LEVERAGING BIOLOGY: DISCOVERING EFFICIENCIES IN CROPPING SYSTEMS

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In the Big Picture perspective, all we're trying to do out in those fields of crops is to 'leverage' the biology to our benefit—to extract a little more than we put in (hopefully a whole lot more, but this is often not the case unfortunately). After all, the crops we grow are merely slightly altered forms of wild plants—selected over the millennia to be more 'user-friendly' than their wild cousins, often with traits such as larger seeds for easier harvesting or processing, less dormancy, more responsiveness to fertilizers, etc. But in the search for greater efficiencies, crop genetics are only one piece of the puzzle.

Think of your fields as ecosystems—you can't sterilize the whole thing and have only the crop out there. Nature isn't easily confined or excluded. Life is quite resilient—the biology just can't be kept out without extreme measures. Think about your shower curtain or bathroom tile—no matter what you scrub it with, the mildew and other living 'gunk' show up again in a few weeks. Or how about hospitals—supposedly nice and sterile, right? Not so—a high percentage of nasty infections and diseases are transmitted during hospital stays and medical procedures, despite the advances of modern medicine. So a person can hardly expect to have complete control over big fields of crops, in the great outdoors—at least not without massive technology, deployed at a staggering cost.

Instead of focusing on wiping out the population of pesky organisms, we should instead be looking to avoid the confrontation, or at getting the suppression some other way. 'Brute force' technology generally fails to subdue biology—the technology is very costly, plus, the target often evades the control measure (particularly if used repeatedly), and the side-effects are sometimes unanticipated and unpleasant. So we need to look for ways to manipulate the system to get what we want—to find those places where we can exert small pressures and produce big changes, to leverage biology in our favor. Give me a lever and a place to stand, and I will move the world. Or at least nudge it. Really, what we want to do is mostly observing, with very little intervening—a good system will run fine by itself much of the time.

HIRED GUNS

While some 'rules' undergird the whole shebang, most of the practical pieces must be learned in dribs and drabs—the effects are often rather specific to a location and the circumstances involved, and not all that predictable (at least with our current knowledge). What is predictable: for much of what you could want done, biology provides a way, although sometimes the pace is too slow for us.

One of the most visible ways of leveraging biology is using beneficial organisms to control harmful ones—essentially nurture your allies and let them fight your wars for you. We've heard about the importance of "beneficials" for years, and how some farmers purchase and release beneficials in their fields to boost numbers—i.e., bio control. The problem was in having to purchase and release them. Why not ensure that their numbers were high from the start? This is what can occur in a well-managed no-till system. Keeping crop residues on the surface holds moisture and creates an environment suitable for these beneficial organisms, ensuring their population builds early and stays strong. Lady beetles and lacewings are often given most of the credit, but spiders actually do much of the work when it comes to controlling damaging insects and aphids. In cotton, for example, spiders are very important for controlling fleahoppers (Pseudatomoscelis seriatus). For years, I had noticed fleahoppers damaging some early squares (buds) in our no-till cotton fields, but often the levels never became all that serious, even if no control measures were taken. I always wondered what was doing the control for us, until I realized much of it came from spiders capturing the fleahopper nymphs (there may be other control mechanisms also—the point is that fleahoppers rarely reach damaging levels in well-managed no-till cotton).

Establishing a good beneficial population early involves providing habitat and a food source for them, by keeping residue on the surface (or, better yet, a growing crop) and not spraying insecticides. Spiders and lady beetles will feed on a wide range of other organisms, and can establish populations long before damaging insects ever show up—but these beneficials can't prosper in the barren wasteland of a tilled field. However, a winter cover crop killed just before cotton emergence (or even early post-emerge)1 really builds the spider and lady beetle population early, which will typically control thrips, aphids, and bollworms (having some milo and corn in the vicinity really helps, too, as the bollworm [a.k.a. earworm] moths prefer to lay eggs in those crops). Consequently, in well-managed no-till cotton in Kansas we have virtually eliminated post-emerge insecticide use—without Bt varieties.

