Successful No-Till on the Central and Northern Plains

D.L. Beck, J.L. Miller, and M.P. Hagny[1]

Presented at the ASA conf. Baltimore, MD, Oct. 1998

Utilizing no-till farming practices has been consistently identified as a method which is capable of conserving soil moisture, reducing soil erosion, improving water quality, benefiting wildlife, increasing labor use efficiency, limiting machinery investments, sequestering atmospheric carbon dioxide, etc. Claims are less consistent when it comes to identifying the impact no-till can have on making individual producers more profitable. In fact, research data can be found that support the conclusions that no-till is less profitable, more profitable, or of equal profitability to conventional systems. It appears that the "devil is in the detail" meaning that factors such as trial location(s) and duration, experimental methods (rotations, seeding equipment, fertilizer practices, etc.) and the economic assumptions employed play a major role in determining the calculated relative profitability of the tillage practices tested. This inconsistency makes it difficult to predict with a high degree of certainty which tillage system would be best for individual producers with differing management styles, locations, and economic circumstances. The problem occurs because an attempt is being made to use research that was designed to test a system component (tillage) to make judgments about the system as a whole (profitability), and because the comparisons often neglect to optimize cropping strategies for each tillage regime, resulting in agronomic practices that inherently favor one system. This uncertainty and the unpredictability that results from this approach substantially slows adoption of no-till and leads to some early adopters abandoning no-till when unforeseen problems arise. There is an increasing amount of system-based research being conducted but, due to the lead time needed for reaching valid conclusions, its value will be limited in the immediate future.

---

[1] Dwayne L. Beck is the Research Manager at Dakota Lakes Research Farm near Pierre, South Dakota, USA. Jason L. Miller is an USDA Natural Resources Conservation Service agronomist at Dakota Lakes Research Farm. Matthew P. Hagny is an independent agronomist with Pinnacle Crop Technologies Inc. based in Salina, Kansas, USA.

Waiting until valid systems-based research is conclusive will entail foregoing the potential benefits of no-till systems during the interim unless other methods can be devised to obtain the needed information. If economic theory's assumption of rationality is correct (or at least a dominant force), widespread adoption of no-till by producers in an area could be used as an indicator that the systems they employ are economically superior. This would be especially true if adoption has continued for a relative long period of time without a consistent trend for producers to return to tillage-based systems. Analyzing the systems used by producers with differing economic, environmental, and edaphic situations should reveal key commonalities which allow no-till systems to express economically some well-known agronomic strengths. Similarly, those areas where growth has been slow or reversion to tillage is common most likely indicate that a proper system has not been developed to maximize the no-till benefits for those circumstances. Evaluating these unsuccessful attempts to ascertain if there were obvious variations or omissions as compared to successful systems may shed light on possible alternate paths which need to be pursued. To date, early evidence suggests some of the relevant architecture underlying these systems which ultimately determines their degree of success:[2]

I. Commonality among successful systems.
    A. Diverse rotations with at least three crop types.
        1. Workload spreading benefit.
        2. Primary method of pest control.
            a. Stacking concept.
        3. Crop environment modified by sequence.
            a. Corn after pea, corn after wheat, corn after soybean.
            b. Winter wheat after spring wheat.
            c. Spring wheat after sunflower.
        4. Diversity within and among rotations to spread risk.
            a. Weather risks (drought, planting delays, winter kill)
            b. Pest risks
            c. Price risk

    B. Increase in intensity as compared to conventional systems in area.
        1. Crop more often/little or no fallow.
        2. Deep rooted crops
            a. Concept of exploring deep root zones not used by wheat.

    C. Low disturbance systems.
        1. Residue clearance.
        2. Less power required
        3. Superior operation in wet soils.

---

[2] To a large degree, these factors or structural components do not exist independently of one another. Many agronomic, economic, and engineering considerations interact, as will be explained.

        4. Residue movers used where appropriate
        5. Affects weed seed cycling and viability.

    D. Heavy emphasis on sanitation and competition principles.
        1. Seeding rate.
        2. Row Spacing.
        3. Fertilizer placement.
        4. Seeding depth and spacing.
        5. Residue spreading.
            a. Chaff spreaders
            b. Stripper headers.
        6. Preventing weed seed production or introduction.

