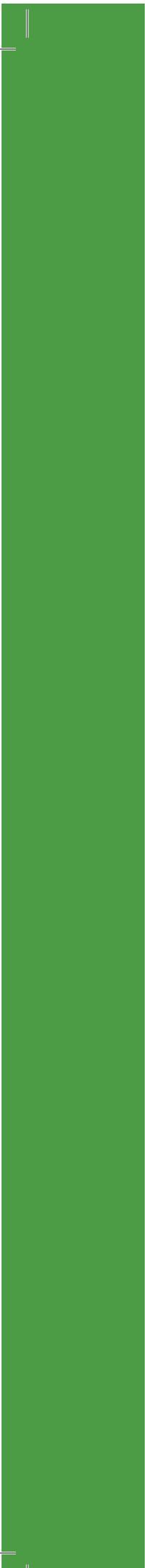


*No-till
Cropping Systems in
Oklahoma*

E-996

*Oklahoma Cooperative Extension Service
Division of Agricultural Sciences and Natural Resources
Oklahoma State University*





Foreword

Early, prestatehood maps of what is now Oklahoma show a patchwork of territories and unassigned areas. These lands were coveted by the pressing population of European-Americans who would soon dramatically change the face of the yet unborn state. A new and different patchwork developed as settlers tilled and planted. For two decades, beginning in the early 1890s, acres planted of cotton and wheat doubled every couple of years with “king cotton” growing the fastest. Potential problems related to typical agronomic practices of the day coupled with the often fragile soils of our state became apparent to scientists at the fledgling Oklahoma Agricultural and Mechanical College in Stillwater. In his book *Agriculture* (an edition of the *OSU Centennial History Series*), Donald Green photocopied a set of class notes taken by Jessie Thatcher in the mid 1890s. Some of the excerpts indicate that Oklahoma A&M was already passing early conservation tillage on to students. Ms. Thatcher wrote, “The productiveness of the soil depends more upon the condition, than upon the quantity of the elementary substances in it.” Her notes went on to say, “The crop (residue) itself if applied as a fertilizer could have much the same effect as the application of manure produced by feeding the crop to animals. Shading the soil by growing crops, such as, clover or grass, or covering it with straw or leaves will increase the fertility of the soil and make the land more productive.”

The State of Oklahoma has come a long way since those prestatehood years. So too has the little Land Grant college in Stillwater and the science it develops and extends to the people of the state. Conservation tillage and agronomic practices evolved since those early days, with the Oklahoma State University’s Division of Agricultural Sciences and Natural Resources assuming the role of scientific leader in changing practices that once led to the tragic Dust Bowl. The Division and its Oklahoma Agricultural Experiment Station and Oklahoma Cooperative Extension Service partnered with other state and federal agencies and many of the producers in the state to develop, test, and demonstrate tillage

and agronomic practices that would better conserve the soil, its moisture, and nutrients. More recently, changes in government programs, plant genetics, low impact practices, farm equipment, and growth of biofuels open the potential for new and dynamic cropping systems. Often, conservation tillage (minimum till, no-till, etc.) practices can be employed to improve the success of these cropping systems and help assure the sustainability of the land.

OSU scientists and their colleagues around the country, along with producers, have tested and revised many conservation tillage practices. This circular is designed to help those producers think about how such practices might fit into their cropping systems. It provides the basics for those producers, as well as some insights for producers already employing an array of conservation tillage methods. This circular should not be the end of your investigation into conservation tillage practices for your operation, but rather the starting point to seek out more information from your local Cooperative Extension educators, other federal and state agency personnel, OSU scientists, and your fellow producers.

The land so coveted by early producers and its soil remains an important and dynamic force in our economy. It is imperative that today’s producers and landowners employ the best management practices for the economic viability of their operations and the sustainability of this valuable resource. We trust that *No-till Cropping Systems in Oklahoma* will prove an important resource in that process. The contents of this circular are made possible through the Oklahoma Cooperative Extension Service, Oklahoma Agricultural Experiment Station, Oklahoma Natural Resources Conservation Service, and Oklahoma Conservation Commission with funding support for its printing from the Oklahoma Natural Resources Conservation Service.

