New Thoughts on Crop Sequencing

Matt Hagny
Pinnacle Crop Tech. Inc. (consulting)
P.O. Box 952, Salina, KS 67402
Exapta Solutions (product sales)
(785) 820-8000 (Exapta)
(785) 825-7127 (Pinnacle/Matt)
www.exapta.com
mhagny@kscable.com

Hagny, an independent crop consultant, has focused on no-till cropping systems in Kansas and Oklahoma since 1994. All Matt's clients have adopted continuous permanent low-disturbance no-till systems with rotations typically including corn, milo, soybeans, cotton, sunflower, cowpeas, alfalfa, spring & winter wheat, and cover crops. He guides decisions on rotations, fertility, equipment selection and adjustment, variety selection, and weed, insect and disease avoidance and control. In addition to conducting some research on crop varieties, cover crops, and pest control, Matt also spends lots of time tinkering with no-till seeding equipment, which sometimes leads to useful new insights and a few unique products marketed or being developed by Exapta Solutions.

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Sometimes I'm accused of being hard-headed (or at least strongly opinionated), but actually I'm open to re-evaluation and intelligent discussion of any and all topics. As a good scientist would point out, he or she isn't absolutely 100% certain of *anything.* All statements have some degree of probability of being the exact truth, ranging from something being very near a 100% probability of being true (something that is solidly grounded in theory and which has been extensively tested and nearly all the research lines up on one side) to very unlikely to be true (where the evidence comes in heavily on the other side). Since we can never be sure we have thought about any given subject in just the right way, or tested it like so, we can *never* be *absolutely certain* of a statement being true (even though we sometimes think or say that we are 100% certain of something, we really shouldn't be – nothing can ever be proven that definitely).

With this in mind, let's take a look at crop rotations. Crop rotation is a science that has been long neglected, and is only now starting to regain some credibility. We have so very much work to do in this area (one of the reasons for the neglect is the length, scope, and difficulty of doing rotational studies). In the following notes, I will discuss some of our past experiences and current thinking on rotations. Realize that our state of understanding changes, and many, if not most, of these ideas will be in need of revision or outright discarding within a few short years. Some of the ideas will survive, and others will perhaps prompt valuable new thought processes. The attrition is not a mark of failure, just a sign of progression (science and understanding don't advance in a nice steady motion, like you sometimes read or hear). And it is also simply a reflection of the nature of the puzzle: there may be hundreds of ways of improving any given rotation for a certain producer in a certain area, but there are assuredly thousands or millions of ways of screwing it up.

History and Reasons for Rotations

Crop rotations are nothing new. Early agriculturalists practiced this by moving to a new area and clearing it, cropping for a few years, and then moving on. More recently, George Washington (who was quite the agriculturalist when he wasn't fighting wars or running the country) was busy on his Mt. Vernon farm carefully recording and analyzing which crops did well following certain others, and which did not. A highly practical businessman, he was.

A century ago, the farmers on the U.S. Plains had highly diverse rotations for a number of reasons, including the need to be largely self-sufficient (like needing nutritious feed for their horses and draft animals, or being able to have milk and eggs on the table), which was due to the lack of convenient transportation and refrigeration. Cheap reliable movement of goods (with cars and trucks replacing horses, roads being improved, etc.), affordable tractors, and similar innovations began to cause the abandoning of some of the diversity of crops grown. While becoming more specialized is common in many industries, and is generally much more efficient than doing everything yourself, the consequences for farming were not anticipated and have turned out to be rather disastrous. Weed and pest problems increased, and soil quality was declining with each year of tillage (which was getting more aggressive as tractors became more convenient), all of which greatly expanded the demand for technologies to 'solve' these problems -- giving rise to synthetic fertilizers, pesticides, and even bigger tractors and tillage tools. These technologies became widely adopted during the mid-1900s, and further accelerated the development of monocultures or (at best) very short rotations (U.S. Farm Programs caused further losses of diversity). The new technologies often were remarkably and vividly powerful in addressing certain problems (that we had created), and eventually became so firmly engrained in our thinking of how to grow crops that we completely forgot about other ways of accomplishing the same goals. I am not at all suggesting discarding those technologies; they are wonderful tools, but would work so much better if we had a good understanding of biology and used a systems approach to growing crops.