II. Commonality amongst systems with limited success.
    A. Lack of diversity in crop rotation.
        1. Machinery costs (per acre) were higher not lower.
        2. Worked well initially but less well or failed after 6 to 10 years
    B. High disturbance seeding.
        1. Benefit of early growth offset by negative factors.
        2. Often used to alleviate problems better cured with diverse rotations
    C. Emphasis on fertilizer placement overshadows seed placement concerns.
    D. Intensity was not increased or was increased without adding diversity.

One area with considerable adoption of no-till methods (and very little reversion to tillage systems) is the central and north-central U.S. Great Plains.[3] The following is a distillation of our knowledge gained from studying no-till systems in these areas, as well as thoughts for applying the concepts elsewhere.

Crop Diversity

Rotational diversity reflects the extent to which differing types of crops are used. Diversity can spread risk (both production and marketing), reduce weed and pest populations, manage workloads, allow more varied herbicide choices to prevent resistance, and create good seedbeds for

---

[3] In 1990, approximately 123,729 hectares (305,612 acres) in South Dakota were no-tilled. By 1997, that amount has increased by more than eight-fold to 1,028,023 hectares (2,539,216 acres). Similarly, no-till acreage in Kansas grew from an estimated 188,585 hectares (466,000 acres) in 1990 to 840,307 hectares (2,076,431 acres) in 1997. Conservation Technology Information Center, West LaFayette, IN.

subsequent crops.

To prevent confusing subtle differences with more important issues, it is helpful to think of the wide assortment of crops as being from major groupings. There are four types[4] of plants most commonly grown as crops:

1. cool-season grasses – i.e. wheat, barley, oats (*Triticum aestivum/T. durum, Hordeum vulgare, Avena sativa*)
2. warm-season grasses – i.e. corn, sorghum, millet (*Zea mays, Sorghum bicolor, Panicum miliaceum/Setaria italica/Pennisetum glaucum*)
3. cool-season broadleaves – i.e. peas, lentils, flax (*Pisum sativum, Lens culinaris, Linum usitatissimum*)
4. warm-season broadleaves – i.e. sunflower, safflower, soybean, cotton (*Helianthus annuus, Carthamus tinctorius, Glycine max, Gossypium hirsutum*)

Between the major categories of plant types there exists very different growth and maturity habits. These traits will affect seeding and harvest periods, pest susceptibilities, temperature demands/tolerances, and water use characteristics (see Table 2). Utilizing crops from each of the major groups will, by its very nature, diminish many of the weeds and pests associated with a particular crop type. However, even using multiple species within a crop type, such as corn along with sorghum or millet, can add useful diversity to a rotation.

Crops of the same type tend to have similar pests and similar water and heat needs, and can be considered approximate substitutes when measuring diversity. Within the groups, specific crops can be selected to fit particular conditions. For example, lentils and peas are both cool-season broadleaves but lentils perform better in drier climates. Winter and spring wheat are both cool-season grasses but differ in their seeding and harvest dates. Soybeans and cotton are both warm-season broadleaves, but cotton requires far more heat and tolerates drier conditions than soybeans.

Diversity does more than solve agronomic problems; it can reduce risk and overhead. To the extent planting and harvesting windows do not conflict or overlap, more crop types permit more acres to be farmed with less equipment. To make the most economic use of farm machinery and labor resources which were formerly used in doing tillage, they must be redirected, not left idle. Cutting the number of tractor hours by 50% nearly doubles the fixed costs associated with each of those hours. Growing more types of crops will allow the machine to be used more efficiently

It could be useful to compare the diversity of various crop rotations by creating a diversity index (for more details see "Defining Diversity and Intensity" at www.dakotalakes.com). Briefly, rotation diversity increases according to:

---

[4] As with all categories, some liberties are taken. Cool-season vs. warm is a bright-line distinction in grasses physiologically (C3 vs. C4 pathways), even though some C3 species, such as rice (*Oryza sativa*) have tropical growth habits. Broadleaves do not possess such a clear division (although great acclimation differences exist between species) but probably still exemplify greater genetic and phenotypic diversity than the grasses.

the years separating the same crop type
the presence of both grass and broadleaf crops
the presence of both spring- and fall-seeded crops
the presence of both warm- and cool-season crops

Diversity decreases if crops must be seeded and/or harvested during the same time period.

