monthly**
January	0.15	0.09	0.23	0.33
February	1.03	0.24	0.63	0.67
March	2.05	0.15	1.61	0.90
April	0.44	1.06	2.03	2.05
May	1.13	3.67	1.13	2.94
June	1.15	1.09	2.04	3.68
July	2.47	1.25	1.44	2.48
August	0.74	3.62	1.35	1.97
September	1.44	3.99	-	1.25
October	0.35	0.26	-	1.26
November	0.85	0.79	-	0.56
December	0.02	0.52	-	0.42
Total	11.82	16.73	-	18.51
April 1 to Sept. 1	5.93	10.69	7.99	13.12

	1932 Monthly	1933 Monthly	1934 Monthly
January	0.38	0.07	0.05
February	0.10	0.03	0.06
March	0.32	1.98	0.85
April	1.61	0.71	0.12
May	2.07	2.48	0.38
June	4.45	1.96	3.25
July	0.93	4.15	1.29
August	3.95	0.47	0.40
September	0.87	1.42	2.14
October	0.92	0.02	1.54
November	0.20	0.17	0.73

December	0.27	0.72	0.64
Total	16.07	14.18	11.45
April 1 to Sept 1	13.01	9.77	5.44

	August 1 to July 1	August 1 to August 1	October 1 to Aug 1
1986-1987	15.44	17.91	9.11
1987-1988	9.70	10.95	9.16
1988-1989	16.85	18.26	10.65
1931-1932	15.12	16.05	14.43
1932-1933	13.44	17.59	12.77
1933-1934	7.51	8.81	6.92
Long Term	16.03	18.51	15.29

Total Precip. October 1, 1986 to August 1, 1988.....18.27   Normal Precip. for this 22 month period............33.80

INTRODUCTION

The agricultural practice of intentionally planting crops for later harvest most likely began when primitive hunter-gatherers noticed plants growing from seeds discarded near their campsites provided a more convenient food supply and often flourished better than those in last years patch. They had unwittingly discovered one of the oldest, most important, and underemphasized concepts in agriculture; the rotation effect.

They practiced the oldest and simplest form of rotation; farming and moving on. These early bands were nomads who began to stay in one place only long enough to plant, tend, and harvest a crop. As the amount of virgin land in a given area declined and the societal and financial cost of moving increased; the intervals between moves began to lengthen. Eventually, however, crop production would decline to the point that some or all of the members were forced to migrate to other areas. Europeans settlers came to North America looking for rich, virgin, land to farm. The westward movement of settlers in North America contained both new immigrants and a large percentage of farmers from "back east" looking for soil that was not "worn out". Even today slash and burn agriculture is practiced in the tropics as a method of rotation.

In areas where virgin land was gone, farmers began developing (through trial and error) farming methods similar to ones being practiced today. The need for and value of rotations became recognized but was viewed by most to be an inconvenience; a constraining force to be mitigated through the use of "improved farming methods", witchcraft, prayer, luck, or even more drastic measures. Intensive tillage which buried crop residues was and still is a relatively effective method of reducing the severity of certain foliar plant disease outbreaks when proper rotations are not followed. As the effects of tillage mined the soils organic matter, the need for methods of furnishing adequate nitrogen for crop growth began to appear. This led initially to fertilizing with animal wastes or other sources of organic matter; and later the introduction and widespread use of inorganic nitrogen fertilizers. The rotational benefit of summer fallowing became recognized and the practice more commonplace, especially on the prairies of North America. Improved crop growth following fallow was often attributed to improved soil moisture, when in reality it was largely the result of rotational pest control benefits and fallow's ability to supply two years soil derived nitrogen for use by one crop. The high cost and detrimental effects of fallow (soil erosion, saline seeps, and organic matter decline) led to the search for farming practices that would allow continuous cropping.

Several approaches common in more humid areas were tried on the dry prairies with limited success. Growing a green manure crop from the legume family "wasted" a substantial amount of valuable moisture not only when it was growing but more importantly as a result of the intensive tillage needed to plow it down. Animal manure was effective, but the larger acreages and the less concentrated livestock husbandry methods in the west limited its efficiency. Small population density and large acreages, possessing relatively small income potential per acre, negated the use hand labor on a scale comparable to humid regions.

This has led to where we are today. Farmers have found that the use of intensive tillage in conjunction with some combination of fertilizers, herbicides, fungicides, and insecticides will allow them to grow an adequate yield of a given crop in rotations that would produce unacceptable results should any of these tools be omitted. The reasons behind their choice to grow their crop in this manner vary with each situation. Some obviously are economic caused to a large extent by acreage base limitations used as a criterion for participation in the U.S. farm program and Canadian marketing quotas which discourage flexibility in crops grown. Other reasons include tradition and a lack of sufficient information of alternatives to present practices. Well established producers see little reason to change procedures or let their sons and grandsons change procedures that have worked well for them in the past. This is especially true if significant number of long term research and demonstration projects have not been performed to prove the viability of new technology. The widespread urban view that farmers use the procedures they do because the large corporations have them "hooked" on new machinery or chemicals or that the producers do it strictly out of greed is hogwash. There are speculators that broke large segments of prairie in the seventies out of greed but they are the exception rather than the rule. The need and desire to maximize profit is the engine that makes a capitalistic system function. It is the reason food is plentiful in both the U.S. and Canada. The best and surest way to eliminate practices detrimental to the long term productivity of the land, to the environment, or to other segments of society is not through regulation but rather by funding research into developing less harmful alternatives capable of producing adequate and legitimate profit.

Where are farming practices on the prairies headed in the future? Will they follow the conventional approach of intensive tillage used in combination with other modern practices? It is not likely because of increased energy costs and the heightened awareness of the deleterious direct and indirect effects of soil erosion. Will the LISA approach be the wave of the future? It may depend on how "Low Input", "sustainable" and even "agriculture" are defined. Does low input refer only to "unnatural" agricultural chemicals and fertilizers (the vision of many advocates of the LISA system) or to all inputs including machinery, true labor costs, fuel, management, and the costs associated with increased risk? Are all "unnatural" inputs off limits or will the use of safe, cost effective, inputs be encouraged? Does sustainable refer to soil productivity, the profitability of the operation, pristineness of the environment, the viability of the local social and business community, or to some combination of these? Does agriculture mean only the production aspects or does it include the industries and business that now produce, transport, and supply the inputs and transport, process, and market the output. These and other questions remained to be answered. The only certain aspect of agriculture in the future is that nonagricultural interests will be more heavily involved in determining the agriculture's course. Consequently, all segments of agriculture must do a better job of understanding not only what has to be done to succeed but also why it is done this way and what other effects it has. With this in mind, the emphasis of this discussion will focus less on what works at Redfield or Pierre, S.D., and more on the numerous factors which must be considered when planning rotations, why they responded the way they did, and what effect they have on input costs and profits.

Rotation: the key to successful no-till

For the sake of this discussion, crop production practices will be lumped into one of three broad categories: Tillage, Rotation, and Technology. Each producer uses a different mix of these three factors to grow a crop. Each of these factors has positive aspects and negative ones. The key is finding the right combination for each situation. Take the nomadic tribesmen introduced previously; they used a high degree of rotation, a minimal amount of tillage, and no technology. Summer fallow systems common to the prairies at the beginning of this century employed a high degree of tillage, an intermediate amount of rotation, and almost no technology. Conventional farming systems of today utilize an intense amount of tillage, substantial technology, and only minimal rotation. All of these systems successfully grew crops. When it comes to crop productivity and the factors defined above, it appears that at least two out of three are required to make a system work. This is the Rule of the Big Three: 1 is not enough, but 2 out of 3 isn't bad. This refers only to the requirements to consistently grow a crop; outside factors such as soil erosion concerns, environmental impacts, and economics need to be considered separately.