Our grandparents and great-grandparents not only had diverse rotations, but also a very good grasp of the notion that some crops species promoted and others inhibited the following crop. Their rotations certainly weren't haphazard. They had developed many guidelines for sequencing, derived from observation and also careful experiments being conducted by researchers at that time. That understanding is gone. Many otherwise astute farmers and researchers today seem oblivious to crop sequencing as significantly affecting yields, costs, and risk level.

Once again, we should repeat to ourselves the reasons for rotation. We could divide the list into agronomic and economic reasons, but this is artificial, as any substantive agronomic differences will be translated into dollar differences sooner or later. (But bear in mind that these systems are highly complex and interactive, so we are once again talking about probabilities of outcomes. Single-year observations, or even multi-year replicated research, often will not accurately assess the probabilities. There is always some guessing to be done.) And so, our list of reasons for rotation: 1) to reduce pest pressure, by mechanisms including lack of host, direct biological suppression of pests, and windows of applied technology, 2) yield increases (something well documented, but not fully explained, and apparently going beyond known pest reduction – probably involving changes to the soil ecology and soil physical properties), 3) risk spreading, 4) more efficient use of labor and machines.

Arid or Semi-arid (western KS, NE, SD; eastern CO; TX panhandle)

The old tillage-based rotation in these areas was typically wheat >>fallow, although 'ecofallow' (wheat >>milo (or corn) >>fallow) became quite widely adopted in some areas in the last couple decades. With the high altitudes (cool nights) and deep soils typical of the region, combined with the dramatic improvement of moisture storage/extraction with no-till, summer crops are remarkably workable (even more so than in some higher rainfall areas, such as south-central KS, which tends to have poorer soils and much hotter temperatures). In attempts to move beyond the ecofallow-type rotation, producers have often added broadleaf crops, such as sunflowers, to replace the fallow year (wht >>corn >>'flowers). Soybeans have also moved remarkably far into progressively drier regions. Soybeans, dry beans, and sunflowers are rather interchangeable, and some producers split this rotational niche amongst more than one of these crops. Although much less drought tolerant than sunflowers, soybeans do have some advantages over sunflowers including low input costs, fewer disease and pest problems, and ease of management esp. with RR soybeans. Since you were going to have to do weed control on the fallow anyway, why not have some RR beans out there competing with the weeds? Seed (and inoculant) would

be the only additional cash outlay, and the returns could be substantial – as I've previously mentioned, soybeans are a lot like fallow, but with a chance of grain. Yield differences in the following wheat crop may not be all that substantial. The old idea of using fallow in trying to store moisture to raise a big wheat crop just isn't very efficient – wheat simply doesn't respond to the extra stored moisture by pumping out huge yields, partly due to the short grain-fill period in our climate, and partly due to wheat not being so good at extracting deep profile moisture. Still, a crop finishing as late as soybeans immediately preceding w. wheat may not be optimal for this region.

In the semi-arid regions, one problem with transitioning directly to winter wheat following the beans or 'flowers is the dryness of the soil, and the inconsistency of fall establishment of the w. wht. This can be avoided by planting spring wheat, which has been shown to work rather well in areas as diverse as Garden City, Newton, and Osage City, if managed properly (the devil's in the detail). Also, fields of sunflower stalks tend to blow badly in the Chinook winds coming off the Front Range, especially if wheat has been seeded in them (the 'flower stalks have been flattened by seeding, and the soil loosened even further by the drill openers). Dwayne Beck has ingeniously devised a system to avoid this by planting lentils along with the sunflowers in the spring. The lentils aren't thick enough to compete with the 'flowers (lentils aren't all that aggressive anyway), and the bushy plants and tougher residue can withstand the drill openers to keep wind speeds down at the soil surface, along with helping anchor the soil.

A twist on this rotation is to use an earlier-maturing crop to store a bit more moisture for w. wht stand establishment. Proso millet has been the crop of choice in many of these areas. Although a late-season water-user, it still is done a little before soybeans or 'flowers, plus the thick upright residue of millet stores the next rounds of moisture very effectively, as well as protecting wheat plants during the winter. Chickpeas (garbanzo beans), field peas, canola, oats (for hay), oat/pea mixes, and triticale forage are some others that are commonly used to transition from the summer crops to winter wheat. If there are going to be 2 years of wheat in the rotation, triticale may not be such a good choice, as it will undoubtedly start building some disease pressure in that year, which may become a problem by the time you get to the 2d-year wheat (you would essentially be doing 3 years in a row of very closely related plants). On the other hand, some evidence and casual observation indicates oats to be an excellent crop preceding wheat (probably something to do with soil biology that no one quite understands yet).