Ross O. Love
Assistant Director
Oklahoma Cooperative
Extension Service

No-till Cropping Systems in Oklahoma

This publication is designed to assist individuals interested in a no-till cropping system in making decisions that affect the production of their operation. We wish to thank the following individuals for their contributions toward this publication.

Authors

Chad Godsey
Extension Cropping Systems Specialist
Oklahoma State University

Gregory F. Scott
Soil Scientist, USDA-NRCS
Stillwater, OK

Jimmy G. Ford
Soil Scientist, USDA-NRCS
Stillwater, OK

Mike Smolen
Extension Water Quality Specialist
Oklahoma State University

Randy Taylor
Extension Agricultural Engineer
Oklahoma State University

Mark Schrock
Professor Emeritus
Biological and Agricultural Engineering
Kansas State University

Robert E. Wolf
Extension Specialist, Application Technology
Kansas State University

Francis M. Epplin
Professor, Agricultural Economics
Oklahoma State University

Hailin Zhang
Extension Soil Fertility Specialist
Oklahoma State University

Case Medlin
Extension Weed Specialist
Oklahoma State University

Robert M Hunger
State Extension Pathologist
Oklahoma State University

John P. Damicone
State Extension Pathologist
Oklahoma State University

Tom A. Royer
IPM Coordinator and Extension Entomologist
Oklahoma State University

Jeff Edwards
Small Grains Extension Specialist
Oklahoma State University

J.C. Banks
Extension Cotton Specialist
Oklahoma State University

Rick Kochenower
Area Agronomy Specialist
Oklahoma State University

We would also like to acknowledge the following organizations for their support and cooperation in making this publication possible: the Oklahoma Cooperative Extension Service, Oklahoma Agricultural Experiment Station, Oklahoma Conservation Commission, and especially the Oklahoma Natural Resources Conservation Service for providing funding to print this manual.

Editor

Janelle Malone
Extension Assistant
Oklahoma State University

Production Editor and Graphic Design

Gayle Hiner
Sr. Communication Specialist
Oklahoma State University

Photos not otherwise credited: Todd Johnson, Ag Communications Services, Oklahoma State University.



Table of Contents

| | |
|--|----|
| Chapter 1. Introduction..... | 1 |
| Chapter 2. Soil Quality and No-till..... | 3 |
| Chapter 3. Effects of No-till on Water Quality..... | 9 |
| Chapter 4. No-Till Equipment..... | 11 |
| Chapter 5. Sprayers for No-till Crop Production..... | 21 |
| Chapter 6. Economics: No-till versus Conventional Tillage..... | 27 |
| Chapter 7. Soil Fertility and pH Management for No-till..... | 37 |
| Chapter 8. Weed Management..... | 41 |
| Chapter 9. Disease Management..... | 45 |
| Chapter 10. Insect Management..... | 49 |
| Chapter 11. No-till Crops..... | 55 |
| Wheat..... | 55 |
| Soybeans..... | 57 |
| Cotton..... | 58 |
| Sorghum..... | 59 |
| Corn..... | 61 |
| Chapter 12. Cover Crops..... | 65 |
| Chapter 13. Personal Experiences..... | 69 |





Introduction

Chad Godsey
Extension Cropping Systems Specialist
Oklahoma State University

No-till Anxiety: Getting Started

Many producers have probably considered switching to a no-till production system at one time or another but have felt anxiety about switching from their conventional tillage practices. It's natural for anyone who has farmed for any length of time to feel anxious about trying a new system. For a producer to establish and learn a new system, it may seem daunting, but it can be done with careful planning and surrounding yourself with knowledgeable people. Following are a few obvious benefits of no-till and some general suggestions if considering a switch to no-till.

“With fuel and machinery costs increasing at the rates they have the past 10 years, I can't believe that there is anyone that hasn't tried no-till.”