Pioneers of no-till or zero-till recognized early on the outside benefits offered by this new technique. It saved fuel, prevented soil erosion, and furnished habitat for wildlife. But more importantly it conserved water. Prairie farmers were quick to recognize the value of this concept. Finally, they could produce a wheat crop every year without the hassle and expense of fallowing. Unfortunately they had not been taught the Rule of the Big Three. Technology, no matter how intense, was not enough to consistently cover for a lack of both tillage and rotation. Certainly, there are cases of wheat being successfully grown several years in a row using no-till; but just as certainly the prairies are littered with the carcasses of crop failure that resulted when lady luck didn't choose to favor a continuously no-tilled crop. More often than not, the unfortunate producers, and especially their neighbors (also unaware of the RULE), placed the blame on the use of no-till. They were right, in that situation, no-till should not have been used. Unfortunately most did not realize that lack of rotation could just as correctly been named the culprit. Each case like this that occurs is passed from neighbor to neighbor and father to son as warning to avoid the use of no-till.

No-till pioneers, both farmers and researchers, are not to be chastised for these mistakes. It is through mistakes that learning occurs. Everyone had become a little arrogant about the wonders that technology could work; forgetting to pay proper respect to the help being received from tillage. Failures forced no-tillers to dig deeper and look harder for the answers needed to take advantage of the increased moisture provided by no-till. What was discovered was rotation, the oldest concept of crop production. Factors involved in Planning A Rotation:

By now you have probably noticed the term rotation has been used exclusively by itself rather than as it is usually found in conjunction with the word crop. This has been by design, since crop rotation is only one type of rotation that must be planned into a complete no-till system. Granted it is probably the most important factor, since it determines what you have to sell. Flexibility in the types of crops you grow and the relative acreages of each is limited to a certain extent by geography, climate, soils, government policy, and other factors beyond your direct control. Crop rotation, therefore becomes the logical starting point in planning your program.

The following are a series of steps similar to what is done in planning rotations for the land at Redfield and Pierre. A few of the steps have been modified to better reflect a farmer's situation. The first procedure needed is to write down the crops allowed to be grown and the maximum number of acres of each which can be produced within the limits established by government policy. This list should include all the crops allowed, not just the ones grown at the present time. Review this list and cross off any crops that are totally unsuited to the local environment. In other words, a producer three hours north of Swan River, Manitoba you could probably feel safe in crossing off cotton and peanuts. Divide the remaining list into two smaller lists. One should contain all the crops that are grown now, have been grown in the past, are grown in the area, or that have been considered as a possibility (don't forget to put maximum acreages on this list too). The remaining crops should be put on the second list. Now begin to differentiate the crops on list one. Leave one column blank for future use and make a column denoting whether they are a grass crop or a broadleaf. Make another column describing whether they are an annual, biannual, perennial, or winter annual in growth habit. Make another denoting normal seeding time i.e. early spring, late spring, early fall, late fall. The next column should denote normal harvest time. List the effective rooting depth of the crop in the next column. The next column should contain the height of stubble normally remaining following harvest. The next should describe the amount and nature of the stubble i.e. heavy and course, light and fine, etc. Make another column denoting the minimum and recommended rotation interval for each crop (years before it should be grown again). No number 1's should occur in this column.

Using the list just compiled make a new list of potential crop rotations. Some should be familiar, similar to ones used now or in the past; others should be more daring. Try to vary the properties of succeeding crops as much as possible i.e. a grass should follow a broadleaf, a high water user follows low water users, summer annuals follow winter annuals. Make a few rotations that contain only high and only low water use crops. Go through this list eliminating any rotations that have cropping intervals shorter than those recommended. Study the list for crop sequences which could produce devastating disease or insect outbreaks (in many areas wheat should never follow corn because of the threat of head scab). Don't be afraid to seek assistance from the extension service or private consultants.

Once you have pared the list down to size, begin using a separate sheet of paper for each potential rotation. List each crop in the rotation in one column. Put the total available water (soil water plus in season precipitation) needed to produce your yield goal for each crop in the next column. This is a difficult number to quantify accurately and only locally generated data should be used. Bear in mind that for any given year the amount of yield per inch of water will vary dramatically. There are two methods commonly used to arrive at water use efficiency numbers: the threshold concept and straight response curve. Most recent work uses the threshold idea. This approach attempts to find the amount of moisture needed to produce the first few bushels of yield and then measures the amount of increase each additional inch of moisture with produce. This probably is a better system, but a much harder one to find useful numbers for since it has not been used as long. A scientist by the name of John Cole averaged results from 15 research centers in the spring wheat production areas of the great plains and found that "on average" (those words again) about 8 inches of moisture (stored or from rain) was required for spring wheat to produce grain. Each additional inch of moisture increased yields 2.2 bu/acre. This number is about twice as high as the 1.3 bu/acre/inch number cited by other scientists using a straight response curve in the same area. Remember however they credit all moisture while Dr. Cole uses only that in excess of 8 inches.

Often times, when normal precipitation values are used, the final results are not too different. Using their numbers, 17 in. of available water (soil storage + in season rainfall) should produce (17 x 1.3) 22 bu. of spring wheat per acre according to the straight line method. Using the threshold method the predicted yield would be (9 x 2.2) 20 bu/acre. Fairly good agreement. The methods do not agree as well at extremes (7 in. and 30 in. produce results of 0 and 9; and 49 and 39 bu/a for these methods). The need to use local data results from the fact that in a cooler climate, where water requirements are less, the yield produced per inch of water is much greater. Data from Saskatchewan states that 10.5 inches of soil water plus precipitation will produce 14 bushels of wheat and that 6 bushels are gained for each inch after that. Using their data would result in predicting (6.5 x 6 + 14) 53 bushels of wheat with the same 17 inches of water. Table 3 denotes the straight response curve values used to plan rotations at Redfield.

Once a water use requirement formula has been determined for each crop, obtain local weather records showing normal precipitation by month. Using the normal harvest date information already written down, calculate the amount of precipitation received from the time the previous crop has ceased to use water (2 to 4 weeks prior to harvest) until the succeeding crop quits using water. Label this column "Precipitation Available". Immediately eliminate any rotations which contain crops that do not receive enough moisture in a "normal" year to produce a harvestable crop. A harvestable crop is defined as having sufficient yield to pay twice the harvesting and transportation costs.

Table 3: WATER USE EFFICIENCY ESTIMATES USED AT REDFIELD
Straight Line Response Method

	Yield per inch of Water	Average Yield Goal bu. Or ton/acre	Water Use Inches
Corn	6.0 bu	100	16.7
Soybeans	2.2	37	16.7
Oats	5.3	70	13.0
Barley	4.6	60	13.0
Rye	3.0	49	13.0
Flax	1.8	23	13.0
Sorghum	5.8	97	16.7
W. Wheat	3.1	40	13.0
S. Wheat	2.5	32	13.0
Alfalfa	0.14 ton	2.6	18.5
Hay	0.12	2.2	18.5

Label the next column "water available for storage" .This is the amount of water received between cessation of water use in the previous crop and the time the present crop begins to use a substantial amount of water. This water must be stored in order to be useful so we will use this value later in examining a soil's suitability for a particular rotation. For spring seeded crops total precipitation from 2 to 4 weeks prior to harvest of one crop until 4 weeks after seeding the next is generally used. Obviously a crop like winter wheat will not use significant water until the spring after it is seeded. Situations which leave little or no stubble (soybeans, fallow with no trap strips) should receive little credit for snowfall. Crops with stubble should receive credit based on stubble height, architecture, and snowfall characteristics in the area. A good reference for this is an article written by Steppuhn, Austenson, and Dyck in the 1987 Mandan Zero Till Conference Proceedings. At Redfield it is assumed the one-half of the November and March precipitation will fall as rain and one-half as snow. All precipitation in Dec-Feb. is considered to be snow. Credit of up to 1.5 inches of water per foot of stubble height (1.3 mm per cm) is given if sufficient snow will occur.

