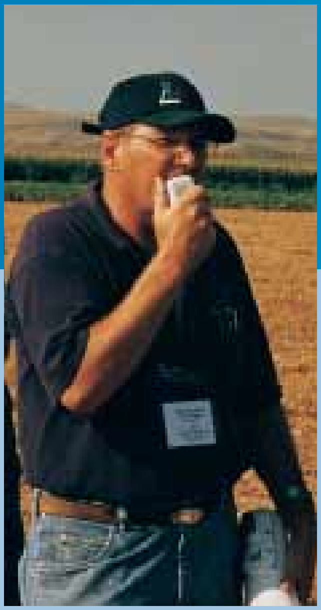
Photo by Matt Hagny.

An Emphasis on Rotations

by Dwayne Beck

TECHNIQUE

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Yes, it's worth reading again.

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 more diverse 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 generally not as effective at breaking weed, disease, and insect cycles as are black fallow, green fallow, or production of a properly chosen crop (or cover 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. (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, ability of stubble to catch snow, rooting depth characteristics, soil characteristics, precipitation patterns, and other factors.
9. Seedbed conditions at the desired seeding time can be controlled through the choice of the previous crop(s), with differing characteristics in regard to residue color, amount, 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, using only a single-year of each type. This is the most common rotation.

Examples: 1) Winter Wheat >>Corn >>Fallow; 2) Wheat >>Canola; 3) Spring Wheat >>Corn >>Soybean;


Photo by Matt Hagny.

Whatever your rotation, both sequence and interval are critical. In some climates, soybeans provide an excellent transition from the summer grass crops (corn & milo) into wheat.

4) Corn >>Soybean; and 5) W. Wheat >>Corn >>Pea

Advantages: Simplicity; limited number of crops to manage and market.

Disadvantages: Limited number of crop sequence and interval combinations. For example, all corn is sequenced behind wheat or all wheat goes into broadleaf stubble. In other words, this style is consistent in both sequence and interval. Conditions for each crop are the same on all of the acreage, which increases risk that any production problems encountered would affect all the acres of that crop.

Simple Rotations with Perennial Sequences: Simple rotations that are diversified by adding a sequence of numerous years of a perennial crop.

Example: Corn >>Soybean >>C >>Sb >>C >>Sb >>Alfalfa >>Alf >>Alf >>Alf

(many others exist)

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.

Humans tend to operate in a different time frame than other species. Days, hours, and years have a totally different meaning to a bacterium or fungus than they do to a tree.

Marketing Perennial Crops 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 each of 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 both 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 of corn >>soybeans in a simple rotation.

Photo by Doug Palen.

Doing significant acres of alfalfa poses workload problems, although perennials can improve rotations.

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.

The main reason agriculture faces issues with resistant weed and insect biotypes is that cropping programs create conditions that favor certain individuals amongst the pest population and keep these conditions in place long enough, frequently enough, and/or predictably enough to allow that biotype to become the predominate population.

Compound Rotations: Combination of two or more simple rotations in series to create a longer, more diverse system.

Example: S.Wheat >>Corn >>Soybean >>Corn >>Soybean.

(This results from a combination of the S.Wheat >>Corn >>Soybean, and a Corn >>Soy rotation)

Advantages: There are still a limited number of crops to manage and market. This approach creates more than one sequence for some crop types. In the example, there is diversity in both sequence and crop environment for corn (but not soybean or wheat). Diversity exists in interval for all crops except wheat.

Disadvantages: There is a limited ability to spread workload since 2/5 of the acreage is in corn and 2/5 in soybeans.

Complex Rotations: Rotations where crops within the same crop type vary.

Examples: 1) S.Wheat >>Corn >>Sunflower >>Sorghum >>Soybean; and 2) Barley >>Canola >>Wheat >>Pea.

The first example is similar to the one cited for compound rotations. Sorghum has been substituted for one of the corn crops, and sunflowers for one soybean. In the other example, a barley has been substituted for a wheat crop, and pea for a canola.

Advantage: This type of approach is capable of creating a wide array of crop type by sequence combinations. If the crops are chosen wisely there is substantial ability to spread workload. This approach is effective at combating many crop-specific pest problems such as cyst nematode in soybeans, blackleg in canola, or corn rootworm in corn. (*Editors: However, if a biotype of corn rootworm arises that lays eggs in wheat stubble or growing wheat, this approach has no effect—corn always follows wheat in the example.*) Pests such as white mold that have multiple hosts respond similarly to the way they behave in compound rotations.

Stacking should not be unfamiliar because it is the way 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.

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

Stacked Rotations: One of the lesser-known approaches we call a 'stacked' rotation. This includes rotations where annual crops are grown in succession (normally twice) followed by a long break.

Example: Wheat >>Wheat >>Corn >>Corn >>Sb >>Sb

(The example is a 'pure' stack, where the same crop species is used in the second year; a variation uses a different species of the same crop type in the second year, such as sorghum following corn, which captures some but not all of the advantages of stacking. Also, the above example is 'fully' stacked in that every crop is grown two years in succession.)

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 bacterium or fungus than they do to a tree. Some species populations 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' 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 with longer ranges of 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.

Rotations containing only one crop sequence or one interval will eventually select for a species (or a biotype within a species) that is suited to the particular conditions. Stacking greatly reduces the selection pressure for any certain biotype.

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 favor specific individuals amongst the population and keep these conditions in place long enough, frequently 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 is suited to the particular conditions. In the case of a species biotype, the population will continue to grow and purify as long as the conditions remain the same.

