# Managing Agricultural Ecosystems

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I was originally asked to address the question "Are crop rotations important in light of present farming practices and technology?". My first instinct was to turn in an abstract and a proceedings document that both contained one word: YES. Once I decided to take a more comprehensive route the issue became one of trying to limit the amount of content. Crop rotation design is just one tool that is used in trying to manage an ecosystem and ecosystem processes. If the farmer does not mimic the water, energy, and mineral cycle of the native system, degradation is a consequence. Natural systems tend to maximize the amount of sunlight that is harvested. They also tend to maximize the number of species present (species entropy) when they are not subjected to dramatic outside forces. They also do not leak nutrients. If they do, they turn into deserts. Almost all of the agronomic problems we face (weeds, diseases, insects, fertility, etc.) can be traced to problems with ecosystem processes.

Many common agricultural practices are designed to create dramatic disturbances that will allow simplification of the ecosystem. Tillage is one of these practices. Recognition of the destructive impacts of tillage on soil and water (both on and off site) has led to the development of practices that are now lumped under the term "Conservation Farming". This refers to soil and water conservation. In reality, soil and water conservation is part of what needs to be done in order for agriculture to be a renewable industry rather than (as it predominately is now) an extractive industry such as mining, petroleum, etc. Conserving soil and water resources should be a primary goal for every producer. However, the present economic system does not directly reward a farmer for conserving the soil and water with which he works. In fact with numerous "conservation farming" techniques the opposite occurs. The producer is often faced with the decision whether to conserve the resource or maximize profit. If he doesn't do the latter, someone else will be farming his land in the future; mining the soil that he conserved. For this reason, conservation **cannot be the only goal**. Maximizing short-term profitability also cannot be the only goal if a producer hopes to remain (or have his family remain) on the land he farms.

The Dakota Lakes Research Farm has both a research and a production enterprise. The production enterprise must produce sufficient profits to fund a majority of the operational expenses of the research enterprise. For this reason, the first priority of the production enterprise is to be profitable.

This dual enterprise structure was established in 1983 in an attempt to provide an independent source of funding that was less prone to influence by special interests and politics. This required substantial change in what was then a conventional tillage based research operation. Substantial expansion in the amount of land managed was required to provide a sufficient base to operate both a production and a research enterprise. If conventional farming practices were to be used on both the production and research enterprises a large investment in machinery and manpower would be required. This did not appear to be a prudent course. Consequently, it was decided that the production enterprise would be designed to utilize the manpower available and require only minimal investment in new machinery. The plan was to accomplish this through the use of diverse crop rotations. Weak-link analysis indicated that moisture would be a limiting factor for many of the potential rotational crops. Consequently, a key component of this plan was adoption of moisture conserving practices to allow growing of high water use crops in a region where their production was marginal with conventional tillage.

A holistic or systems approach was taken. This meant that component and technique choices were based on evaluation of how that choice would impact other components in the system. It was evident that (in 1983) there was not an adequate amount of knowledge available on the type of farming system needed for this situation. This meant that many of the component choices required to build the system could not be based directly on research data or producer's experience as is commonly done in agriculture. Consequently, many choices were based on fundamental agronomic and ecological principles using natural cycles and native vegetation as a guide. Research projects were initiated concurrently to better define components and techniques for areas where knowledge was lacking.

The present operation at the Dakota Lakes Research Farm is substantially different than what was begun in 1983. Only part of this difference is due to technological changes that have occurred in the last 30 years. A majority of the difference stems from developing a better understanding of what happens when crops are grown in a manner that places heavy emphasis on developing a healthy and biologically active soil ecology and uses cultural practices (rotation, sanitation, competition) as the primary methods of pest control.

An example of this philosophy sees weed problems as a symptom that the farming system does not contain sufficient diversity (the weed is Mother Nature's way of trying to add diversity). With conventional thinking attempts would be made to control this weed with herbicides or tillage. The systems approach adds a crop to provide the diversity that was lacking. With this philosophy, attempts are made at preventing problems by addressing the cause rather than merely treating the symptoms as they appear.

Many of the farmer practitioners of the Dakota Lakes technique refer to accepting this approach as having a "brain transplant" since it requires developing new skills and a different attitude. Most important among these is the need to realize that to be sustainable and profitable on a long-term basis the farming system must be designed such that natural cycles and principles become an ally rather than an enemy. Inputs such as fertilizers or pesticides then become methods to augment or initiate natural cycles rather than being tools designed to stop processes that are natural.

