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Beck serves as a Professor, Plant Sciences Department, South Dakota State University since February, 1983. He received his B.S. Chemistry - Northern State Univ. (1975), and his Ph.D. Agronomy - South Dakota State Univ. (1983). From 1983-1990, he was the Research Manager, James Valley Research Center, SDSU. And from 1990-present, he is the Research Manager, Dakota Lakes Research Farm. From 1985 until now, his emphasis has been on developing no-till systems for irrigated and dryland areas in central South Dakota.
Primary achievements deal with development of programs that have allowed producers to profitably adopt no-till techniques in a large portion of central South Dakota. Identification of the extremely important role played by crop rotation in minimizing weed, disease, and insect problems while increasing potential profitability was the key contribution of this project.
The Dakota Lakes Research Farm consists of 850 acres of owned land of which 280 acres is irrigated. An additional 380 acres of land is rented for research purposes. The entire operation is managed using no-till techniques.

An Emphasis on Rotations
By Dwayne Beck

There are many factors involved in designing an appropriate no-till system. Among the most important is the rotation to be used. The following outline is designed to aid the process. If you have not visited our web site www.dakotalakes.com or read the booklet No-till Guidelines for the Arid and Semi-arid Prairies it is strongly suggested that you do so.

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, 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 predominates 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.