Crop rotations can be viewed at two levels: across the whole farm and on individual fields. Some producers refer to "rotations within rotations" to describe their idea of using several well-chosen rotations simultaneously, allowing different sequences or crop choices (eg., sunflower vs. soybean) to maximize efficiencies. Substituting crops changes the level of economic risk of the rotation, while the risk of growing each crop depends primarily on its place in the rotation.

Above all, diversity should improve profitability and/or decrease risk. Diverse rotations will be most profitable only if they have proper water use intensity, include adapted crop types and varieties, and are designed and managed properly. Changes in economic, agronomic, engineering or political factors may force more changes in the future.

Crop Diversity Impacts

The agronomic advantages to diverse rotations can be easily measured by improved yields and/or reduced inputs (assuming proper intensity for that climate, soil, and tillage regime).
For example, the rotational interval impact on winter wheat yields has varied from year to year at the Dakota Lakes Research Farm at Pierre, South Dakota. In 1994, a dry year, produced the following results: a rotation with a two-year break between wheat crops (example: w.wheat-corn-pea) yielded four bushels/acre better than every-other-year wheat (example: w.wheat-fallow). A rotation with two years of wheat back-to-back and then a two-year break between wheat crops (example: s.wheat-w.wheat-corn-sunflower) produced a five bushel/acre increase over every-other-year wheat.

In 1995, a wet year, produced the following results: a rotation with two-year break between wheat crops yielded ten bushels/acre better than every-other-year wheat. A rotation with two years of wheat back-to-back and then a two-year break between wheat crops produced a six bushel/acre increase over every-other-year wheat. Finally, a rotation with a three-year break between wheat crops (example: w.wheat-corn-soybean-field pea) yielded 14 bushels/acre better than every-other-year wheat. To date, the Dakota Lakes Research Farm has shown a two-year break between wheat crops will on average result in seven bushels/acre more wheat when compared to every-other-year wheat. Wet years conducive to early disease development exacerbate the yield advantage to the long rotational interval away from wheat or other cool-season grasses.

Rotations involving corn and soybean are producing similar yield trends; as rotation diversity and crop intervals increase, crop yields increase.

The answer to the question very few have asked is rotational stacking ("short break/long break"), which complements the idea biological time (as contrasted with chronological time). The question: won't no-till's dependence on rotation (the time when field is growing a non-host crop) simply select for pests that are capable of surviving in rotations with very long breaks of non-host crops (long chronological time between host crops)? We suspect this will not be a problem if we ultimately implement rotations so that biological time is maximal and we don't *consistently* reward genetics for long chronological dormancy. This is conducted by planting a given crop type twice in the rotation (generally in consecutive years), followed by a period (three or more years or crops[5]) in which that crop type is not grown. The "consecutive" component increases the proportion of the pest's genetic population possessing short-dormancy traits.[6] Any tendency for specific pests of a given crop type to survive the long chronological break is naturally held in check by the forces of predation, plus biological and chemical degradation, of these organisms in their susceptible dormant state (the concept of biological time). Rotations designed to control the various pest biotypes just adds another layer of prevention, ensuring that we don't inadvertently select for long-dormancy biotypes in some organisms detrimental to crop production.

Cropping Intensity

Rotational intensity is the level of demand for water created by the crop sequence. The level of intensity should match the water supply. Therefore, no-till rotations should be more intense that conventional-till rotations. For example, a wheat-fallow rotation could become wheat-corn-fallow or wheat-corn-millet-fallow.