The next column should contain normal precipitation during the crop season. Label it "crop season water". The next column is labeled "water needed from storage". This is calculated by subtracting "crop season water" from the amount of water required to produce an average crop. Analyze any rotations which require more water from storage than there is water available for storage in a normal year. Evaluate if this situation could be mitigated by improving snow catch. Table 4 contains examples of these sheets for a Corn-Soybean-Spring Wheat-Winter Wheat rotation.

Table 4: PERTINENT WATER DATA FOR ROTATION PLANNING

Rotation	Water Required	Precipt Avail	H2O for Storage	Crop Season Water	H2O from Storage
Corn 100 bu/A	16.7	23.0	14.2	8.1	8.6
Soybeans 37 bu/A	16.7	18.5	10.4	8.1	8.6
Spring Wheat 32 bu/A	13.0	15.4	5.7	7.9	5.1
Winter Wheat 40 bu/A	13.0	17.3	9.3	6.6	6.4

Lay these lists aside for awhile and take out the soil maps for all of your fields. For each major soil determine the depth to a root restricting layer, if any are present (if no restrictions occur use 6 ft), and the available water holding capacity per foot (the SCS, PFRA, or extension service has these maps and data; sand, silty clay, and silt loam will hold approximately 1, 1.5, and 2.0 in/ft). Multiply root zone depth by water holding capacity to determine the total water holding capacity of each soil. If the soils in a field vary little in total water holding capacity, use the value associated with the predominant soil. If the soils in a field vary widely in available water holding capacity attempt to divide the field in a manner that will segregate the soils as much as possible. If the field cannot be split in a reasonable manner, use the water holding capacity of the predominant soil, if there is one, otherwise use the lower of the predominant soils. Make a list with all of your fields designations in one column arranged in order of total water holding capacity (to 6 ft.). Make columns showing the actual water holding capacity of the soil if the crop has 3, 4, and 6 ft. rooting depths.

Compare your "water list" to the sheets containing your rotations. Some fields may not have sufficient water holding capacity to store moisture for certain crops even if a proper rotational sequence is followed. For each rotation list the fields (or soil types) where the available water holding capacity is equal or greater than the amount of "water required from storage" for all of the crops in the rotation. Be sure to use the appropriate crop rooting depth when comparing storage needed to storage available. Producers farming sandy or shallow soils may discover that there are few if any rotations where the soil is capable of holding sufficient water to produce and average crop in a normal year. Rotations requiring the least amount of water storage should be assigned to these fields. No factor has been included to account for runoff that does not enter the soil. Under a proper continuous no-till system with good earthworm activity little or no runoff will occur. This topic will be addressed later. You now have a list of potential rotations for each field that should be relatively safe from devastating disease and insect pests, and have sufficient water to produce at least an average crop yield goal in a normal year. That does not mean these rotations are all created equal, some will produce more income, some will require less input cost, and some will fit your land, equipment, labor, and government program better than others. They need a closer look.

For each field make a table similar to Tables 5 through 7 using the appropriate water holding capacity of the soil and every rotation that is applicable to that soil. For each crop in each rotation calculate the total water available in a normal year. This would be the sum of "crop season water" and the smaller of either "water available for storage" or "available water capacity" (for the soil in this field to normal rooting depth of the crop). The degree to which total water available in a normal year exceeds that required to grow an average crop is your safety factor or insurance. Calculate (using your locally developed crop response equations) the yield you would expect to receive from each crop in a normal year. This will not be the same as "Average crop yield goal" since the amount of soil moisture storage will vary with rotation, stubble height, rotation interval, etc.

This is sufficient data to get you started but a little more information can prove quite valuable. Calculate expected yield for each crop, field, and rotation using 50% and 150% normal precipitation. You must do each component separately since soil moisture storage will be more efficient in a dry year and less efficient in a wet one. Everyone does crop budgets based on an average year, this lets you plan for drought and floods also.

A few examples using diverse rotations and soil types will be made. The rotations are Spring Wheat-Barley, Spring Wheat-Soybeans, Corn-Soybeans, Spring Wheat-Corn-Soybeans, Corn-Barley-Winter Wheat, Corn-Fallow-Winter Wheat, and Spring Wheat-Winter Wheat. The soils are a coarse sand having a water holding capacity of 1 in/ft, three feet deep over gravel, a deep silt loam with a water holding capacity of 1.8 in/ft and a deep silt loam with a water holding capacity of 2.4 in/ft. The sand could provide 3 in. of water for all crops; the first silt loam 5.4 in. to small grain and 7.2 in to corn and soybeans, and the second silt loam 7.2 in to small grain and 9.6 in to corn and soybeans. Spring cereals are seeded April 1, begin using water May 1, and cease water use July 15. Corn and soybeans begin water use June 1 and quit September 1. Winter wheat begins May 1 and ceases use July 1. A brief summary is helpful in making the necessary calculations.

	Rainfall			Snow (water equivalent)		
	Dry	Normal	Wet	Dry	Normal	Wet
July 1-May 1	4.9	9.7	14.6	1.1	2.2	3.3
July 1-June 1	6.3	12.6	18.9	1.1	2.2	3.3
July 15-May 1	4.3	8.5	12.8	1.1	2.2	3.3
July 15-June 1	5.7	11.4	16.1	1.1	2.2	3.3
Sept 1-May 1	2.7	5.3	8.0	1.1	2.2	3.3
Sept 1-June 1	4.1	8.2	12.3	1.1	2.2	3.3

Table 5. CALCULATIONS FOR A SANDY SOIL HAVING A TOTAL AVAILABLE WATER HOLDING CAPACITY OF 1 IN/FT WITH GRAVEL AT 3 FT.

Rotation	Type of Year	Rainfall Since Last Crop	Snow Credit	Total Water Stored	Rain During Season	Total Water	Proj. Yield
Spring Wht	Dry	**4.3**	**1.1**	**3.0**	**4.0**	**7.0**	**18**
	Norm	**8.5**	**1.5**	**3.0**	**7.9**	**10.9**	**27**
	Wet	**12.5**	**1.5**	**3.0**	**11.9**	**14.9**	**37**
Barley	Dry	**4.3**	**1.1**	**3.0**	**4.0**	**7.0**	**32**
	Norm	**8.5**	**1.5**	**3.0**	**7.9**	**10.9**	**50**
	Wet	**12.5**	**1.5**	**3.0**	**11.9**	**14.9**	**69**
Spr. Wht	Dry	**2.7**	**0.4**	**3.0**	**4.0**	**7.0**	**18**
	Norm	**5.3**	**0.4**	**3.0**	**7.9**	**10.9**	**27**
	Wet	**8.0**	**0.4**	**3.0**	**11.9**	**14.9**	**37**
Corn	Dry	**5.7**	**1.1**	**3.0**	**4.1**	**7.1**	**43**
	Norm	**11.4**	**1.5**	**3.0**	**8.1**	**11.1**	**67**