Some other possibilities exist for this niche ahead of wheat, including cowpeas for hay, or sunn hemp as purely a cover crop or 'green fallow' – producing N, using some extra water, and creating a nice 'snow fence' to protect the wheat seedlings. More work needs to be done on this. While producing cash grain or hay crops would, at first look, appear to be best, using certain cover crops to transition to wheat may have value. The idea with all of these is to finish water use early and have a thick upright stubble to help establish and protect winter wheat seedlings; the crops that use moisture late into the summer and/or have little residue (soybeans and sunflowers) may be better followed by spring wheat. Some producers use both strategies.

Once transitioned to wheat, doing a second wheat crop ('stacked' wheat) makes good sense in these drier areas. Wheat does well in these regions, and this stack works exceptionally well within the context of a 4- or 5-year (or longer) rotation, although having wheat 2 out of 4 years of a rotation runs into some problems eventually.

After the wheat stubble is kept clean and carried into the following year, corn, milo, or forage sorghum is commonly planted. These crops make use of the stored water very effectively, more so than many of the b-lf crops, which are less determinate. Corn and milo often do remarkably well in this region, owing to the moderate temperatures and the moisture savings of no-till. As these crops were typically not planted at all in the arid regions prior to no-till (at least, not for the past 70 years or so), or were considered extremely risky, there has been some reluctance to do them as a consistent part of the rotation. There has

been even more reluctance to do them as a stack, reasoning that the second year of corn (or milo) is much more vulnerable than the first one following the wheat (less time to accumulate moisture in the profile, and less fine upright stubble to cut evaporation losses). However, some producers in these areas are having success with adding the stacked corn, especially when the two corn years follow two years of wheat, and if they've been improving their soil and residue cover with a number of years of low-disturbance no-till. In some cases, the push to go to stacked corn is a result of a need to lengthen the rotation, often to get a handle on 'cheatgrass' that resurges in the second cycle of the rather popular rotation of wht >>wht >>corn >>broadleaf. While that rotation has been a wonderful stepping-stone for many producers, it has become abundantly clear that longer intervals are needed (technology *could* be employed to 'solve' the cheatgrass problem, but just delays the day of reckoning – the cheatgrass is hinting at other problems lurking in this rotation).

Some areas within this region have extremely sticky, low-OM clay soils, typically wet spring weather, and very short planting windows for corn. Consequently, producers in these locations sometimes have trouble getting all their corn acres planted into wheat stubble, particularly stacked wheat stubble. Some are looking at doing canola between the wheat year(s) and the corn year(s), which may make some sense. Chickpeas, field peas, and 'flowers preceding corn have also been done, but sometimes with substantial yield loss to the corn (which is the opposite of what occurs in some very cool climates where *lack* of heat is limiting for corn). Proso millet preceding corn is another one that has been done – its stubble is intermediate in amount and is easier to plant than wheat stubble. Generally, preserving every bit of moisture with heavy stubble preceding corn is best, but runs the risk of not being able to get the corn planted. Perhaps cover crops hold the key? – you would have the heavy wheat stubble, but control the moisture level with the cover crop. Another possibility might be to have 1/3 of the corn planted into lighter stubble, and the other 2/3 in wheat stubble but not stacked wheat, something like wht >>corn >>canola (or millet) >>corn >>canola (or millet) >>wht >>corn >>chickpea >>wht >>chickpea (nothing is stacked, but you're still doing a 'cyclical' rotation with both short and very long breaks).