Greg Leonard
Afton, OK

The biggest attribute of no-till is long-term productivity of your soil. When a soil is tilled, it loses a key ingredient, carbon. Soil carbon makes up more than half of the soil organic matter. Soil organic matter is a critical determinant in water-holding capacity and overall soil productivity. Soil organic matter has continued to decrease during the past several decades due to intensive tillage. In the western part of Oklahoma, organic matter levels in soils prior to

tillage were probably in the two to three percentage range, while today it would be hard to find a conventional tilled soil with organic matter greater than two percent.

Research has indicated no-till increases organic matter in the top three inches of soil and will tend to conserve more moisture compared to conventional till systems. Moisture savings is the second most important benefit of no-till. It has been estimated in conventional till systems with little or no surface residue that precipitation storage efficiency is 20 percent, so if you receive 10 inches of rain during your fallow period, you only conserve two inches of the 10 you received. Precipitation storage efficiency estimates have been 40 percent in no-till. You can conserve two times as much moisture in a no-till system compared with a conventional till system. There are numerous other benefits to no-till, such as reduced wind and water erosion, time savings, fuel savings, decreased soil compaction, and reduced labor requirements. Greater detail about the benefits of no-till can be found in later chapters.

Finding a knowledgeable no-till producer in your area that has experience with no-till is important. They have worked through some of the same problems that you will probably encounter. Extension educators and Natural Resource Conservation Service district conservationists are also available for information, so there are several sources to answer questions. Keep asking until you find a suitable answer. When making a transition to a no-till system you often hear about slight yield reductions the first three to five years. Many would argue that this is management related and can be overcome by making adjustments to equipment, herbicide/pesticide programs, etc. Also make sure your soil fertility is adequate and you have no compaction problems. This is a perfect example of learning from somebody that has already faced the challenge of converting.

When switching to a no-till system, be prepared to be criticized. There may be comments such as “What in the world is he doing?” and the list could

go on and on. In some parts of the world and even in the U.S. no-till production systems are the norm not the exception. Oklahoma is behind in the adoption of no-till compared to surrounding states.

“What would the neighbors think? Am I just too lazy to be on a tractor all summer?”

**James Wuerflein
Kremlin, OK**

Time savings is often mentioned when talking with no-till producers. It has been estimated that on a 500 acre farm, the time savings can be as great as 225 hours or almost four 60-hour work weeks in a given year, so it may be important to find a hobby to take up extra time.

When considering switching to no-till, it is recommended to have a well-thought-out plan that encompasses the following aspects. Consider soil testing, crop rotation, soil compaction, and how no-till will effect other farm enterprises (e.g., cattle). Be

dedicated and want no-till to work. If you go into no-till with an “I think it is going to fail attitude” it probably will and you will be back to square one. Always remember that no one production system will work the same for everybody. We hope the information in this circular will help establish a successful and profitable no-till cropping system. Use your apprehension to your benefit, which means finding answers to questions.

“It is a trial and error endeavor, just when you think you have it figured out...something else happens, weather, weeds, insects, etc. Once you decide to do it, stick with it, be flexible and learn all you can from different sources.”

**David Shultz
Altus, OK**

Chapter 2

Soil Quality and No-till

Gregory F. Scott
Soil Scientist, USDA-NRCS
Stillwater, OK

What is “Soil Quality?”

Since tillage began, crop producers have been aware of important soil properties affecting plant growth and yield. The term *tilth* evolved from an old English term meaning tillage, and included many of these properties in one term. A soil was often referred to as having ‘good *tilth*’ if it had stable aggregates, high organic matter content, was easy to till, did not crust easily, made a good seedbed, took in water readily, and had a low bulk density. Soils with poor *tilth* crusted easily, were hard, difficult to till, had low organic matter, and were difficult to prepare for planting. Thus, *tilth* refers to “the physical condition of the soil in relation to plant growth” (Brady and Weil, 2002). In the last few years, the term ‘soil health’ or ‘soil quality’ has replaced ‘*tilth*.’ Soil quality includes the properties mentioned above, but includes soil temperature, water content, soil faunal populations, pH, fertility, and nutrient cycling.