	Wet	17.1	1.5	3.0	12.2	15.2	91
	Dry	4.1	1.1	3.0	4.1	7.1	16
Soybeans	Norm	8.2	2.1	3.0	8.1	11.1	24
	Wet	12.3	2.2	3.0	12.2	15.2	33
	Dry	2.7	0.4	3.0	4.0	6.6	18
Spring Wht	Norm	5.3	0.4	3.0	7.9	10.9	27
	Wet	8.0	0.4	3.0	11.9	14.9	37
	Dry	5.7	1.1	3.0	4.1	7.1	16
Soybeans	Norm	11.4	1.5	3.0	8.1	11.1	24
	Wet	17.1	1.5	3.0	12.2	15.2	33
	Dry	4.1	0.4	3.0	4.1	7.1	43
Corn	Norm	8.2	0.4	3.0	8.1	11.1	67
	Wet	12.3	0.4	3.0	12.2	15.2	91
	Dry	4.1	1.1	3.0	4.1	7.1	16
Soybeans	Norm	8.2	2.1	3.0	8.1	11.1	24
	Wet	12.3	2.2	3.0	12.2	15.2	33

Table 5 Continued. SANDY SOIL

Rotation	**Type of Year**	**Rainfall Since Last Crop**	**Snow Credit**	**Total Water Stored**	**Rain During Season**	**Total Water**	**Proj. Yield**
	Dry	4.9	1.1	3.0	4.0	6.6	17
Spr Wht	Norm	9.7	2.0	3.0	7.9	10.9	27
	Wet	14.6	2.2	3.0	11.9	14.9	37
	Dry	4.3	1.1	3.0	3.3	6.3	20
Winter Wht.	Norm	8.5	1.5	3.0	6.6	9.6	30
	Wet	12.5	1.5	3.0	9.9	12.9	40
	Dry	4.3	1.1	3.0	3.3	6.3	20
Winter Wht	Norm	8.5	1.5	3.0	6.6	9.6	30
	Wet	12.5	1.5	3.0	9.9	12.9	40
	Dry	6.7	1.1	3.0	4.1	7.1	43
Corn	Norm	12.6	2.1	3.0	8.1	11.1	67
	Wet	17.1	2.2	3.0	12.2	15.2	91
	Dry	2.6	1.1	3.0	4.0	6.6	30
Barley	Norm	5.3	2.1	3.0	7.9	10.9	50
	Wet	7.9	3.0	3.0	11.9	14.9	69
	Dry	8.0	0.4	3.0	3.3	6.3	20
Winter Wht	Norm	15.9	0.4	3.0	6.6	9.6	30
	Wet	23.4	0.4	3.0	9.9	12.9	40
	Dry	6.7	1.1	3.0	4.1	7.1	43
Corn	Norm	12.6	2.1	3.0	8.1	11.1	67
	Wet	17.1	2.2	3.0	12.2	15.2	91
Fallow -	**Totals added to Winter Wheat**						

Rainfall since last crop - Total precipitation received as rain (not snow) in the interval between when the previous crop ceased using water and the present crop began using water. One half of November and one half of March precipitation was assumed to be rain, the remainder snow.

Snow Credit - Water equivalent of snow catch calculated assuming 1.5 in of water for each foot of stubble height or total snowfall whichever is less.

Table 6. **CALCULATIONS FOR A SILT LOAM SOIL HAVING AN AVAILABLE WATER HOLDING CAPACITY OF 1.8 IN/FT**

Rotation	Type of Year	Rainfall Since Last Crop	Snow Credit	Total Water Stored	Rain During Season	Total Water	Proj. Yield
Spring Wheat	Dry	4.3	1.1	5.4	4.0	9.4	24
	Norm	8.5	1.5	5.4	7.9	13.3	33
	Wet	12.5	1.5	5.4	11.9	17.3	43
Barley	Dry	4.3	1.1	5.4	4.0	9.4	43
	Norm	8.5	1.5	5.4	7.9	13.3	61
	Wet	12.5	1.5	5.4	11.9	17.3	80
Spring Wheat	Dry	2.7	0.4	3.1	4.0	7.1	18
	Norm	5.3	0.4	5.4	7.9	13.3	33
	Wet	8.0	0.4	5.4	11.9	17.3	43
Corn	Dry	5.7	1.1	6.8	4.1	10.9	65
	Norm	11.4	1.5	7.2	8.1	15.3	92
	Wet	17.1	1.5	7.2	12.2	19.4	116
Soybeans	Dry	4.1	1.1	5.2	4.1	9.3	20
	Norm	8.2	2.1	7.2	8.1	15.3	34
	Wet	12.3	2.2	7.2	12.2	19.4	43
Spring Wheat	Dry	2.7	0.4	3.1	4.0	7.1	18
	Norm	5.3	0.4	5.4	7.9	13.3	33
	Wet	8.0	0.4	5.4	11.9	17.3	43
Soybeans	Dry	6.7	1.1	7.2	4.1	11.3	25
	Norm	11.4	1.5	7.2	8.1	15.3	34
	Wet	17.1	1.5	7.2	12.2	19.4	43
Corn	Dry	4.1	0.4	4.5	4.1	8.6	52
	Norm	8.2	0.4	7.2	8.1	15.3	92
	Wet	12.3	0.4	7.2	12.2	19.4	116
Soybeans	Dry	4.1	1.1	5.2	4.1	9.3	20
	Norm	8.2	2.1	7.2	8.1	15.3	34
	Wet	12.3	2.2	7.2	12.2	19.4	43

Table 6 continued. **SILT LOAM SOIL WITH 1.8 IN/FT WATER HOLDING CAPACITY**

Rotation	Type of Year	Rainfall Since Last Crop	Snow Credit	Total Water Stored	Rain During Season	Total Water	Proj. Yield
	Dry	4.9	1.1	5.4	4.0	9.4	24

Spring Wheat	Norm	9.7	2.0	5.4	7.9	13.3	33
	Wet	14.6	2.2	5.4	11.9	17.3	43
	Dry	4.3	1.1	5.4	3.3	8.7	27
Winter Wheat	Norm	8.5	1.5	5.4	6.6	12.0	37
	Wet	12.5	1.5	5.4	9.9	14.3	44

	Dry	4.3	1.1	5.4	3.3	8.7	27
Winter Wheat	Norm	8.5	1.5	5.4	6.6	12.0	37
	Wet	12.5	1.5	5.4	9.9	14.3	44
	Dry	6.7	1.1	7.2	4.1	11.3	68
Corn	Norm	12.6	2.1	7.2	8.1	15.3	92
	Wet	17.1	2.2	7.2	12.2	19.4	118
	Dry	2.7	1.1	3.8	4.0	7.8	36
Barley	Norm	5.3	2.1	5.4	7.9	13.3	61
	Wet	8.0	3.0	5.4	11.9	17.3	80

	Dry	8.0	0.4	5.4	3.3	8.7	27
Winter Wheat	Norm	15.9	0.4	5.4	6.6	12.0	37
	Wet	23.4	0.4	5.4	9.9	15.3	47
	Dry	6.7	1.1	7.2	4.1	11.3	68
Corn	Norm	12.6	2.1	7.2	8.1	15.3	92
	Wet	17.1	2.2	7.2	12.2	19.4	116

Fallow Totals added to Winter Wheat

Rainfall since last crop - Total precipitation received as rain (not snow) in the interval between when the previous crop ceased using water and the present crop began using water. One half of November and one half of March precipitation was assumed to be rain, the remainder snow.

Snow Credit - Water equivalent of snow catch calculated assuming 1.5 in of water for each foot of stubble height or total snowfall whichever is less.