Tillage selection is a primary example of this different approach. In natural systems, **tillage is a catastrophic event** (associated with glaciers, erosion, volcanoes, etc.) that occurs only rarely. Both macro and micro fauna are profoundly impacted. Soil dwelling species are disrupted to an even greater degree than those that can migrate to more suitable habitat. With frequent and repeated tillage, the soil ecology becomes predominated by species that require tillage in order for residue and nutrient cycling to occur. Since tillage generally occurs prior to plant growth being initiated, nutrients have been placed in a mobile form before they are needed, making them vulnerable to loss. If tillage is not performed, lack of aeration (caused by the poor soil structure that results from repeated tillage) causes nutrient cycling and crop growth problems. In undisturbed natural systems, nutrients and residues are cycled by a complex web of macro (grazing animals, earthworms, mites, spring tails, etc.) and micro (fungi, VAM, bacteria) fauna. In this system, residues are maintained to protect the soil until new plant growth occurs. Canopy conditions created by this new growth allow residue decomposition rates to accelerate. This residue decomposition releases nutrients for use by the subsequent crop when they are needed. If this system were not properly balanced, the prairies of North America would either be desserts or hay stacks. In farming systems designed to mimic undisturbed natural systems, fertilizers are utilized to replace nutrients exported from the system and are applied in a manner to provide an early competitive advantage to the crop that is to be harvested.

This complex web does not reappear quickly when a soil that has been tilled for a number of years is managed without tillage. The soil structure and organic matter lost during the tillage period does not reappear quickly either. For this reason, initiating low-disturbance techniques requires careful planning in regard to how the transition can be made without sacrificing short-term profitability. Many of the struggles and failures associated with producers adopting low disturbance methods traces to inadequately addressing this issue.

Similar analysis can be performed in relation to the impact tillage choice will have on weed pressure, insects, diseases, etc. Nutrient and residue cycling was chosen to provide an example of the thought processes involved.

The Dakota Lakes Research Farm did not initially choose to use reduced tillage techniques because of the soil and water conservation benefits; or due to the fact that soil health and nutrient cycling would be improved; or for wildlife benefits; or for carbon sequestration potential; or any of the other benefits brought to light in the last 10 to 20 years. The decision was made on the basis of the potentially improved profitability that the moisture conservation and workload spreading characteristics provided. The ultra-low disturbance, diverse crop rotations system that has evolved also owes much to the desire to maximize the utilization efficiency of manpower and machinery resources. It has also resulted in lower pesticide use and higher yield levels than anticipated. It is believed that much of this is due to a better understanding of the use of natural cycles. It is also quite possible that soil health and soil ecology play a much greater role than has been realized in the past.

It is almost certain that no producer will utilize exactly the same system components used at the Dakota Lakes Research Farm. Their physical (soil, climate, etc.) and fiscal (machinery, capital, manpower) resources differ from ours. Their choice of components should reflect these differences. The fact that the basic laws of nature function the same independent of these differences does indicate that the "SYSTEMS" approach successfully used at the Dakota Lakes Research Farm (and more importantly by producers in other parts of the world) may provide insight in potential approaches to be used in developing improved farming systems.

**Customizing the "SYSTEM"**

The Dakota Lakes Research Farm enterprise presents a good example of how basic principles are used to create systems suited to differing physical resources. At the present time, the operation manages slightly und er 900 acres of land. Some of this land is classed as a short-grass prairie due to the fact that it has shallow clay soils that limit available water holding capacity. Some of the land is short-grass prairie because of sandy soils that limit available water holding capacity. Some land is classed as mixed-grass prairie because the soils have good water holding characteristics. Some of the land is irrigated. This removes water availability as a primary constraint. Some land is close to the headquarters. Other land is located a substantial distance from the headquarters. Some of the land had a history of over 50 years of wheat-fallow management with tillage; some had never been tilled (it was brought into production from native sod without tillage). It would be unwise to attempt to manage each of these situations with the same components. They are, however, all managed using the same approach to create a system designed to optimize the contribution that particular property makes to the operation. This approach is based on the application of fundamental agronomic and biological principles. **These principles do not change**.