It is probably best to provide a few examples (even though these examples pertain to corn insects, similar mechanisms for pest biotype shifts could occur in any crop). In the Corn Belt and in irrigated areas on the plains in the U.S., 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 as the corn rootworm beetle (there are several 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, the corn rootworm beetles have 'devised' two known survival strategies. In western areas an "extended-diapause" biotype has become common and in some 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 in some regions because the persistent and widespread use of the corn >>soybean rotation was consistent in the interval between successive corn crops. This gave this biotype competitive advantage.

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 a suitable survival strategy to develop into predominance. During this period the producer becomes convinced he has developed the ultimate cropping program. Then, almost without warning, the system fails.

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 the majority of corn in an area is seeded following wheat for many years.

In the fully stacked wheat >>wheat >>corn >>corn >>soybean >>soybean example, the sequence for corn

Canola can have a fit in some rotations. In dry regions, it is a good seedbed for wheat.

and the interval between corn crops is unpredictable in the time frame of an insect. (It looks very predictable to humans.) This greatly reduces the selection pressure for any certain biotype, and creates selection pressures that push in opposite directions. Just as importantly, some of the population with normal habits (feeding on corn, laying eggs in corn, eggs hatching the next spring) have 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 a 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 pests, 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' (new) 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, 32, 64; or 1, 10, 100, 1000). Since decay works the same as growth in reverse, a short break is not enough 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.

Populations may grow quickly once they establish. The reason: growth and decay curves for biological systems follow geometric patterns. (Examples: 2, 4, 8, 16, 32, 64; or 1, 10, 100, 1000). Since decay works the same as growth in reverse, a short break is not enough to decrease some problems sufficiently.

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 is VAM, the mycorrhizal 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 *Rhizobia* bacteria associated with legume crops. Soybeans grown following soybeans are capable of fixing more N because higher populations of the proper *Rhizobium* exist in the soil. The soil is also lower in mineral nitrogen sources since the previous year's 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 studied much.

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 Research Farm for an irrigated rotation of s.wheat >>w.wheat /double-crop forage sorghum >>corn >>corn >>soybean >>soybean would be as follows. Year One: spring wheat—no herbicides at planting, 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 herbicide-tolerant technology like LibertyLink 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 (maybe twice) 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), etc. 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.

In Argentina, several years of pasture commonly break up rotations with grain crops. Here, soybeans are emerging from killed sod in western Buenos Aires province.

It would be possible to fill several more pages with stacked rotation concepts. 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.

Photo by Tom Will.

Chickpeas (garbanzos) are a human-edible grain commanding significant premiums if the quality is good, and are therefore more risky than other crops. Some western South Dakota producers have had very good success with chickpeas in some rotations. Chickpeas blur the distinction between cool-season and warm-season broadleaf crops.

He would then seed it continuously to sorghum until shattercane overwhelmed him. At that point he would seed sunflowers in successive years until diseases 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 observed 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. Fewer crops means less workload spreading.

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

Examples: 1) Canola >>W.Wheat >>Soybean >>Corn >>Corn; and 2) 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 wheat to winter wheat 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 s.wht >>w.wht >>pea >>corn >>millet >>sunflower rotation is designed for cool and dry regions. The two cool-season grasses in a row follow a 4-year break for that type. The two wheat crops build deep soil moisture and surface residue. Winter hardiness of the w.wht 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 second-year corn or forage sorghum) tolerates the carryover. 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 wheat crop. Herbicides with longer residual can be used in the spring wheat 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.

Part of the theory of stacked rotations involves taking advantage of positive plant associations before negative associations can build to harmful levels.

The above discussion is meant to be an overview of some strategies that will allow producers and those working with them to better understand the 'art' of rotational planning.

Further Notes 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 only 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 rota-

tions 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. The difference is in the long-term outcome.

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

The spring wheat to winter wheat stack is especially powerful in areas where winter hardiness is an issue.

- 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 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!*

Crop Characteristics Important in Rotation Planning

Crop	Type	Water Use
Winter Wheat	Grass (Cool-season)	Low
Spring Wheat	Grass (Cool)	Low
Oats	Grass (Cool)	Low
Barley	Grass (Cool)	Low
Corn	Grass (Warm)	High
Sorghum	Grass (Warm)	High
Millet, Proso	Grass (Warm)	Low
Millet, Pearl	Grass (Warm)	Mod/High
Soybean	Broadleaf (Warm)	High
Sunflower	Broadleaf (Warm)	High
Field Beans	Broadleaf (Warm)	Mod/High
Cotton	Broadleaf (Warm)	High
Cowpea	Broadleaf (Warm)	High
Mung bean	Broadleaf (Warm)	High
Chickpea	Broadleaf (Cool*)	Mod
Safflower	Broadleaf (Warm*)	High
Flax	Broadleaf (Cool)	Low/Mod
Canola	Broadleaf (Cool)	Low/Mod
Field Pea	Broadleaf (Cool)	Low
Lentil	Broadleaf (Cool)	Low
Lupin	Broadleaf (Cool*)	Mod
Alfalfa	Broadleaf (Warm)	Very High

*blur the distinction between cool- & warm-season habits.

Subject: Keep up the good work!

To: Editors of Leading Edge . . .

You guys are doing an absolutely fantastic job with your Leading Edge publication and I really look forward to receiving it. I especially like how you bring in upcoming academic journal articles. Clearly, you have taken the high road throughout, with science the centerpiece. But, being somewhat philosophical myself, I have also greatly enjoyed your past articles that may have been a little more historical/philosophical. All in all, besides being genuinely interesting, your publication is providing a tremendous service to those making decisions around no-till technologies—especially in the Great Plains. So, keep up the good work.

Terry Kastens
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—via e-mail