Growing crops that utilize significantly more water (eg., alfalfa, corn, soybean) will increase intensity. Growing crops more frequently (double-cropping or eliminating fallow) also increases intensity, as does the practice of cover crops. Cover cropping involves seeding a species (often a legume) that will not be harvested for grain or forage but simply uses excess water, maintains biological activity, positively modifies the seedbed environment, and (if a legume) adds nitrogen. Experimentation is being conducted to ascertain the viability of broadcast seeding various cover crops in particular crop sequences (eg., after wheat, between corn crops).

---

[5] For cooler climates, a year is a crop. In longer season areas, multiple cropping may be practiced. Growing a crop creates micro-climatic changes that enhance biological and chemical activity (over what would occur in a largely inert stubble field) so that biological time no longer correlates with chronological time. In terms of pest suppression, both are relevant. For instance, mycoparasitism would be mostly associated with biological time, while chemical degradation of resting spores would proceed more along chronological time.

[6] Obviously, pest with numerous life-cycles during the span of one annual crop already have considerable reward for short dormancies (as do those organisms with high mobility to seek out favorable conditions), resulting in the prevalence of short-break genetics.

Insufficient intensity causes numerous ill effects. No-till's improved moisture retention & availability has been well-documented. The initial reflex is to use this windfall exclusively to guard against drought. This is akin to being insurance poor -- the most obvious risk is eliminated but at a very heavy cost. The cost here is lost opportunity for growing crops highly responsive to extra moisture. Additional water equates to more profit potential only if exploited with higher cropping intensity. Failure to use the extra water in a soil under no-till management will also result in problems with plant growth, soil quality, and field operations.
Using at least three of the four major crop types (see "Diversity" section) will result in a mix of high and low water-use crops. The desired mix will depend on moisture availability. Soils with high water-holding capacity support greater intensity than coarse soils. Cooler climates permit greater intensity than warm climates with equal precipitation. If fields are consistently too wet, then the current rotation lacks intensity. If fields are too dry, intensity is too high.

Several generations of experience in an area have probably found the appropriate level of intensity for tillage-based systems. This is not so with no-till cropping systems in some areas of the Great Plains. Some insight can be gained by using common conventional tillage rotations as a starting point (rotation intensity can be calculated by using Table 1) and recognizing that adopting low disturbance no-till typically increases crop intensity capacity by 33-100%.

The magnitude of the intensity increases can be gauged by examining some common rotational changes that have occurred in conjunction with the successful adoption of no-till in various locales on the Great Plains. When comparing no-till rotations from diverse regions, it is instructive to first compare native vegetation, rather than rainfall. Native vegetation takes into account precipitation probabilities, evaporation, elevation, soils, etc.

I. Native vegetation areas on the Great Plains.

- A. Mixed- to short-grass prairie areas
    1. Western North Dakota (Golden Valley County)
    2. North-central South Dakota (Corson, Walworth, Potter Counties)
    3. South-central South Dakota (Lyman County)
    4. Southwestern South Dakota (Bennett County)
    5. Eastern Colorado.
    6. Northwestern Kansas.

- B. Mixed- to tall-grass prairie
    1. Northeastern South Dakota (Brown and Spink Counties)
    2. Southeastern South Dakota (Charles Mix County)
    3. Central Kansas
    4. South-central North Dakota

Central and western South Dakota is classified as being a mixed-grass prairie ecosystem. However, some locations within that area have soil limitations that will promote a short-grass prairie ecosystem. The traditional conventional tillage rotations consisted of wheat-fallow with spring wheat in the north and winter wheat in the south. With no-till the rotations have increased substantially in diversity and intensity. Rotations in western and central South Dakota now include, for example: 1) spring wheat-winter wheat-corn-broadleaf, 2) wheat-corn-broadleaf, 3) spring wheat-corn-field pea-winter wheat-soybean, 4) spring wheat-winter wheat-field pea-corn-millet-sunflower, 5) wheat-corn-chemfallow, 6) spring wheat-winter wheat-sunflower-sorghum-chemfallow, etc.
As you move east across South Dakota, the native vegetation changes from the mixed-grass prairie to the tall-grass prairie. Typically in eastern South Dakota, corn-soybean production is practiced with conventional tillage. Therefore, the challenge is to incorporate a cool-season grass into the rotation and maintain or increase the intensity. This can be accomplished with cover crops, double-cropping (two crops grown to maturity the same year), and/or relay-cropping (essentially double-cropping but the second crop is established before the first crop is mature). Example rotations include: 1) spring wheat-winter wheat/CC clover-corn-soybean-corn-soybean, 2) spring wheat-winter wheat/DC forage sorghum-corn-soybean-corn-soybean, 3) spring wheat-winter wheat/DC millet-soybean-corn-corn-soybean, 4) spring wheat-winter wheat/CC clover-corn-corn-soybean-soybean, etc. If even more intensity is needed, cover crops can be grown more frequently. Other ways to maintain the diversity and increase the intensity in the tall-grass prairie is the addition of a perennial crop such as alfalfa to the rotation.