One of these basic principles is that water utilization intensity must be **proper**. In other words the water use must match the water available. If the system is not sufficiently intense problems such as water logging, saline seep formation, nutrient loss, traffic ability problems, etc. are common. If the system is too intense, poor yields due to water stress or stand establishment problems are likely. Under irrigated conditions at Dakota Lakes the intensity of water use is limited only by the amount of growing season and heat received in the summer and by the availability of capital, manpower, and equipment to pump water from the Missouri River when it is needed. The choice to limit intensity under irrigation therefore is based on fiscal (manpower, equipment costs, energy) resources. On the dryland portion of the operation, intensity of water use is controlled by physical resources (soil type, rainfall, climate, etc.). In both cases, improper intensity results in management problems and less than optimum profitability. No-till management allows (requires) more water use by the crop (transpiration) since less water will be wasted by the direct and indirect impacts of tillage (evaporation and runoff).

Another basic principle is that diversity must be **adequate (appropriate)**. As mentioned before, lack of diversity provides an opportunity for weed and disease organisms to build to harmful levels. The cost of controlling these opportunistic species and the capability to do so needs to be evaluated in each situation as it compares to what can be accomplished by using more diverse crop rotations. Under irrigated conditions at the Dakota Lakes Research Farm, corn (field and popcorn) and beans (edible and soybean) are the crops capable of returning the most increase in yields from the fixed costs associated with the irrigation development. If all acres were devoted only to these crops much of this increase would be offset by increased variable costs (pesticides), reduced efficiency in use of fixed machinery resources, and reduced yields. In addition, energy costs would rise on both a per acre and per unit of production basis. Some of this is caused by lower yields but most is due to a reduction in electricity price if the supplier is allowed to control (turn off) the irrigation pumps during periods of peak electrical demand. By devoting part of the acreage to rotational crops which do not share the same peak water use characteristics as corn and beans this can be done without limiting the ability to supply all crops with their full water needs. Consequently, on the irrigated portion of the operation, adding diversity has more impact in reducing variable costs than on reducing fixed costs although both are benefited. Conversely, on the dryland portion of the operation adding diversity provides the most benefit to reducing fixed costs (land, family labor, and machinery) per unit of production (not necessarily per acre). Variable costs are also reduced dramatically (especially pesticide inputs) once the system is in place and working properly. This may not be true during transition periods. Seed and fertilizer costs change very little on a per unit of production basis.

The bottom line of this approach is to view each farming operation as unique. The goal is to optimize the utilization of the resources (land, labor, capital, and machinery) available to that operation in a profitable and environmentally compatible manner. This requires devising a unique system for each operation, owner, parcel of land (and even portions of a piece of property), etc. rather than attempting to devise a farming recipe that fits all fields of all producers in all situations.

**Common Characteristics**

This is not meant to imply that there are no common characteristics amongst the most successful no-till systems being used at Dakota Lakes and by real producers throughout the plains and prairies. Foremost among these is the inclusion of three or four crop types (cool-season grass, cool-season broadleaf, warm-season grass, and warm-season broadleaf) in the rotations used. Where cool-season crops are traditionally grown, addition of the warm-season grass component provides more benefit (adds more diversity) that adding a warm-season broadleaf because of the commonality of some diseases (such as white mold) and herbicide programs among warm and cool-season broadleaf crops. Rotations that are not consistent in terms of either **interval or sequence** provide the best protection against species shifts and biotype resistance. In other words rotations such as wheat-canola or wheat-canola-wheat-pea are consistent in both interval and sequence. Wheat always occurs in alternate years and always follows a cool-season broadleaf. Rotations such as s.wheat-w.wheat-pea-corn-millet-sunflower are not consistent in either interval or sequence. Rotations should have crop type to crop type intervals of a minimum of two years somewhere in the rotation. Extended perennial phases (grass seed, alfalfa) minimize agronomic problems associated with the low diversity rotations in the annual cropping portion of the rotation. This approach is useful in some situations but does not normally lead to optimization of machinery and labor resources. Perennial sequences are an excellent way to “jump start” the system. Another trend that is obvious especially in the Dakotas, Kansas, Nebraska, and Colorado is a move to the use of lower disturbance techniques as rotations improve. This trend is stymied at times by limited choices in seeders that have the capability to properly place fertilizer while accurately seeding with low-disturbance. Dormant seeding of spring cereals (especially wheat) has become a predominant practice for many producers. This technique shifts workload from the busiest time of the year to a less busy time. When this is properly done, benefits for many operations far outweigh the risks. Dormant seeding of canola is not as well proven and consequently is not as widely employed. Producers (especially those with livestock) are beginning to utilize cover crops as a means of adding diversity and intensity to their systems (adding beneficial biology)

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**Wrapping it up**

The best definition of a farmer is someone that takes sunlight, water, and carbon dioxide and turns them into products that can be sold. Each operation needs to evaluate how good of a job they do at performing those tasks. What percentage of the sunlight that falls hits living tissue? What percentage of the water that falls enters the soil and is used by plants and how much causes harm by leaching or running from the land. Ate the nutrients cycled or "leaked"? Ecosystem that leak nutrients (including carbon) for extended periods of time, turn into deserts.