Similar measures keep European and southwestern corn borers at bay—a good supply of lady beetles will devour most of the eggs and larvae, although it is strictly a 'numbers game.' Some areas of the northern U.S. Plains tend to have consistently higher numbers of corn borer, prompting the question of which biological suppression Beck has speculated that bats (the flying mammals, not the baseball stick) may well do the trick, consuming a number of corn borer moths each night before the moths lay their eggs. So perhaps we should be building bat habitat in our fields. Other insect problems can also be avoided with good management. Corn rootworm can be handled by rotation, so long mechanisms might be available. Of course there's Bt, a human-engineered utilization of

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[1] The cover crop often adds yield, too—many times the best cotton comes from fields where wheat cover is killed about the time of cotton planting.

biology.[2] But we'd like something on a more affordable and renewable level. Dwayne as the rotation isn't too short or predictable (see issue #1 on stacking)—this is basically deprivation of a host. Chinchbugs in milo aren't as bad in no-till, although I'm not sure why (I've been told it is due to a fungus). Greenbugs and other aphids in corn and milo are generally reduced in no-till, as has been documented by some researchers.

Sure, we haven't got all the pests under control yet, and sometimes we get 'ambushed' by something (such as snails in South Australia). We still fight grasshoppers—we haven't found much for ways to marshal their natural enemies against them yet, although they don't seem any worse in no-till than anywhere else (in fact, just the opposite seems to occur—the grasshopper populations seem to move in from the grasslands and brome waterways). Sunflower headmoth defies biocontrol, at least thus far. Often it is simply insufficient knowledge.

A JUNGLE OUT THERE

What about weeds? They do seem to 'disappear' when left on the soil surface, which is well documented (see Randy Anderson's data in issue #1, or Leon Wrage, an SDSU weed specialist). Some of this is biology (predation), and some is just pure weathering and chemical degradation. Leaving the weed seeds on the soil surface maximizes these mechanisms. Temperature fluctuations and sunlight are strongest on the surface, as well as the most feeding by ants, beetles, crickets, etc. And the same microbial and fungal feeding that degrades stubble also works to destroy weed seeds. The greatest amount of biology is almost always in the duff layer on the surface and the half-inch of soil underneath, which is also true of nearly all other ecosystems on land—the interface of a substrate, minerals, gases, and sunlight. Generally, most of these decay processes are accelerated under crop canopy conditions (by keeping the humidity higher). These processes seem to go along just fine by themselves, especially after a few years of no-till (indeed, sometimes our crop residues decay a little more quickly than we'd like). Weed seeds are further disadvantaged by just lying loosely on top—a poor place to germinate, except in very damp environments.

Another component of biological control of weeds is competition from your crop. Sunlight and nutrients are limited in supply, not to mention pure physical space to grow. What is it you don't like about weeds? Obviously, they take something away from your crop's growth and yield. Turning this around helps level the playing field—so make the crop as competitive as possible. Proper seed and fertilizer placement help 'build' a vigorous crop, as does selecting quality seed (usually larger seeds with high germination) with genetics to grow quickly. Thicker stands and narrower rows will help, too. Anderson showed that using a tall variety in narrower rows with N placement reduced

[2] In the wild, the bacterium *Bacillus thuringiensis* produces substances toxic to Lepidopteran (moth and butterfly) larvae, such as corn borer. Researchers successfully moved the genetic snippet for producing this protein into several corn genomes, causing the resulting "Bt" corn plants to produce those toxins in some of their tissues. In the wild, such shuffling of genetic material between species is known to occur when mediated by viruses—genetic 'engineering' is an ancient occurrence.

weed seed production by 40 to 45% in wheat. Of course, rotations are key to effective biological control, as crops will be competitive at different times of the year.

Beyond competition for resources, weeds may even actively suppress crop growth with 'chemical warfare'—emitting compounds to limit the growth or even kill neighboring plants (the first herbicides were used by Nature!). Sometimes this works the other way as well, and a crop will do a decent job of actively suppressing one or more weed species. This chemical warfare, or allelopathy, is only beginning to be understood yet is another biological tool to be used to our advantage, if only we would.