In northwestern Kansas and eastern Colorado (short-grass prairie), tillage-based wheat-summerfallow systems are being supplanted by no-till rotations similar to those in use in central South Dakota, such as: 1) wheat-wheat-corn-millet, 2) wheat-wheat-corn-sunflower, 3) wheat-wheat-sorghum-sorghum-chemfallow, etc.

In central Kansas (tall-grass prairie), higher rainfall and a longer growing season lends itself to double-cropping. Typically the continuous wheat rotation (with intense tillage) is replaced with no-till: 1) wheat/DC sorghum-corn-soybeans, 2) wheat/DC sorghum-soybeans-corn-corn-soybeans, 3) wheat/DC beans-corn-corn-beans, etc. Moving west into drier areas sees the double-cropping reduced or eliminated in favor of cover crops, such as the Austrian Winter fieldpea.

As previously discussed, sorghum and corn are considered to fill the same niche in the rotation, although differences exist in adaptability to extremes of climate (at least in current commercially available seedstocks), yield potential, water-use pattern, insect susceptibility, and herbicide options. Dryland conventional-till sorghum is not uncommon historically in central Kansas, but very rare in south-central Kansas and north-central Oklahoma. However, central Kansas is much further south and west of traditional dryland corn production areas -- dryland corn would not be sustainable in this area without no-till practices mitigating heat and droughty spells. Even with no-till, producers try to plant the bulk of their corn acreage into high residue conditions for yield stability.

In central and south-central Kansas, as well as Oklahoma, cotton and soybeans become interchangeable in the rotation. Substituting cotton for soybeans results in the later cotton harvest often interfering with fall establishment of winter wheat. Cotton's dark-colored and scarce residue make it a warm seedbed, but also one which is more drought-prone. This makes it somewhat undesirable for rotating to sorghum and highly undesirable for corn in any climate where moisture may become limiting. Consequently, we are experimenting with winter-seeded (dormant) winter-wheat and with spring wheat following cotton. Early results indicate spring wheat may be the crop of choice.

Again, cotton and soybeans have little history in central Kansas, often being considered beyond the western edge of dryland soybean capability as well as too far north for cotton production. With adoption of no-till and other good agronomic practices, dryland soybean yields in central Kansas sometimes rival those under irrigation, but yield stability has yet to be achieved. The movement of cotton into central and south-central Kansas has little to do with no-till (although it works fine in our no-till systems); its success derives from lack of boll weevil pressure, as well as the fact that these new producers do not try to grow this crop under monoculture.

Stacking warm-season grass crops (corn or milo) back-to-back is a no-till practice gaining popularity in central Kansas, as is stacking wheat crops in the drier areas. Cover crops or relay-cropping would permit successive-year wheat crops in the wetter areas, although the implications are not well investigated at this time. Successive broadleaf crops are possible where water erosion is not a concern, but not yet practical on sloping soils due to the sparse residue production inherent in broadleaf crops and the poor condition of the soils after a century or more of intensive tillage. Cover crops and/or improvements in soil structure may permit this technique.