Soil and water conservation are a consequence or side benefit of utilizing properly designed no-till systems. Sustainable profitability must be the primary goal in order to assure that conservation continues long-term. The best systems attempt to mimic native vegetation in terms of intensity (water use) and employ as much diversity as needed to optimize the system. Each resource (land, machinery, labor, etc.) is managed to optimize its contribution to the operation without overtaxing its capability.

# An Emphasis on Rotations

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

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

## Classification of Rotation Types

It is sometimes easier to discuss concepts if they are placed into categories of some sort. We have developed the following scheme with this in mind. This classification is totally arbitrary and is meant to serve only as a tool to help understand rotation planning.

**SIMPLE ROTATIONS:** Rotations with only one crop of each crop type used in a set sequence. This is the most common type.

EXAMPLES: Winter Wheat-Corn-Fallow; Wheat-Canola;
S. Wheat-W. Wheat-Corn-Sunflower; Corn-Soybean; Winter Wheat-Corn-Pea

ADVANTAGES: Simple-limited number of crops to manage and market.

DISADVANTAGES: Limited number of crop sequence/interval combinations. All corn is sequenced behind wheat or all winter wheat goes into spring wheat.stubble.
In other words this style is consistent in both sequence and interval. Conditions for each crop are the same an all of the acreage.

**SIMPLE ROTATIONS WITH PERENNIAL SEQUENCES:** Simple rotations that are diversified by adding a sequence of numerous years of a perennial crop.

EXAMPLES: C-Sb-C-Sb-C-Sb-Alf-Alf-Alf-Alf and many others.

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

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

For instance: If the producer could only harvest 400 acres of alfalfa in a timely manner with the machinery and labor resources available, he would be limited to having 300 acres of each corn and soybeans in the above rotation. If he expanded his corn and soybean acreage more than this, the rotational benefit of the alfalfa sequence would be negated on the extra acreage. If he had 400 acres of alfalfa and 1000 acres each of each corn and soybeans (leaving the alfalfa for 4 years), alfalfa would be placed on any given field only one time in a 24-year period. He would in essence have 6 years of corn-soybean in a perennial sequence rotation and 14 years or corn soybeans in a simple rotation. Perennial sequence rotations have substantial benefit when used on fields close to the farmstead or feedlot. A producer could allocate 1,000 acres in proximity to where the forage would be used to a perennial sequence rotation. His remaining acreage could be managed in a more diverse rotation that did not involve perennials. Another option for obtaining a larger percentage of annual crop acres is to combine a more diverse type of rotation and a perennial sequence.

**COMPOUND ROTATIONS**: Combination of two or more simple rotations in sequence to create a longer more diverse system.

EXAMPLE**:** S. Wheat-W. Wheat-Corn-Soybean-Corn-Soybean.
This results from a combination of the Corn-Soybean and S. Wheat-W. Wheat- Corn-Soybean rotations.

ADVANTAGES: There are still a limited number of crops to manage and market. This approach creates more than one sequence for some crop types. There is diversity in both sequence and crop environment for corn and wheat (not soybeans). Diversity exists in interval for all crops.

DISADVANTAGES: There is a limited ability to spread workload since 1/3 of the acreage is in corn and 1/3 in soybeans.

**COMPLEX ROTATIONS:** Rotations where crops within the same crop type vary.

EXAMPLE: Barley-W.Wheat-Corn-Sunflower-Sorghum-Soybean or Barley-Canola-Wheat-Pea. This is similar to the example cited for compound rotations. Barley has been substituted for one of the wheat crops; sorghum for one corn; and sunflowers for one soybean.

ADVANTAGE: This type of approach is capable of creating a wide array of crop type x sequence combinations. If the crops are chosen wisely there is substantial ability to spread workload. This approach is effective at combating species-specific pest problems such as cyst nematode in soybeans, blackleg in canola, or corn rootworm in corn. Pests such as white mold that have multiple hosts respond similarly to the way they behave in compound rotations.