Table 7. CALCULATIONS FOR A SILT LOAM SOIL HAVING AN AVAILABLE WATER HOLDING CAPACITY OF 2.6 IN/FT

Rotation	Type of Year	Rainfall Since Last Crop	Snow Credit	Total Water Stored	Rain During Season	Total Water	Proj. Yield
	Dry	4.3	1.1	5.4	4.0	9.4	24
Spring Wheat	Norm	8.5	1.5	7.8	7.9	15.7	39
	Wet	12.5	1.5	7.8	11.9	19.7	49
	Dry	4.3	1.1	5.4	4.0	9.4	43
Barley	Norm	8.5	1.5	7.8	7.9	15.7	72
	Wet	12.5	1.5	7.8	11.9	19.7	91

Spring Wheat	Dry	2.7	0.4	3.1	4.0	7.1	18
	Norm	5.3	0.4	5.7	7.9	13.6	34
	Wet	8.0	0.4	7.8	11.9	19.7	49
Corn	Dry	5.7	1.1	6.8	4.1	10.9	65
	Norm	11.4	1.5	10.4	8.1	18.5	111
	Wet	17.1	1.5	10.4	12.2	22.6	136
Soybeans	Dry	4.1	1.1	5.2	4.1	9.3	20
	Norm	8.2	2.1	10.3	8.1	18.4	41
	Wet	12.3	2.2	10.4	12.2	22.6	50

Spring Wheat	Dry	2.7	0.4	3.1	4.0	7.1	18
	Norm	5.3	0.4	5.7	7.9	13.6	34
	Wet	8.0	0.4	7.8	11.9	19.7	49
Soybeans	Dry	6.7	1.1	7.8	4.1	11.9	26
	Norm	11.4	1.5	10.4	8.1	18.5	41
	Wet	17.1	1.5	10.4	12.2	22.6	50

Corn	Dry	4.1	0.4	4.5	4.1	8.6	51
	Norm	8.2	0.4	8.6	8.1	16.7	100
	Wet	12.3	0.4	10.4	12.2	22.6	136
Soybeans	Dry	4.1	1.1	5.2	4.1	9.3	20
	Norm	8.2	2.1	10.3	8.1	18.4	41
	Wet	12.3	2.2	10.4	12.2	22.6	50

Table 7 continued. SILT LOAM SOIL WITH 2.6 IN/FT WATER HOLDING CAPACITY

Rotation	Type of Year	Rainfall Since Last Crop	Snow Credit	Total Water Stored	Rain During Season	Total Water	Proj. Yield
Spring Wheat	Dry	4.9	1.1	6.0	4.0	10.0	25
	Norm	9.7	2.0	7.8	7.9	14.7	37
	Wet	14.6	2.2	7.8	11.9	19.7	49
Winter Wheat	Dry	4.3	1.1	5.4	3.3	8.7	27
	Norm	8.5	1.5	7.8	6.6	14.4	46
	Wet	12.5	1.5	7.8	9.9	17.7	55

Winter Wheat	Dry	4.3	1.1	5.4	3.3	8.7	27
	Norm	8.5	1.5	7.8	6.6	14.4	46
	Wet	12.5	1.5	7.8	9.9	17.7	55
Corn	Dry	6.7	1.1	7.8	4.1	11.9	71
	Norm	12.6	2.1	10.4	8.1	18.5	111
	Wet	17.1	2.2	10.4	12.2	22.6	136

Barley	Dry	2.7	1.1	3.8	4.0	7.8	36
	Norm	5.3	2.1	7.4	7.9	15.3	70
	Wet	8.0	3.0	7.8	11.9	19.7	91
Winter Wheat	Dry	8.0	0.4	7.8	3.3	11.1	34
	Norm	15.9	0.4	7.8	6.6	14.4	45
	Wet	23.4	0.4	7.8	9.9	17.7	55
Corn	Dry	6.7	1.1	7.8	4.1	11.9	71
	Norm	12.6	2.1	10.4	8.1	18.5	111
	Wet	17.1	2.2	10.4	12.2	22.6	136

Fallow Totals added to Winter Wheat

Rainfall since last crop - Total precipitation received as rain (not snow) in the interval between when the previous crop ceased using water and the present crop began using water. One half of November and one half of March precipitation was assumed to be rain, the remainder snow.

Snow Credit - Water equivalent of snow catch calculated assuming 1.5 in of water for each foot of stubble height or total snowfall whichever is less.

Construction of tables such as this represent a substantial amount of work, but they will pay for the time spent many times over. A word of caution should be included here. In calculating predicted yields no attempt has been made to adjust for differences due to disease, weed, or insect pressure, etc. In reality rotations such as the spring wheat-winter wheat combination may exhibit substantially lower yield due to these considerations. In fact, such a rotation probably should not have made the "first cut" when those having potential disease problems were eliminated. It is included to make just such a point later on.

In reviewing the soil moisture data and predicted yields contained in Tables 5-7 several expected and unexpected results occur and points concerning comparisons of no-till and conventional tillage practices need to be made. It is quite evident and expected that the soil's ability to store water is a primary limiting factor to crop yields in normal and wet years even on the soils having an available water holding capacity of 1.8 and 2.6 in/ft. The surprising result of this analysis is that in a good share of the rotations soil water holding capacity is also a primary limiting factor in normal to dry years, especially on the two soils having lower water holding capacity. Most comparisons and evaluations of no-till vs. conventional tillage have been done using rotations common to conventional tillage situations. In many of these rotations there is sufficient water, even in dry years, to allow 2 to 4 inches to be wasted through the use of tillage and still allow the soil to be full at seeding time. Unless these trials are done on sites having sufficient slope and for a long enough period of time to allow runoff to play a role, very little difference in yield would be expected. Most research to date has been done on relatively level ground for periods of only a few years. This can be likened to comparing the ability of a world class weightlifter and the local banker by having them lift a 20 pound barbell. There would be no significant differences found. If the contest were made more challenging by increasing the weight 20 fold; the differences become evident. The above analysis and actual results from Redfield (to be shown later) demonstrate that high water use rotations such as corn-soybeans can be successfully and profitably grown no-till in an environment where they are not considered a viable options for conventional tillage systems.

The last remarks to be made about water deal with a subject that has only recently surfaced to any great extent in North America, earthworms. No attempt was made in calculating water relation data to adjust for runoff losses. The reason for this is quite simple. In the Redfield environment several years of continuous no-till leads to a tremendous increase in earthworm activity in the soil. The burrows which they form have increased the infiltration capacity of these "tight" soils to the point that they will not produce any runoff even if 6 inches of rain is received in 15 minutes. They will take 40 inches of rain in 3 hours also with no runoff. If any tillage is performed that cuts these burrows the soil can only accept about 2 inches of water in a three hour period. It is obvious that as long as no tillage is performed, runoff is no longer a factor that needs to be considered. Dr. Bill Edwards who works with runoff and erosion for the USDA-ARS has produced dramatic and well documented data demonstrating similar effects where runoff was eliminated from a no-till field planted on a slope of greater than 20% that produces no runoff in a 40 inch per year rainfall area.

Most of the work with earthworms and their effects on the soil has been done in Europe, Australia, and New Zealand. It indicates that an active population of earthworms not only increases water infiltration rates, but also incorporates residue and fertilizers into the soil. They are mother nature's plow according to Charles Darwin who wrote a book on earthworms. There is also an indication that they can improve soil aeration, and increase the available water holding capacity of a soil by at least 30%. After reviewing this literature it is of little surprise that many researchers and producers have been finding increased advantages and decreasing management problems with no-till as the number of years the system has been used increases. The experience at Redfield indicates that the problems of saturated surface soils at seeding time, often cited as a primary problem for no-till, occurs only until sufficient macropore are present to move excess water deeper into the soil where it is protected from evaporative losses and does not interfere with field operations. Excessively heavy residue and the resulting allelopathic effects it can have are also reduced after a period of years. It is felt that the positive effects of earthworms may be one of the most important keys to successful no-till programs. Consequently a graduate research assistant has been assigned to evaluate some of the factors affecting present earthworm populations in both no-till and conventionally tilled fields and developing ways to introduce them in situations where they have not occurred previously or have been eliminated by numerous years of tillage.