One definition of soil quality is “the capacity of a soil to function within the ecosystem boundaries and interact positively with the external environment” (Larson and Pierce, 1991). Soil quality describes how effectively the soils:

- accept, hold, and release nutrients and other chemical constituents;



Photo courtesy of USDA

Jimmy G. Ford
State Soil Scientist, USDA-NRCS
Stillwater, OK

Soil Quality

Good soil qualities are enhanced with no-till practices. With time, favorable changes occur that affect:

- Organic matter content
 - Water infiltration
 - Structure
 - Temperature
 - Bulk density
 - Soil organism populations
 - Hydraulic connectivity
 - Nutrient cycling
- accept, hold, and release water to plants, streams, and groundwater;
 - maintain suitable soil biotic habitat; and
 - respond to management and resist degradation.

This definition shows how soil quality ideas have embraced ecological concepts. However, the

“Remember, it is hard not to go get a plow when things look like a wreck and your neighbors are talking about you, but if you plow, you will mess up soil structure and earthworm activity.”

David Shultz
Altus, OK

Figure 1. Soybeans double-cropped into wheat stubble, Kay County, Oklahoma.

simplest definition may be 'the ability of the soil to do its job,' and the main job we ask of soil in farming is to grow a crop that meets our yield goal (Figure 1).

No-till Effects on Soil Quality

One surprising benefit of no-till is how this system naturally enhances the soil's ability to do its job. Producers can expect improvements in soil quality in both the short- (five years) and long-term (20 or more years) (Sá, et al., 2004.). Ceasing tillage and practicing crop rotation allows natural soil forming processes to proceed. Benefits accrue from year to year when the disruption of tillage is removed. Crop rotations increase the diversity of the system and accelerate the rate of change. This chapter discusses improvements in the individual components of soil quality, but all the components are interrelated.

"Long term no-till leads to improved soil tilth and structure, soil health, water infiltration, and raising organic matter percentage."

**James Wuerflein
Kremlin, OK**

Organic matter

Organic matter (OM) increases are due in part to ceasing tillage. Tillage introduces an abundance of oxygen to the soil that accelerates the action of microorganisms that mineralize organic matter. The simple act of ceasing tillage brings the oxygen supply back in balance and creates an environment where organic matter can increase (Derpsh, 2005). Roots in the soil and crop residue on the surface supply the raw materials for stable organic matter. Even though the bulk of the residues are consumed during respiration by decomposers, a small fraction is converted into soil OM.

The increase in OM influences the water holding capacity, aggregate stability, nutrient cycling, and nitrogen demand. Water holding capacity in soil is largely the product of surface area, where a combination of adhesion and cohesion holds water as a film on the surface of the soil particles. The surface area-to-weight ratio of OM is much larger than mineral particles, so OM holds a large amount of water for its weight. Small increases in OM increase water holding capacity. Organic matter functions as glue for soil aggregates and structural units (blocks, prisms, or granules) and increases aggregation and structural strength. Over time, the soil regains the strength to support vehicles, equipment, and livestock even when wet. Soil OM also functions as a

reservoir for nutrients, and as soil organisms feed on old OM, they release available nutrients back into the system. Creating conditions where organic matter can increase also creates a new demand for nitrogen, since nitrogen is a necessary component of OM. Soil organisms need nitrogen to decompose plant residue and incorporate it into OM. This nitrogen is not lost, but is 'banked' until soil organisms mineralize it and cycle the nitrates to feed crops in future years. Many producers report that this new nitrogen demand is temporary and continues about 10 years.

Carbon is the most important nutrient in the ecosystem. It makes up the bulk of dry matter in all organisms. While plants get carbon from the air (CO₂), all other life depends on the consumption of plant-derived, carbon-based foods for energy and structural components. Organisms that live in the soil depend on plant residues, roots, and soil OM for the carbon to live and carry on various beneficial functions below ground. A large amount of soil OM is an indicator of a properly functioning ecosystem. If topsoil (the top seven inches) has three percent organic matter, it will have about 4,800 tons of organic matter in 160 acres. Under no-till, some organisms are always creating soil OM, while others are decomposing OM, but the trend is increasing OM and feeding the dynamic food-web of underground organisms.