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

**STACKED ROTATIONS**: One of the less well-known approaches is one we call stacked rotations. This includes rotations where crops or crops within the same crop type are grown in succession (normally twice) followed by a long break.

EXAMPLE: Wheat-Wheat-Corn-Corn-Sb-Sb; Barley-Wheat-Pea-Canola

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

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

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

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

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

In the stacked Wheat-Wheat-Corn-Corn-Soybean-Soybean example the sequence for corn and the interval between corn crops is unpredictable in the time frame of an insect. (It looks very predictable to humans). Just as importantly, some of the population with normal habits (feeding on corn, laying eggs in corn, eggs hatching the next spring) has been kept alive due to the corn-corn stack. This will dilute the population of those with aberrant behavior.

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

The second part of the stacked concept is to have a long break (crop to crop interval) in the rotation. From a diversity standpoint it is better to have a mixture of intervals. To provide maximum protection against pest with short cycles, one of the intervals must be sufficiently long to allow populations of certain diseases or weeds to drop to low levels. Careful study of growth and decay curves demonstrates that “first year” crops on a given piece of land experience few crop specific pest problems. If the crop is planted a second time in succession on this “virgin” site, it does as well or maybe even better. It is only during the third year (or more) that problems begin to appear. These problems often grow very quickly once they establish. The reason this happens is that growth and decay curves for biological systems follow geometric patterns. (Examples: 2, 4, 8, 16, 13, 64 or 1, 10, 100, 1000). Since decay works the same as growth in reverse, a short break is not sufficient to decrease some problems sufficiently. This is especially true if they have survival mechanisms like seed dormancy. The power behind a perennial sequence is the long break. The theory behind stacked rotations is to provide a long break somewhere in the system.

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

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

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

It would be possible to fill several more pages with stacked rotation concepts. I believe most readers will be able to develop these themselves once they begin to think about it. We will conclude with a final example. Recently, I saw an agronomist give what he thought was a negative example of a producer’s rotational planning. He stated that the gentleman would seed a particular field to wheat every year until jointed goatgrass pressure became sufficient to preclude wheat. He would then seed it continuously to sorghum until shattercane overwhelmed him. At that point he would seed sunflowers in successive years until white mold became a major problem. At that point he began again with the wheat program. My response was that the producer was at least responding to the natural cycles in his field. It might be better if he anticipated these occurring so that the switch could be made in advance. However, he probably was doing a better job than someone who blindly planted a corn-soybean, wheat-canola-wheat-pea, or wheat-corn-soybean rotation and was surprised when he had to keep changing technology to deal with "new" problems.

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

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

## ROTATIONS UTILIZING BOTH STACKED AND NORMAL SEQUENCES:

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

Examples include Canola-W.Wheat-Soybean-Corn-Corn and S.Wheat-W.Wheat-Pea-Corn-Millet-Sunflower.

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

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

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

It is hoped that the above discussion has been helpful. It is meant to be an overview of some rotations strategies that will allow producers and those working with them to better understand the "art" of rotation planning.

The following are some statements concerning rotations:

I have no better chance of designing the best rotation for you than I have of choosing the best spouse for you. There are things in life that you have to do on your own. I can point out some factors you should consider when choosing a rotation.

There is no "BEST" rotation. No one can design a rotation that will work every year under every circumstance. It is a probability game. There are bad rotations that work well for a while. There are good rotations that fail at times due to weather or other uncontrollable factors. Poor gamblers make money at times; good gamblers lose money at times.

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

Producers with more risk tolerance (financially and psychologically) will be more comfortable with riskier rotations. Properly designed "risky" rotations can make more money in the long run but can result in substantial losses over the short-term.

The best approach to spreading risks is to use more than one rotation (preferably sequentially to make an even longer complex rotation).

Rotations used may differ depending on the soils involved. In other words, some of your land may require a different rotational approach than other land you farm. Some of the reasons for this include inherent soil characteristics, past history, weed spectrum, distance from the farmstead, landlord, etc.

Most farmers are good at designing rotations once they start trying.

The rotations used may have to change as market, soil, climate, and enterprise, conditions change. That is to be expected. When designing a rotation, be thinking of ways you could change it.

Don't be afraid to ask for advice, but accept no recipes from others. DO YOUR OWN COOKING.