The common misconception that inorganic fertilizers and herbicides kill earthworms is not substantiated in the research that has been done. Inorganic fertilizers increase earthworm populations. Farmyard manure has a greater positive effect since it has both plant residues and nutrients. Herbicides in general have no negative effect. Certain insecticides, fungicides, and soil fumigants are toxic to earthworms. One of the biggest detriments to surface feeding species is tillage which disturbs there burrows, buries their food, and exposes the soil to wider fluctuations in moisture and temperature. This fact was easily demonstrated to interested visitors at Redfield by easily digging hundreds of worms in the no-till herbicide demonstration plots and subsequently being unable to fund any in an adjacent conventionally tilled field.

The single most important factor involving earthworms for producers on the prairies is their ability to eliminate runoff. Close behind however is the less well documented potential they have for increasing available soil water holding capacity by 30% or more. The effect this will have on yield can easily be demonstrated by adjusting the soil water column in Tables 5-7 upward then recalculating yields. In all but the driest years yields will be increased substantially.

One calculation that is valuable for evaluating rotations will be called Precipitation Use Efficiency. This number is obtained by expressing the Total Water Available as a percentage of Total Precipitation. It is a way of comparing soils and rotations for their ability to use the most valuable commodity on the prairies (or the buffalo commons), moisture. Calculations for the soils and rotations in Tables 5-7 are listed in Table 8.

TABLE 8: PRECIPITATION USE EFFICIENCY OF VARIOUS ROTATIONS
Redfield, South Dakota

Rotation	Total Precip. Received		Percent of Precipitation Used		
			Sandy 1 in/ft	Silt Loam 1.8 in/ft	Silt Loam 2.6 in/ft
Spring Wheat	Dry	9.3	75	100	100
	Norm	8.5	59	72	85
	Wet	27.8	54	62	71
Barley	Dry	9.3	75	100	100
	Norm	18.5	59	72	85
	Wet	27.8	54	62	71

Spring Wheat	Dry	7.6	92	93	93
	Norm	15.2	72	88	89
	Wet	22.8	65	76	86
Corn	Dry	10.8	66	100	100
	Norm	21.5	56	71	86
	Wet	32.3	47	60	70
Soybeans	Dry	9.3	76	100	100
	Norm	18.5	60	83	100
	Wet	27.8	55	70	81

Spring Wheat	Dry	7.6	89	93	93
	Norm	15.2	73	88	89
	Wet	22.8	65	76	86
Soybeans	Dry	10.8	66	100	100
	Norm	21.5	52	71	86
	Wet	32.3	47	60	70

TABLE 8: continued PRECIPITATION EFFICIENCY

Rotation		Total Precip. Received	Percent of Precipitation Used Sandy 1 in/ft	Silt Loam 1.8 in/ft	Silt Loam 2.6 in/ft
Corn	Dry	9.3	75	92	92
	Norm	18.5	60	83	90
	Wet	27.8	55	70	81
Soybeans	Dry	9.3	75	92	100
	Norm	18.5	60	83	100
	Wet	27.8	55	70	81

Spring Wheat	Dry	9.9	67	95	100
	Norm	19.8	55	67	74
	Wet	29.7	50	58	66
Winter Wheat	Dry	8.6	73	100	100
	Norm	17.2	56	70	84
	Wet	25.8	50	55	69

Winter Wheat	Dry	8.6	73	100	100
	Norm	17.2	56	70	84
	Wet	25.8	50	55	69
	Dry	11.5	62	100	100

Corn	Norm	22.9	48	67	81
	Wet	34.4	44	56	66
	Dry	7.6	87	100	100
Barley	Norm	15.2	72	88	100
	Wet	22.8	65	76	86

	Dry	16.2	39	54	69
Winter Wheat	Norm	32.4	30	37	44
	Wet	48.6	27	31	36
	Dry	11.5	62	100	100
Corn	Norm	22.9	48	88	81
	Wet	34.4	44	76	66

Fallow Totals added to Winter Wheat

Precipitation use efficiency indicates how completely the resource is being used. The higher the numbers the better job is being done to use what falls. The lower numbers indicate where waste occurs. For any given soil type the lower numbers also indicate safer rotations from the standpoint of dry years. It is obvious that increased efficiency occurs whenever the available water holding capacity of a soil in increased in normal to wet years. These data also demonstrate the tremendous inefficiency associated with several common conventional tillage rotations, especially those involving fallow. A strictly small grain-fallow rotation common in many areas would be even more inefficient than the one included which contains a high water use crop prior to the fallow.

Using the water data generated for each field or soil type and each potential rotation, eliminate those that do not work or pose too great of a risk for your operation. There will probably still be several rotations that are applicable to each field so more thinning will be necessary.

WEED CONTROL

The next aspect affected by rotation is weed control. Just as crops have different growth habits, likes, and dislikes; so do weeds. Seeding a spring small grain crop year after year is destined to produce a wild oat and pigeon grass (wild millet) problem sooner or later. Likewise seeding winter wheat year after year, even if separated by a fallow, leads to a downy brome (cheatgrass) infestation. Every crop rotation, especially those done no-till, should contain a good diversity of crop types to prevent the favoring of heavy weed infestations. That is a given that has been discussed earlier. The next step in choosing a particular rotation for each field or set of fields is to utilize what you know about the weed pressure that exists now and was present in the past. Certain of the rotations will be able to "clean up the mess" more cheaply and easily than others. However, this does not mean that the bottom line will be better; just that management will be easier. If you are switching from conventional tillage to no-till, expect a shift in weed pressure with large seeded weeds (sunflower, cocklebur, etc) being less adapted to no-till environments and small seeded weeds still capable of growing.

Evaluate the proposed rotations for each field. Is there a herbicide program available for the crops in the rotation that will effectively control the weeds present without carrying over to injure subsequent crops in the rotation. If not, it is best to eliminate that rotation from consideration. This is a fairly complex decision and may again involve consultation with the extension service or private consultants.

Now believe it or not the job becomes more complex. From a weed control perspective it is important to not only rotate crops but also rotate the types of herbicides used. Use of some herbicides which have the same or similar modes of action year after year can lead to development of weed biotypes with substantial tolerance to herbicides from that family. This does not appear to be true for all herbicide families but is for some compounds. It used to be that simply rotating crops assured that the herbicides used would differ in mode of action. This is no longer true. The selling of the same herbicide under a different name depending on whether it is to be used in small grain or soybeans makes it extremely difficult to keep on top of this and other concerns. Perhaps the best way to handle this is to outline several complete weed control programs for each rotation based on field histories, good no-till weed research information, and your experience. If faced with a decision between an herbicide more effective on large seeded weeds and one with more activity on small seeded weeds, choose the one active on the small seeded weeds. Have these evaluated by someone who is familiar with your area and the properties of the herbicides you wish to use. Also determine the cost of each program and evaluate spraying times for the degree to which they interfere with other farming operations.

A brief explanation of programs used at Redfield may be helpful. Two types of programs are utilized in the no-till systems: postemergence sprays, and early preplant soil applied applications. Rainfall is too sporadic to make planting time applications work consistently. It is also important to devote the limited amount of machinery and labor available to seeding when the time is right and handle spraying duties before and after seeding. Post emergence sprays are used predominantly on crops seeded in the fall or early spring, since these can be completed before the weather becomes hot and dry enough to substantially reduce the effectiveness of the postemergence sprays. Chemicals that allow treatment at very early stages of plant development are chosen for this reason and also to eliminate the need for a burndown spray at planting. For instance, small grains are seeded as early as possible usually before weed growth has begun (a light rate of 2,4-D was used in the fall if winter annual broadleaf weeds were present in the stubble). The small grain and common early weeds such and kochia and russian thistle, gained from the neighbors, emerge at the same time. A single spray of bromoxynil + MCPA is usually all that is required. A postemergence grass herbicide could be included if necessary.