One striking example of the failure to make use of competition is the "ecofallow" program in western Kansas, which is basically a wheat >>milo (or corn) >>summerfallow rotation. After a few cycles, windmillgrass (Chloris verticillata), prairie cupgrass (Eriochloa contracta), and other "go-back" grasses dominate the system, resulting in the desire to 'solve' the problem with tillage—using v-blades, undercutters, plains plows, or whatever you want to call them. The interesting thing is that these grasses do not 'blow up' or become prevalent in other systems—only in that rotation. These grasses share a few tough management characteristics, such as tolerance to low rates of glyphosate, but also are weak in that they don't produce much seed and are not terribly aggressive in their growth habits. Why did they come to dominate? The system gave them an opportunity. The herbicides used (low rates of glyphosate + growth regulators in the wheat stubble and again in the summerfallow, atrazine + acetamides in the milo) were not particularly good on the windmillgrass, etc., and in fact helped them by removing competition from other weed species susceptible to those herbicides (pigweeds, kochia, foxtails). Of course, the crop competition was zero in the summerfallow year, only moderate in the wheat year (with a long summer for the windmillgrass to recover), and not overly wonderful in the wide-row (30 to 40-inch) milo either. Soon, the thing fell apart—Nature had found the Achilles' heel of this cropping system.[3]

While many now consider the v-blade an integral part of their management of that system, it need not be so. Many producers have cleaned up problem fields of those grasses with good rotations and proper herbicide selection, relying on more 'fop' and 'dim' herbicides and higher rates of glyphosate. But the death-knell to those weeds is a dense canopy above them during the summer—they cannot tolerate being shaded. Putting a vigorous broadleaf summer crop into the rotation fixes the problem with biology, and has many other desirable attributes as well. I have clients who have nearly eliminated windmillgrass and cupgrass in some fields by using narrow-row soybeans and well-chosen herbicides, without any mechanical tillage devices whatsoever. Despite a constant supply of windmillgrass blowing in from borders and adjacent pastures, we see no windmillgrass problems developing. Summer broadleaf crops other than soybeans

[3] The ecofallow program also caused shifts in annual grass biotypes and species toward those more tolerant of acetamides, since this was almost the only major pressure being applied to some of the summer grasses. In some regions, nutsedge also became predominant under ecofallow or similar systems that provided the opportunity. As Beck observes, "Mother Nature is an *opportunist*—she's not a bitch."

appear to address the problem similarly, in varying degrees, depending on their canopy and growth characteristics.

Rotations, competition, and weed seed disappearance have dramatic impacts on weed populations in no-till fields. However, herbicides still pick up the slack, partly because we do not sufficiently exploit these other control measures, and partly because we have bred crops to have fewer defensive traits while going for bigger yield potential. The most economical system will make judicious use of all these means.

UNHEALTHY LIVING

What about crop diseases? Diseases aren't quite as obvious as insects and weeds, and may not receive as much attention. But they're still in the realm of biology, and of biological controls.

Disease-causing organisms all have resting (dormant) stages, called spores, conidia, apothecia, perithecia, sclerotia, etc. depending on the structure produced. These can survive for some time until coming into contact with a new host. Interfering with disease infection and/or progression in plants can involve several mechanisms, such as reducing the levels of these resting stages in the environment (soil or air), disrupting their 'sensing' of the proper host, or enhancing the plant's defense mechanisms.

Reducing inoculum load may involve longer intervals of non-host plants, or other ways of increasing attrition of the resting structures—time, chemical weathering, and biological predation are your allies. Having a crop growing in the field often creates conditions that either accelerate the death of these enemies, or that actually fake them out of dormancy (only to find themselves trying to infect a non-host species, or one that isn't the cash crop).