On the semi-arid southern plains, windmillgrass (a perennial short-statured rhizominous grass, *Chloris verticillata*) has been a problem for the ecofallow-type rotation, with the 'solution' typically involving v-blades (a.k.a. under-cutters or plains plows) during the fallow year. Some control is gained, but at substantial cost. This grass species is also prevalent in field borders, ditches, pastures, and lawns (in my lawn anyway) in somewhat higher rainfall areas, such as central Kansas, but we have had excellent results in cleaning it up in some long-term no-till fields where it was noticeable, and have prevented it from increasing in any fields despite its seed heads tumbling along in the wind and having a trace presence almost everywhere – if it were going to be a problem for us, we would know by now. I suspect we do the most damage to it with our broadleaf crops (soybeans, sunflowers, cotton) in the rotation, since they are typically treated with 'fop' or 'dim' herbicides (Poast Plus, Select, etc.) during the early summer, or with mid-season glyphosate (in RR beans or RR cotton). Also, the dense canopies of the broadleaf crops (esp. drilled soybeans) really put the stress on the windmillgrass by shading, which may be as effective as anything done with herbicides. Dense stands of wheat, and using more corn than milo in the rotation may help also, by doing more shading early in the season. Although the b-lf crops used may be different in the more arid regions, I am strongly convinced that the same techniques will bring the windmillgrass under control in those areas as well, without the need for tillage.

Higher Rainfall regions (central/eastern KS, OK, NE, SD)

These areas were typified by tillage-based rotations consisting of continuous wheat, often with a light scattering of other crops, typically milo, corn (often for silage), alfalfa, and a bit of summerfallow. Some of the first changes many no-tillers in these areas make is increasing corn and milo percentages and adding broadleaf crops, often soybeans, but sometimes cotton or sunflowers. With the moisture savings of no-till, the stacking of wheat is problematic, as is carrying wheat stubble over to the following year.

However, stacking the milo or corn crops is workable enough in many areas of more humid regions, although the yields have been more erratic in some of the more southerly areas.

One of those areas is central Oklahoma and central/south-central Kansas (particularly the narrow band of lower elevations just west of the Flint Hills) where corn and milo yields aren't as high as you'd expect given the rainfall amounts/probabilities. Sustained high temperatures, esp. nighttime temps., cause high plant metabolism rates during the night, consuming photosynthate (sugar) reserves and leaving little for grain; drought multiplies the problem. Some of this can be mitigated with genetics, although it is still a major concern. To avoid worsening the problem, corn and milo are generally not seeded into low-residue broadleaf stubble in the most affected areas – milo and corn only follow wheat or corn or milo. As far as differences between corn and milo for preceding soybeans or cotton, there doesn't seem to be that much difference, or at least we haven't noticed anything.

For the b-leaf crops, some initial interest in sunflowers in the mid-1990s has gradually died out, due to pest pressure and inability to obtain maximum yields in high-moisture environments (really high-yielding 'flowers are in slightly drier climates). Soybeans are by far the most common, and the transition from soybeans to wheat works much better here than in the more arid regions previously discussed. Cotton is advancing in acreage rapidly in the southerly areas, and proving to be highly profitable and much more tolerant of heat, drought, and poor soils than are soybeans. Cotton as a stack is becoming much more common, and works well before moving on to wheat in the rotation. Some work with cover crops between the cotton years has been done, typically some sort of winter grass (often wheat, although oats -- especially winter oats -- has lots of potential in my opinion). The transition from cotton to wheat is often tight, due to the late harvest of cotton. If the window for winter wheat seeding is lost, some producers have been waiting and drilling spring wheat into cotton stubble starting in mid-January if soil conditions allow. This has been rather successful (more so than planting winter wheat too late), and really is the only option we see as viable for cotton stubble (not a good place to put corn or milo).

There is getting to be more stacked soybeans in the region also, which are working well. In addition to controlling erosion, I suspect there are other advantages to using a cover crop between the two soybeans, at least on some of the acres (contrary to what you might guess, testing so far indicates no yield loss in the soybeans from cover cropping with winter cereals, even when it turns off very dry in mid-summer). Although some experimentation has been done with rye, the most logical choice would seem to be winter or spring oats. We are currently trying to determine how far north winter oats will survive, and which varieties work best (we may try mixing some varieties, perhaps eventually creating our own adapted landrace of winter oats).