Late seeded spring crops normally receive early preplant applications of residual soil active herbicides. These are applied either early in the spring, or late in the fall, depending on the longevity of the herbicide, its solubility, and the label. Early preplant programs improve the consistency of soil applied herbicides by increasing the time available for activation moisture to occur. In many ways they have the advantages of PPI (preplant incorporated) programs without the tillage. Think of it as incorporating with time instead of tillage. Herbicides which are root active and/or are taken up by the roots for action elsewhere are preferred; especially when residue is coarse textured. Shoot inhibiting herbicides can be used where residue is light or fine. Some early preplant programs work better if one-half to two-thirds of the chemical is applied early and the remainder before the crop emerges. Proper early preplant programs eliminate the need for burndown treatments at planting (saving both time and money) and shift spraying times to less busy periods. Herbicide programs used on the seven rotations listed previously are included in Table 9. The approaches used allow rotation of chemicals, and also rotation of application method with chemicals having similar modes of action since some weed species may be tolerant to one application method or the other but not both.

It is interesting to note that with the programs used at Redfield, in most cases, no more herbicide is used than is common in conventional tillage systems. The exception is the one to two low rate sprays of glyphosate plus 2,4-D following small grain harvest.

TABLE 9: HERBICIDE PROGRAMS FOR NO-TILL ROTATIONS
Redfield, South Dakota

	Herbicide	Active lb/a	Spraying Time
Spring Wheat	Harmony (M6316)	0.03	May 1
	Landmaster (Glyphosate+2,4-D)	0.2 + 0.5	August 10
Barley	Bronate (bromoxynil+MCPA)	0.3 + 0.3	May 1
	Landmaster (Glyphosate+2,4-D)	0.2 + 0.5	August 10

Spring Wheat	Bronate (bromoxynil+MCPA)	0.3 + 0.3	May 1
	Landmaster (Glyphosate+2,4-D)	0.2 + 0.5	August 10
	Plus Atrazine (1.0 lb ai)	1.0	
Corn	Bladex + Dual		March 25
	(cyanozine+metalochlor)	1.3 + 1.6	
	Bladex + Dual	0.7 + 0.9	May 10
Soybeans	Pursuit (Imazethapyr)	0.07	March 25

Spring Wheat	Bronate (bromoxynil+MCPA)	0.3 + 0.3	May 15
	Landmaster (Glyphosate+2,4-D)	0.2 + 0.5	August 10
Soybeans	Pursuit	0.07	March 25

Corn	Bladex + Dual		March 25
	(Cyanazine + Metolachlor)	2.0 + 1.6	
	Bladex + Dual	1.0 + 0.9	May 10
Soybeans	Pursuit (Imazethapyr)	0.07	March 25

TABLE 9: (continued) HERBICIDE PROGRAMS FOR NO-TILL ROTATIONS
Redfield, South Dakota

	Herbicide	Active lb/a	Spraying Time
Spring Wheat	Harmony	0.03	May 15
	Landmaster (Glyphosate+2,4-D)	0.2 + 0.5	August 10
	Roundup	0.2	Sept 20
Winter Wheat	Bronate (bromoxynil + MCPA)	0.3 + 0.3	April 25
	Landmaster (Glyphosate+2,4-D)	0.2 + 0.5	August 1
	Roundup + Banvel		
	(glyphosate + dicamba)	0.2 + 0.3	Oct. 1

Winter Wheat	Bronate (bromoxynil + MCPA)	0.3 + 0.3	April 25
	Landmaster + 0.75 Atrazine		August 1
	(Glyphosate + 2,4-D + Atrazine)	0.2 + 0.5 + 0.8	
Corn	Bladex + Dual	1.4 + 1.6	March 25
	Bladex + Dual	0.6 + 0.9	May 10
Barley	Harmony	0.03	May 15
	Landmaster	0.2 + 0.5	August 10
	Roundup	0.3	September 10

Winter Wheat	Bronate Landmaster + 2.0 Atrazine		0.3 + 0.3 0.2 + 0.5 + 2.0	April 25 August 1
Corn	Bladex + Dual		1.0 + 2.5	March 25
Fallow	Landmaster	J	0.2 + 0.5	June 20
	Landmaster		0.2 + 0.5	August 5
	Roundup		0.3	Sept 10

A spray of 2,4-D and Banvel are used in late September or early October on perennial weed patches and to control winter annual broadleaf weeds if present.

A spray of 6 oz/acre of glyphosate is used to control volunteer cereals in late august or early September.

INSECTS AND DISEASES

Properly planned crop rotations will experience little disease pressure. The exception to this includes pressure to small grain from the leaf spotting diseases (tan spot, septoria) where shorter than desired rotation intervals or unfavorable weather occur. It is much better to avoid than to treat the problem, but the tools available to deal with leaf spotting disease are quite good. They have never been required at Redfield.

Many insect and insect related disease problems can be controlled through proper rotation and sanitation. Corn rootworm in corn is controlled by varied rotations to other crops. Insect related disease problems such as wheat streak mosaic and barley yellow dwarf are controlled by keeping stubble free of volunteer grain and planting winter grains late. Insect problems such as the flea beetle of canola, the Russian wheat aphid on small grain, seed weevils in sunflower, and corn borer in corn do not lend themselves to being solved by rotation alone, but the severity of infestation can be affected by rotation and other management factors such as planting date, control of volunteer grain, etc. A good field scouting program and when necessary the use of insecticides that are not toxic to earthworms can control the few problems with insects that arise.

KICKING THE TIRES

It is now time to see how the predictions about rotation response work in the real world. This is done using a No-Till Crop Rotation Study which is being jointly supported by the South Dakota Wheat Commission and The SDSU Ag. Experiment Station. This study, which is located 5 miles east of Redfield on the north side of highway 212, covers an L shaped 80 acres of land. Everything at the site is done no-till, meaning only a drill, a sprayer, and a combine are used for all field operations. The seven different crop rotations mentioned earlier are being tested. Each rotation is replicated 4 times in different parts of the field. This results in plots which are just slightly less than one acre in size. All field operations are performed with standard sized equipment.

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

This 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.

Present plans call for the experiment to continue for at least 5 more years in order to complete two full repetitions of the three crop rotations.

Table 10. YIELD FOR THE NO-TILL ROTATION STUDY-REDFIELD 1988-1989
(WATER HOLDING CAPACITY OF 2.6 IN/FT USED)

Rotation	Year	Rainfall Since Last Crop	Snow Credit	Total Water Stored	Rain During Season	Total Water	Actual Yield
Spring Wheat	1988	5.5	0.9	6.4	5.4	11.8	28
	1989	11.8	1.5	7.8	3.9	11.7	35
	NORM	8.5	1.5	7.8	7.9	15.7	39
Barley	1988	5.5	0.9	6.4	5.4	11.8	51
	1989	11.8	1.5	7.8	3.9	11.7	71
	NORM	8.5	1.5	7.8	7.9	15.7	72
Spring Wheat	1988	3.4	0.4	3.8	5.4	9.2	24
	1989	7.5	0.4	7.8	3.9	11.7	30
	NORM	8.5	1.5	7.8	7.9	15.7	39
Corn	1988	9.0	0.9	9.9	6.0	15.9	67
	1989	11.8	1.5	10.4	4.8	15.2	92
	NORM	11.4	1.5	10.4	8.1	18.5	111
Soybeans	1988	7.1	0.9	8.0	6.0	14.0	25
	1989	7.5	2.1	9.6	4.8	14.4	29
	NORM	8.2	2.1	10.3	8.1	18.4	41
Spring Wheat	1988	3.4	0.4	3.8	5.4	9.2	24
	1989	7.5	0.4	7.8	3.9	11.7	30
	NORM	8.5	1.5	7.8	7.9	15.7	39
Soybeans	1988	9.0	0.9	9.9	6.0	15.9	31
	1989	11.8	1.5	10.4	4.8	15.2	33
	NORM	11.4	1.5	10.4	8.1	18.5	41
Corn	1988	7.1	0.4	7.5	6.0	13.5	66
	1989	7.5	0.4	7.9	4.8	12.7	79
	NORM	8.2	0.4	8.6	8.1	16.7	100
Soybeans	1988	7.1	0.9	8.0	6.0	14.0	25
	1989	7.5	2.1	9.6	4.8	14.4	29
	NORM	8.2	2.1	10.3	8.1	18.4	41