Soil Organisms

Earthworm, fungi, bacteria, and other invertebrate populations generally increase with no-till. With many years of tillage and a single crop, the population of soil organisms falls and becomes unbalanced. This can aggravate disease and pest problems, and prevent maintenance of soil structure and OM. No-till creates a stable environment that allows populations to increase and reorganize. Populations typically build back towards the full diversity of organisms that are 'burned off' with conventional tillage. About 5,000 pounds of soil organisms per acre is not uncommon.

Earthworms create stable macropores, consume and recycle organic materials, and help form stable aggregates (Figure 2). Several species will inhabit a soil, each having a particular season of activity and zone of habitation. Some species come to the surface and others do not, while some are mostly horizontal burrowers and others form long vertical burrows. Plant roots tend to prefer earthworm casts and burrows for growth. The burrows usually have a higher bacterial population and higher available nitrogen. Exudates from worms help glue the casts together into stable granular structure (Tugel and Lewandowski, 2000). Earthworms will tend to move into fields after conversion to no-till from adjacent fencerows or pastures.

Soil fungi carry out several functions; one of the most important is the exudation of glomalin, an organic glue important to stable aggregates (Wright,



Figure 2. Earthworms under no-till corn in Reinach silt loam, Kay County, Oklahoma.

1996). Other fungi live in a symbiotic relationship with the plants, providing additional water, phosphorus, and zinc for a supply of energy. A wide variety of bacteria is responsible for nutrient cycling in the soil. Bacteria, fungi, and nematodes finally cycle the vast majority of nutrients the plant uses from crop residues back to the plant. Nematodes carry out a variety of functions, including nutrient cycling and control of harmful organisms (Tugel and Lewandowski, 2000).

The diversity and population of soil organisms increases with time. As diversity increases, the proportion of beneficial organisms increases relative to harmful ones. For instance, predatory nematodes and fungi become more abundant relative to disease-causing nematodes. The organisms visible to the naked eye serve as a proxy for the ones not seen. Thus, an increase in earthworms, insects, other worms, burrows, fungal mycelia, egg cases, etc. indicate a corresponding increase in smaller organisms.

Permeability, Macropores, and Connectivity

Most soils that have never been cultivated have many large pores that allow rapid movement of water and gasses into and out of the soil. These macropores are the result of earthworms, insects, burrowing insects and mammals, and old root channels from woody plants and forbs. Shrinking and swelling of the soil during wet and dry cycles creates stable cracks in the soil that are important macropores in loamy and clayey soils.

Many conventionally tilled soils have lost nearly all of the macropores from the action of plants and animals. Single crop rotation and frequent tillage destroy residue, earthworm habitat, and macropores; and frequent tillage prevents the formation of new pores. Tillage with conventional tools also destroys the continuity of pores from the surface to the deep subsoil. Pores are destroyed, smeared shut, or compacted shut during tillage operations.

Macropores allow rapid and deep penetration of water into the soil. Water stored in the subsoil is

protected from wind and sun but is available for plants. Rapid infiltration of water also allows more water intake during precipitation.

Gas exchange at the surface is important but often not appreciated. During rapid plant growth, plant roots and soil organisms release large amounts of carbon dioxide, and require large amounts of oxygen. A network of large pores allows rapid diffusion of oxygen into, and carbon dioxide out of the soil. If gas exchange is restricted by a compacted or water saturated soil, plant growth may stop.

No-till systems facilitate the formation of large pores by allowing worm populations to recover. They also enhance the connectivity of the pores by not cutting pores with horizontal tillage or plowing. Deep pores connected to the surface allow rapid and deep intake of water and oxygen. Pores created by plants and animals last for several years, so porosity increases yearly as previous years' pores continue to operate. Crop rotations are an important part of increasing the porosity of a soil. For instance, a crop with a deep taproot will leave behind large pores for several years.

Water Content

For any soil, the goal of a producer is to capture as much water as possible, store that water for a crop, and deliver it back to the crop for optimum yield. As the soil improves, the increase in infiltration rate, permeability, and porosity allows more rain to get in the soil before it runs off the surface.