Some of the early no-till rotations used in this region are typified by wht/DC milo >>milo >>soybean; another one would be wht/DC soy (or 'flowers) >>milo (or corn) >>milo (or corn) >>soybean (or cotton). Shorter season areas (north-central KS, Nebraska, SD) cannot consistently get milo to maturity as a double-crop, and may be able to use forage sorghum or millet (pearl, Japanese, foxtail) for hay or forage instead. This may eventually get adopted in more southerly areas also, since DC milo stalks (esp. drilled milo) in addition to the wheat stubble make for some challenging seeding conditions the following spring – taking some of the stalks off the field as forage minimizes the problem. The b-lf crops for double-cropping don't produce nearly so much residue, creating a very nice condition for planting the following year. DC soybeans seem to be the crop of choice for now, again due to low inputs. Some producers have had excellent results with DC sunflowers also. We are experimenting with DC cowpeas for hay, which looks very promising (with a change in the Farm Program, we could be harvesting cowpeas for grain). There has also been quite a bit of farmer experimentation with cover crops for this niche following wheat. Many species and seeding dates/methods for clovers have been tried, without much success. Winter peas the same, although they may have a fit farther south. The vetches have a better record, and have the benefit of being winter hardy so that you have a live root mass to drive over while seeding corn (or milo) the next spring. There are several species of vetch, and some variety differences within any one species.

One other cover crop that looks very promising is sunn hemp (*Crotalaria juncea L.*) , which was tried in some plots this past year and produced exceptional biomass in a short time, and likely fixed a very substantial amount of N. It remains to be seen whether it will have any other positive or negative effects on the upcoming corn crop, or on future crops in the rotation (although it is widely grown in parts of Brazil and Paraguay apparently without major adverse effects). Another possibility is canola for a cover crop for this niche.

As many producers have completed at least one cycle of 4- or 5-year rotations, we have seen a dramatic reduction of 'cheatgrass' and many other winter or early spring weeds (esp. if wintertime herbicides are used ahead of some of the summer crops), to the point of rarely using herbicides for wheat at all any more. Conversely, we have seen considerably less reduction, and in some cases, persistence or even increases in a certain few summer weed species, notably some pigweeds/waterhemp (*Amaranthus spp.*) and toothed spurge (*Euphorbia dentata*). The dynamics of the weed population is purely a result of our choices – of crop sequence, interval, plant density, planting date, row spacing, fertilizer and herbicide usage, etc. Having noticed the changes, we can alter cropping plans and herbicide choices to target those weeds remaining – to continue driving our weed pressure and herbicide costs to even lower levels as some long-term (more than 8- to 10-year) no-tillers have done. One management tool that is often forgotten is haying or making ensilage, which can be timed to destroy many weed species before they produce seed – what a wonderful 'herbicide'!

Our weed dynamics might also be telling us that one year of wheat in 4 or 5 years may not be enough. To accomplish a higher percentage of wheat, we will need stacked wheat, which has been done successfully in the area by quite a number of no-till producers, but hasn't been integrated into a permanent part of their rotation. One of the reasons is excessive moisture, as well as lower returns per acre than some summer crops. The solution to both probably lies in a double-crop for forage or hay, or perhaps simply a cover crop between the two wheat crops (there isn't enough time to grow a DC to maturity for grain, get it harvested, and get the second wheat crop planted, at least not in KS, although this may be do-able in Oklahoma or TX). Cowpeas for hay make good sense for the niche between wheat crops. Sunn hemp or canola may have merit also.

Throwing all of this together, some of our *current ideas* on what comprises one of the better rotations for this area would go something like wht/DC cowpea >>wht/DC cowpea >>corn >>corn >>soy >>[cc oats]/soy, although many variations are possible and may prove better. Obviously, two years of milo can easily substitute for corn, and cotton for soybeans. Another variation might be to plant an oat/pea mix after the 1st soybean, take the oat/pea as hay, and then plant the 2d soybean. The double-crops could also be changed out to a cover crop in one or both years. To further expand the flexibility, some non-stacked sequences can be tacked onto the end or woven into this rotation, perhaps in something like wht/DC milo >>soy >>wht/DC cowpea >>corn >>corn >>soy >> soy. Although the wheat crops aren't stacked, they are much closer together at one place in the rotation in comparison to the other (a one-year, 2-crop break versus a 4-year, 5-crop break) – this 'cyclical' aspect of the rotation accomplishes many of the same things as stacking, i.e., accomplishes both long and short breaks between crops of any particular species and gives you diverse seedbeds. In the words of Dwayne Beck, "We don't want to be consistent in either sequence or interval" – doing the same thing repeatedly will promote pest biotype shifts, undermining the effectiveness of those methods. Mixing up the sequences and intervals can be accomplished in many different sequencing schemes, using either stacking or cyclical types.