This is perfectly illustrated by a recent study of white mold (Sclerotinia sclerotiorum) levels in soybeans as affected by cover crops, conducted by Craig Grau of Univ. Wisconsin. White mold is a scourge of the Northern Plains, especially in areas with 'tight' rotations of susceptible or carrier plants, such as soybeans, canola, and sunflowers. It is worst in humid conditions, and during the late '90s caused much of the Corn Belt to revert to wide-row soybeans and other yield-limiting management strategies, such as planting semi-resistant varieties—all in an attempt to avoid disastrous levels of white mold. Looking for a better way, Grau suspected a biological solution might work. In a no-till corn >>soybean rotation, Grau compared cover crops of winter wheat, spring oats, and spring barley (all non-hosts) grown ahead of soybeans, versus check strips of no cover crop. Over multiple years and locations, Grau found that white mold incidence in the soybeans was significantly reduced by all three cover crops, and that the white mold resting structures had indeed broken dormancy in all of the cover crop strips, but not in the check strips.4,5

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[4] Long-term use of cover crops to prematurely break the dormancy of white mold sclerotia may result in shifts of that species toward more precise germination requirements, i.e., *Sclerotinia sclerotiorum* might begin to break dormancy only when sensing compounds exuded by soybean roots, but not winter small

The game gets more complicated when we realize that disease-causing species change their characteristics in response to their environment. Just like some human pathogens have evolved resistance to all known anti-microbials, so does the population of any given crop pest adapt to the control measures used, including adapting to rotations. For instance, Bipolaris sorokiniana is a soil-borne fungus causing common root rot in both wheat and barley. Five years of monoculture wheat will cause the population of B. sorokiniana to change from being weakly virulent to wheat to becoming highly virulent to wheat, as demonstrated by R.L. Conners and T.G. Atkinson.6 The opposite occurred with five years of continuous barley: the B. sorokiniana increased in virulence to barley but decreased in its ability to colonize wheat. Other studies support the findings of short rotations (or monocultures) causing increases in both inoculum levels and disease aggressiveness for most pathogens.7 Planting non-host crops reduces inoculum levels, but may not alter that pathogen's adaptedness to the host crop, whereas planting crops that are weak hosts or alternate hosts may increase inoculum by allowing the pathogen to reproduce, but may actually reduce the pathogen's aggressiveness in relation to the primary host crop.

UNDERGROUND WORLD

The roots of your crops grow in a unique world—an ecosystem largely unseen and unexplored by humans. Which vascular plants (crops and weeds) are allowed to grow in your fields will radically alter that ecosystem every year.8 Every plant has a 'signature' of root exudates (substances leaking from roots), and these exudates may attract or discourage certain species among the diversity of bacteria, fungi, nematodes, and other organisms in the soil. Those species often vie for root exudates as food sources, to the extent of bacteria that produce antibiotics (to kill the competition) and plant growth stimulants to increase root growth.9 In turn, some of those species will be food for still other species. Other organisms are free-living, adding to the richness of the soil ecosystem. Many of the species found in the soil ecology help the vascular plants, directly or indirectly—by creating or liberating nutrients, discouraging harmful

grains. Cover crops may be highly effective in the short-term however, and would maintain some effectiveness regardless, to the extent that predation and decomposition would be higher under a canopy of cover crop. A number of fungi are known to attack or inhibit *S. sclerotiorum* in the soil, including *Coniothyrium minitans* (which is actually marketed as a biocontrol product), *Sporidesmium sclerotivorum*, *Trichoderma spp*., and several others.

[5] Yields of soybean were highest following the cover crop winter wheat. Whether winter wheat is the ideal cover crop ahead of soybeans remains open to debate—observations in S. Dakota and Kansas indicate allelopathic effects on the soybeans, which do not seem to occur when winter rye or oats are used instead of wheat. In Grau's conditions (high moisture, high disease), the additional growth of the fall-seeded winter wheat (compared with spring-seeded oats or barley) likely overwhelmed all other factors.

[6] R.L. Conners & T.G. Atkinson, 1989, Influence of continuous cropping on severity of common root rot in wheat and barley, *Can. J. of Plant Pathology* 11: 127-132.