Rotational Planning

Diversity and intensity are just facets of a multi-dimensional and interactive agronomic system. For instance, changes in cropping rotations must proceed in tandem with the adoption of low-disturbance seeding since rotational diversity now must do the brunt of the disease and weed control, but increases in cropping intensity depend on improvements in soil structure and surface residue levels accruing once soil disturbance is eliminated. Equipment needs will change to accompany the high residue levels, moist soils, and different crops. A systems approach to rotational planning is needed because agronomic, economic, and engineering considerations will interact.

Many factors beyond simple measures of intensity and diversity must be considered. Two rotations with the same diversity and intensity ratings may differ vastly in profitability due to the particular sequencing and/or choice of crops, with one perhaps providing better yield stability in dry years, or better disease avoidance. Other sequencing considerations include crop water use patterns, historic rainfall patterns, snowcatch ability, disease potentiality, insect cycles, phytotoxic effects of residues, color and amount of previous crop residue, weed control, herbicide rotation and carryover, profit/risk ratio, equipment needs, optimum row widths, seeding and harvesting dates, workload spread, individual attitudes, and access to markets. The range and magnitude of effects of sequencing choices has not been fully investigated.

Crop rotation is the best way to manage risk and improve efficiency. On each farm, diversity and intensity need to be balanced to achieve the desired level of risk and return. High intensity with low diversity (wheat-field bean) offers high risk and potentially high returns until major problems develop. Moderately intense, highly diverse rotations such as spring wheat-winter wheat-corn-sunflower or spring wheat-corn-soybean are less risky and return less gross per acre. They can spread workload and fixed costs, reduce price and weather risk and reduce weed, disease, and insect problems. As a result, these rotations can be profitable. Low intensity with high diversity (winter wheat-millet-canola, winter wheat-corn-oat&pea greenfeed) have lower risk in dry years but less gross returns in good years. Low intensity with low diversity rotations like wheat-canola, wheat-fallow or continuous wheat have little future in no-till. They have high fixed costs per acre, higher risk and lower gross return.

Sanitation

Sanitation involves practices that reduce the movement and severity of pests (weeds, diseases, insects) in a field. One of the more important sanitation measures is timely post-harvest spraying to prevent excessive weed seed production. Another example is mowing along field borders to prevent perennials from producing seed (which can be inadvertently gathered and spread by harvesting equipment). Others are the use of weed-free and disease-free seed and the cleaning of equipment between fields. Scouting and border-spraying to prevent insect migrations between fields can be highly effective for some species. Generally, following sanitation practices is more critical in no-till systems because of the elimination of tillage which previously helped reduce population levels of some pests.

Competition & Natural Defenses

No-tillers everywhere have begun to recognize the importance of crop health and competition as an important first line-of-defense against pests. Steps are taken to give the crop the competitive advantage, such as higher populations, narrower rows, seed placement, fertilizer placement, moving crop residues out of the row, and seed treatments. Well-executed, these strategies give the crop the opportunity to form a quick canopy and shade out many weeds.

Plant health plays an important role in minimizing crop damage by a number of diseases as well as some insects. No-till crops can be considerably healthier than neighboring conventionally tilled crops for a number of reasons, including reduced moisture stress, moderated temperatures (due to crop residues), preservation of beneficial organisms, improved nutrient uptake (due to better water availability & mycorrhizal activity), and better soil aeration and drainage. No-till crops can also be healthier due to rotational effects of modified crop environment (eg., reduced winter injury in winter wheat), nutrient cycling, and enhancing beneficial soil organisms. In this way, the positive health aspects reinforce each other, making the crop more resilient to various stresses.

While the fact that healthy crops suffer less from diseases hardly comes as a shock, the idea of plant health impacting certain insect infestations is not well accepted, or at least not taken seriously. It is the belief of one author (Hagny) that some insect species, such as greenbugs and other aphids, tend to attack predominantly plants that are already distressed. With plants and insects having co-evolved over vast stretches of time, it seems highly plausible that plants employ chemical defense mechanisms against some insects and that such defenses are compromised when the plant is under some forms of stress. There are, however, a number of insect species attacking field crops for which plant health plays no direct role in preventing infestation.