Table 10 continued. NO-TILL ROTATION STUDY 1988-89, Redfield

	Type	Rainfall	Snow	Total	Rain	Total	Actual

Rotation	of Year	Since Last Crop	Credit	Water Stored	During Season	Water	Yield
Spring Wheat	1988	7.8	0.9	7.8	5.4	13.2	18
	1989	12.4	2.0	7.8	3.9	11.7	31
	NORM	9.7	2.0	7.8	7.9	14.7	37
Winter Wheat	1988	5.5	0.9	6.4	4.8	11.2	32
	1989	11.8	1.5	7.8	3.2	11.0	44
	NORM	8.5	1.5	7.8	6.6	14.4	46
Winter Wheat	1988	5.5	0.9	6.4	4.8	11.2	31
	1989	11.8	1.5	7.8	3.2	11.0	53
	NORM	8.5	1.5	7.8	6.6	14.4	46
Corn	1988	10.2	0.9	10.4	6.0	16.4	67
	1989	13.5	2.1	10.4	4.8	15.2	92
	NORM	12.6	2.1	10.4	8.1	18.5	111
Barley	1988	3.4	0.9	4.3	5.4	9.7	39
	1989	7.5	2.6	7.8	3.9	11.7	48
	NORM	8.5	2.2	7.8	7.9	15.7	72
Winter Wheat	1988	15.2	0.4	7.8	4.8	12.6	40
	1989	25.8	0.4	7.8	3.2	11.0	53
	NORM	27.1	1.5	7.8	6.6	14.4	46
Corn	1988	10.2	0.9	10.4	6.0	16.4	67
	1989	13.5	2.1	10.4	4.8	15.2	95
	NORM	12.6	2.1	10.4	8.1	18.5	111
Fallow	Totals added to Winter Wheat						

Table 10 presents the actual precipitation received and the yields recorded for the No-Till Rotation Study during 1988 and 1989. Almost all rotations produced yields at least equivalent to what would be expected given the amount of precipitation received. The exceptions occur in the Spring Wheat-Winter Wheat rotation which exhibits lower yields than those where spring wheat or winter wheat follow barley. Corn yields in 1988 were lower than expected, and much lower than 1989 yields. The hybrid used in 1988 had a black layer date too late for this application. Differences in moisture due to rotation were expressed as expected all other instances. Soybeans and corn yielded -better after wheat than when following row crops. Barley yielded better after wheat than when corn was the preceding crop; just as spring wheat benefited from increased moisture following barley as compared to soybeans. Just as importantly, it appears the water summaries would have predicted a yield increase on fallow in 1988 but not in 1989. This is exactly what happened.

Yields were better overall in 1989 although available water data would not have predicted that to be true. There are numerous reasons that could be brought forth to explain this. One of the primary ones probably is the severe heat that occurred during May and June of 1988 while temperatures in 1989 where near normal. Several days in May and June of 1988 exceeded 100 degrees F. (38 C). This type of heat stress reduces water use efficiency. The other factor that differs between 1988 and 1989 is that there was more water available for storage in 1989. The soil may be doing a better job of storing water than the 2.6 in/ft used in the calculations, or the plants may be reaching deeper than the 3 and 4 feet assumptions made. It seems evident that winter wheat in 1989 went deeper than 3 foot for sure. It will be exciting to track this study through several more years of results.

Table 11: Temperature Data for The James Valley Research Center Redfield, South Dakota

Growing Season Mean Temperatures in Degrees Fahrenheit

	Long Term	1932	1933	1934	1987	1988	1989
May	57.4	61.4	57.3	70.1	62.2	63.1	57.6
June	67.2	70.8	78.6	71.8	70.7	75.7	63.0
July	73.5	76.3	76.3	78.0	76.0	75.9	75.6
Aug.	71.6	73.4	70.8	72.0	68.9	73.1	
Sept.	61.4	61.9	67.6	56.7	61.6	60.1	
Oct	48.9	45.1	47.8	53.8	43.4	44.3	

DOLLARS AND SENSE

It is finally time to make the most important point about crop rotation: in order for it to work for you it has to produce a reasonable profit. With this in mind the No-Till Rotation Study was designed to allow inputs to change as warranted by the environment, crop prices etc. Each rotation is managed with the goal of maximizing profit. Like most farmers no input is used unless it will pay for itself. The costs associated with each rotation are calculated based on actual land rent ($ 30/acre), the prices paid for inputs such as seed, fertilizer, ag. chemicals, etc.; and normalized custom rates for seeding, spraying, harvesting, drying, transportation, etc. Income is calculated using the price being paid by the local elevator for each crop on the day it is harvested. No government program benefits are included. This is a NON-PROGRAM operation. Use of the methods cited above will underestimate the amount of profit a producer should be able to realize under similar circumstances.

TABLE 12: NO-TILL ROTATIONS-AVERAGE RETURN 1988 AND 1989

NET PROFIT OR (LOSS) IN DOLLARS/ACRE

	Rotation Number						
	1	2	3	4	5	6	7
Corn		38			33	50	37
Soybeans	105	68					73
Barley			8		(16)		
Spring Wheat	13	20	18	(10)			
Fallow						(48)	
Winter Wheat				32	44	67	
Net Profit or (Loss)	**59**	**42**	**13**	**11**	**20**	**23**	**55**

The profitability table produces a few surprises. When the study began it was thought that the Soybeans-Spring Wheat rotation would be good from a profitability standpoint. Both crops are high value, the soybeans furnish part of the nitrogen required by the wheat crop and alternating a grass and a legume allows good weed control. It is surprising that it was the most profitable rotation in 1988 and second in 1989 in light of the substantially below normal rainfall that occurred. More astonishing, however is the rotation that finished second in 1988 and led the pack in 1989: Corn-Soybeans. The James River Valley is not exactly what everyone has in mind when they think of the corn belt. It is quite evident that the tremendous moisture saving benefits of no-till allow this system to work where a few years ago it would

have been considered impossible. Although the most profitable so far it is possible that these two rotations have rotation intervals which are too short. In that case the third most profitable rotation may become more important as time goes on. It contains Spring Wheat-Corn-Soybeans. The other four rotations proved to be profitable in 1989 but all except the Corn-Fallow-Winter Wheat rotation lost money in 1988 (it made $6/acre).
The profitability of rotations involving soybeans should become even better in normal and wet years because they do a better job of utilizing the moisture resources available.

You have or can find the information needed to calculate costs and potential returns of almost any rotation you can imagine. Don't sell yourself short by not considering some "wild" alternatives. Try to fit them into your acreage, labor, marketing, and machinery plan. Remember utilizing mostly crops that have similar seeding times or harvesting times will either require larger machinery or delay field operations past optimum. One rotation may return more gross but require more expenditures. Keep you eye on the net return. These decisions you must make, but hopefully you now have better information on the processes involved in planning the production part of successful no-till rotations.

SUMMARY

The bottom line is:

No-till allows utilization of rotations not possible without it and precludes many rotations commonly used in conventional tillage systems.

That thought should be uppermost in your mind as you make your plans.