[7] Some exceptions occur, such as is commonly reported with take-all in wheat—these soil ecologies are termed "suppressive," and are thought to be caused by a resurgence of the 'enemies' or antagonists of the pathogen in question. There is some debate as to whether this is dependent on one or two species, or on entire ecological shifts. In any event, suppressive soil ecologies deriving from monocultures tend to only be effective at controlling a few pests, and do not develop equally in all soils and climates.

[8] Not only which crop is grown, but which *variety*, significantly affects the soil ecosystem.

[9] Jill Clapperton, *Creating Healthy Productive Soils*, from Alberta Reduced Tillage (ARTI) website.

organisms, or just by occupying a niche (a robust ecosystem has great diversity, which discourages both invasion and erratic population swings by the various species).

Soil ecosystems are slow to reveal their secrets. Many of the “rotational effects” we observe are likely caused by shifts in the soil community, as they are not explainable by moisture levels, nutrient cycling, or known diseases—a conclusion reached by many independent researchers worldwide.

Choices of crop sequencing are really one of the ultimate tools available for leveraging biology in the producer’s favor. The consequences of getting it right are big. For instance, in ’02 at Dakota Lakes Research Farm in the w.wht >>corn >>broadleaf rotation, winter wheat yields varied from 8 bu/a to 56 bu/a depending on the preceding b-leaf crop. It was a dry year (understatement), so the wheat after soybeans making only 8 bu/a isn’t so surprising. The shocker is the wheat making 56 bu/a after field peas, but only 28 bu/a after canola and 28 after chickpea. According to Beck, wheat after field peas is always some of the best. Moisture, organic N, and mycorrhizal levels may explain some of the differences, but mostly we just don’t know why.

In another example, Randy Anderson’s long-term work at Akron, CO shows an increase in wheat yields of 46% by having corn in the rotation (w.wht >>corn >>fallow versus w.wht >>proso >>fallow). On the other hand, including sunflower in the rotation decreased wheat yields significantly, even with a year of fallow after the flowers, although the loss was reduced (but not eliminated) if a year of corn was included ahead of the flowers.

Underworld inhabitants also have many desirable effects on soil physical characteristics. Want to loosen and aerate the soil? Earthworms can handle that for you, as can plant roots. Redistribute nutrients? Earthworms again. Help plant roots absorb nutrients and water? Mycorrhizal fungi to the rescue. And all of these helpers work best in continuous no-till.

BUILDING A BETTER SYSTEM

All of this is just leveraging biology in our favor (or not). The secret is in figuring out how to let nature solve your problems for you. Fields are ecosystems, and they may either be on life-support or be quite robust. Sometimes we don’t even know how close they may be to crumbling. The nature of epidemics is such that we have been notoriously poor at predicting and preventing them.

The take-home message is that, in the biological world, brute force generally fails. The target almost always finds ways around the pressure, i.e., the pressure forces the target to change. Even if this weren’t the case, the technology is usually expensive. Biological solutions often can be ‘persuaded’ to work for less cost, and they are ‘on the job’ when and where they are needed—much more so than applied inputs.

None of this is intended to be an "avoid technology" message—technology is wonderful, especially when it is used for those problems at which it excels. However, it seems that we have gotten sloppy in thinking technology will bail us out of every jam, or that every new technology must be the most economical way to doing something. The electronic era certainly didn't spell the end of paper (as some predicted)—we use more than ever—nor will slick new technologies allow you to utterly control everything in your fields and forget about the underlying biological and ecological principles. Your fields will always be a messy tangle of wild biology. Embrace it. Learn to exploit it. This time at least, the future belongs to those with a bit more subtle understanding and finesse.

Editors' Note: To learn more on "leveraging biology," catch our blockbuster array of speakers for the No-Till on the Plains' 2003 Winter Conference in Salina, including venerable no-till researchers Dwayne Beck and Rolf Derpsch. Another featured speaker will be Jill Clapperton, soil ecologist at Lethbridge, Alberta, who will heighten our awareness of fundamental biological happenings in the root zone.

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