Besides plant health, no-till offers other advantages for mitigating infestation and/or damage by various pests. No-till provides an excellent habitat for preserving and building populations of organisms that keep many pest species in check, either by predation, pathogenic effects, alteration of micro-climate, chemical inhibition, or mere competition for resources.

Soil Disturbance

Crops and sanitation can be managed effectively with three crop-type rotations. In a low disturbance no-till system, a weed species will exhaust 98% of its seed bank in approximately a 3-year time frame. During this time, crop types can be grown which allow competitive and chemical control of these weeds. When the original crop is grown again with no chemical control, the problem weed population is greatly reduced. This principle is not applicable in non-diverse rotations using tillage. Even some high disturbance no-till systems will move dormant seeds to the surface where they can germinate.

The tendency, then, is toward ultra-low soil-disturbance. The low-disturbance requirement, together with its effects of maximal surface residues, improved soil structure, and higher soil moisture, demands changes in seeding equipment and new approaches to problems for which tillage is no longer considered an option.

Studying Systems

As previously discussed, a great many of the considerations and choices in implementing or tweeking a no-till production scheme are highly interrelated; cause and effect become inseparably intertwined, mandating a *systems* approach to adopting or researching no-till production.

As crop production becomes more synergistic with (previously ignored) biological processes, it becomes increasingly clear that reductionist science can no longer adequately account for all the repercussions (and perhaps it never did). For instance, the total implications of crop sequence A vs. crop sequence B cannot be fully predicted -- does it increase the yield (or decrease the cost) of crop number two to more than offset the yield loss on crop number three? Nor can the question be subdivided: a separate analysis of the effects of constituent sequences (eg., crops #1 to #2; #2 to #3) does not capture potentially large effects of crop #1 on #3 or vice versa. The only method with acceptable accuracy is to run the two complete systems side-by-side. Unfortunately, very few of these no-till experiments are in existence with adequate rotational intensity & diversity to be meaningful.

Similarly, all the factors affecting pest and pathogen pressures will never be adequately understood. To be sure, we will notice the major influences, but what about the myriad subtleties?

Soil science, too, appears on the verge of crisis. The chemical reactions and nutrient cycles are a hopelessly tangled web of reinforcing and negating pathways. Throw in a few million species of soil organisms, many of which affect nutrient availability, plant health, or each other, and understanding the scene is well beyond our grasp. But lack of complete understanding need not mean utter unpredictability: some islands of stability exist. Perhaps it would be best in some instances to view the soil as a “black box” -- we can’t understand all that goes on inside it, but we can track our inputs and the box’s outputs. In fact, a lot of fertility research has traditionally been done this way. We merely propose expanding the methodology to include other inputs (as well as crop sequences), to run continuously, and to expand the measured outputs beyond yield. Other outputs include soil quality (although yield will eventually demonstrate differences here if the experiment runs long enough), offsite impacts, and number of times the researcher had to intervene to prevent serious losses (measuring the system’s resilience). And, obviously, the black box experiments must be run within a functional no-till system.

Table 1: Calculating Crop Intensity:

Step 1. To compare rotation intensity assign a number to each crop in the rotation based on its crop type (see Table 2). Cool season crops such as wheat, canola, lentil, etc. receive a value of 1 as do short season crops like millet and cover or green fallow crops. Full season crops grown during the warm part of the season (corn, sunflower, sorghum, soybean, cotton, etc.) are assigned an intensity value of 2. Summer fallow is given a value of 0.

Step 2. Sum the intensity values for all crops in the rotation and divide by the number of years in the rotation to obtain an intensity rating.

Some intensity rating examples:

Wheat-Fallow	0.5
Wheat-Corn-Fallow	1.0
Wheat-Corn-Millet-Fallow	1.0
Wheat-Corn-Pea	1.33
S.Wheat-W.Wheat-Corn-Sunflower	1.5
S.Wheat-Corn-Soybean	1.67
Corn-Soybean	2.0
W.Wheat/DC Sorghum-Corn-Soybean	2.33

Since an area's native vegetation integrates precipitation, temperature, elevation, and soil parameters, it serves as a general indicator of suitable no-till cropping intensities. An understanding of native vegetation is useful in developing a no-till program.