Another rotation for someone with an affinity for haying or cattle would be oat (hay)/DC milo >>soy >>oat (hay)/DC milo >>soy >>wht/DC cowpea >>wht/DC millet (hay) >>corn >>corn. Being cyclical for most of the crop species, it accomplishes the short and long breaks for those. In even warmer and wetter areas, it would become desirable to fill in even more niches, such as a cover crop between the two corn crops, perhaps one that's already established before the 1st corn is harvested. Alfalfa is another crop that is an excellent addition to the rotation, particularly in higher rainfall areas since its tremendously deep

rooting potential can recover leached nutrients and use up excess water accumulating in the subsoil. As you can see, many rotations can be designed that are good in the sense of being profitable, not carrying unnecessary risks, and having the short-break/long-break characteristic. These will, of course, vary by region and soils, not to mention the differences in personality, skills, finances, and strategies of individual operations.

Confused? You're Not Alone

So how does a person make sense out of all this? Should you simply not do anything until someone gets it sorted out?? ***No*** **– definitely not. Caution is always sensible in adopting any new method, including new rotations. But that must be tempered by realizing that progress can and does occur, frequently. Many rotations we are now using are undoubtedly better than what we were using just a few years ago, and we will continue to improve them.**

The problem is this: in any location, for any producer, proving which rotation is 'best' would require a 30- or 40-year replicated rotational study – and this would still only be to a 90 or 95% level of probability, and would still include many assumptions or assigned values. By the time someone had collected and analyzed all this data, you'd either be broke (because you had been using a terribly inferior rotation during those 30 or 40 years, for fear of not being 'certain' which rotational changes would actually be improvements), or would have 50 new ideas on rotations dreamt up during the intervening years and in need of testing, or else new technology would have utterly altered the state of the possible (think of time-delay seed coatings, ultra-short-season cotton, super drought-tolerant soybeans, or some non-legume being transformed into a legume with biotech). And even if you ***had*** **identified the 'perfect' rotation (most profitable, most stable, whatever), it would be impossible to implement that rotation every year on large acreages due to weather disruptions. Flexibility is definitely required in this business.**

So make the best of sketchy information. Extrapolation, intuition, and 'thought experiments' can all be useful, particularly after you've gathered and analyzed the best data available. Even then, discipline is required – it's much too easy to take flights of fancy. It's not all that different from the last machinery purchase you made – at the time, were you ***sure*** **it would produce** ***x*** **returns over 5 years? Or the last time you adjusted your fertilizer program, were you** ***sure*** **you needed more of this or less of that? You can drive yourself crazy with second-guessing, but reality makes starkly clear that** ***management must repeatedly make decisions with incomplete information*****. Ask lots of questions, educate yourself, assess the possible payoffs and pitfalls, then make a decision and go on. Rotational decisions are no different. Strike a balance between short-term necessity and long-term potential.**

Underlying Principles

No matter where you farm, certain universal truths apply to rotations. One is the need for diversity -- lots of it -- and all the data I know of supports this, both for increasing yield and reducing costs. Another is proper intensity, which is something we all struggle with, but is striking a balance between continuous self-imposed droughts vs. failing to turn all your rain into grain, and fighting waterlogged seepy soils. Another is the short-break/long-break concept, on which I've written previously (see the Dec. issue of ***Leading Edge*****), and which I strongly suspect holds the key to maximizing the long-term effectiveness of our rotations.**

Coming up with improved rotations is a lot like engineering, say, a car. The very first automobiles weren't much more than a buggy with a tiny engine crudely coupled to the wheels. Over the years, countless inventions both small and large were added, and the components integrated in ever more

seamless designs to create the wonderful cars and pickups of today. All of those improvements were hard-won, reflecting inestimable hours spent tinkering and testing. But bit by bit, the innovations and refinements accumulated. No one woke up one day in the late 1800s and assembled something like a 2002 Chevy Silverado or an Audi A6 Quattro in his workshop. No-till rotations are the same: we'll never get finished, but we will keep improving. Now, could you please hand me that hammer . . . .