1. Environments with trees will support the most intensity.
    a. more water than heat.
    b. easily become too wet.
    c. 100 percent high water use crops and/or cover crops and multiple cropping.

2. Tall-grass prairie mixed with trees.
    a. typical of the corn belt.
    b. supports substantial intensity.
    c. Nearly 100 percent high water-use crops and/or cover crops and multiple cropping.

3. Tall grass prairie with few trees.
    a. Too dry some years with very intense rotations (all high water

use crops).
    - b. 75 to 100 percent high water use crops with limited use of cover crops and multiple cropping.

4. Mixed grass prairie.
    - a. Too dry most years for very intense rotations.
    - b. 50 to 75 percent high-water use crops. No multiple cropping and few cover crops.

5. Short grass prairie.
    - a. Almost always too dry for very intense rotations.
    - b. 50% or less high water-use crops.
    - c. Longer inter crop periods required.
    - d. Some producers may use a small amount of fallow.
    - e. Rotations which allow varying intensity fit for some producers.

6. Short grass prairie mixed with more drought tolerant plants.
    - a. Almost always too dry for a high water-use crop.
    - b. Few if any high water-use crops in the rotation.
    - c. Rotations with fallow and/or flexible intensity.

Table 2: Crop Characteristics Important in Rotation Planning

Crop	Type	Water Use	Seeding*	Critical Water Use Period	Harvest	Harvesting Method	Snow Catch
Winter Wheat	Grass (C)	Low	Sept-Oct	Oct-June	July	Straight/Stripper	Excellent
Spring Wheat	Grass (C)	Low	April-May	June-July	July-Aug	Straight/Stripper	Good/Excellent
Corn	Grass (W)	High	April-May	July-August	October	Corn Head/All Crop	Good
Sorghum	Grass (W)	High	May	August	Sept-Oct	Straight/Flex/All Crop	Excellent
Soybean	Broadleaf(W)	High	May	August	Sept-Oct	Flex Head	Poor/None
Sunflower	Broadleaf(W)	High	May-June	August	Sept-Oct	Pans/All Crop	Fair/Good
Millet	Grass (W)	Low	June	August	September	Swath/Flex/Stripper	Poor/Good
Flax	Broadleaf(C)	Low	April-May	June-July	Aug-Sept	Flex/Swath/Stripper	Fair/Good
Safflower	Broadleaf(C)	High	April-May	July	Aug-Sept	Flex/Swath/Stripper	Fair/Good
Canola	Broadleaf(C)	Low	April-May	July	July-Aug	Flex/Swath/Stripper	Fair/Good
Barley	Grass (C)	Low	April-May	June-July	July-Aug	Swath/Straight/Stripper	Good/Excellent
Oats	Grass (C)	Low	April-May	June-July	July-Aug	Swath/Straight/Stripper	Good/Excellent
Field Pea	Broadleaf(C)	Low/Mod	April	June	July-Aug	Flex/Stripper/Swath	Fair/Poor
Field Beans	Broadleaf(W)	Mod/High	May	July-Aug	Aug-Sept	Swath/Flex/Stripper	Poor/Fair
Cotton	Broadleaf(W)	High	May	July	Oct-Nov	Picker/Stripper	Fair/Good
Chickpea	Broadleaf(W)	Mod	Early May	July	September	Flex/Stripper	Fair/Good
Lentil	Broadleaf(C)	Low/Mod	April	June	July-Aug	Swath/Flex/Stripper	Poor/Fair
Lupine	Broadleaf(W)	Mod	May	July	August	Swath/Flex/Stripper	Poor/Fair
Potato	Broadleaf(C)	High	May	July-August	Sept-Oct	Knife	Poor
Canary Seed	Grass (C)	Low	April-May	June-July	July-Aug	Swath/Straight/Stripper	Good/Excellent
Alfalfa	Broadleaf(W)	Very High	various	May-Aug	May-Aug	Swath/Chop	Poor

*Seeding, Harvest and Critical Water-Use timetables are for the northern U.S. plains (eg. South Dakota)