Crop residues on the surface create an effective barrier that slows water as it runs off the surface and allow more infiltration, especially into the macropores that are developing and increasing in number each year (Figure 3). Those same residues shade and insulate the surface from wind and sun, reducing evaporation from the soil, which is the major loss during fallow periods. The water saved is available for crop production, and a higher moisture content in the surface layer allows more activity in the soil microorganism community that supports plant growth. The soil dries out less often, and the soil organisms operate (nutrient cycling) for a longer portion of the year.

Temperature

In Oklahoma, cold soils are not often a problem, but hot soil is common. Soil temperatures at the surface in summer are commonly 100° F an inch below the surface. The soil heats, dries out, and plant and animal activity ceases. In no-till fields, the soil temperature just an inch below the surface will be 25° F lower than an adjacent tilled field. Typically, these cooler soils have much higher water content. The crop residues shading the surface have a dual benefit of lowering temperature and increasing soil moisture (Figure 4). Plant roots begin to utilize the inter-row



Figure 3. Corn residue on Brewer silty clay loam, Kay County, Oklahoma.

zone that they previously avoided due to heat and dryness. Nutrient availability is higher because the soil fauna are active longer than in a tilled field.

Structure, Aggregate Size, and Strength

Tillage does not create soil structure; it destroys structure and creates clods. Often we spend the fallow period trying to break up those clods for planting. The structure of topsoil in tilled fields is artificially created by numerous trips with plows, disks, harrows, etc. After a rain, it collapses into massive clods, and often forms a crust. No-till allows a natural granular structure to reform; this occurs first at the very top of the soil (Figure 5).

The natural structure that prairie soils have in the surface layer is a product of plant roots, earthworms, soil fungi, and wetting/drying cycles. Earthworms eat soil and their casts form the basic structure of the surface soil. Worm exudates and glomalin from soil fungi are the glues that hold aggregates together. The change from artificial soil structure created by tillage to natural granular structure (Figure 6) does not happen overnight, but structure that forms and is not destroyed lasts for years. As surface aggregates replace the powder-fine surface commonly found in tilled fields, the size of the surface aggregates increases toward the size of the aggregates in the subsoil. Water moves from the surface to the subsoil more easily when there is not a drastic change in aggregate size. Surface tension in the powdery topsoil can inhibit water moving into the subsoil.

The product of reforming soil structure and strength is counter-intuitive to those who are used to clean-tilled fields. The aggregates gain strength to hold up tractors and vehicles, while the density decreases and porosity increases. Conditions approach those of a native prairie that is firm to drive on, but is very porous.

Density

A healthy soil should be about 50 percent solid matter, and at least 50 percent pore space available to hold roots, water, and air. Compaction resulting from conventional tillage reduces the pore space by



Figure 4. Wheat residue on dryland no-till, Cimarron County, Oklahoma.



Figure 5. Worm casts and crop residue, Tabler silt loam, Kay County, Oklahoma.

packing soil particles tightly together. Compaction results in less available water, lower permeability, and oxygen-starved soils. It can prohibit plant roots entering the subsoil, effectively turning a deep soil into a very shallow soil. Compaction (or high bulk density) increases the energy a plant must expend to grow roots through compact soil. Roots tend to be shorter, fatter, and explore less soil (Nadian et al., 1997). Compaction lowers yields by reducing the soil available to the plant and causing the plant to expend extra energy to grow roots rather than put the energy into yield. Roots growing horizontally at the bottom of the tillage layer are a definite symptom of compaction.



Figure 6. Granular structure forming on soil surface, Tabler silt loam, Kay County, Oklahoma.

A soil density of 300 pounds per square inch (psi) will stop the root growth of most plants. In Oklahoma, many tilled fields have more than 300 psi density within nine inches when they are moist. A producer can diagnose the depth, severity, and pattern of dense layers quickly with a soil compaction tester, a three foot piece of steel ¼-inch round stock with a T handle or a commercial product with a pressure meter (such as the Dickey-John Tester, Figure 7).

No-till simultaneously decreases density and reverses compaction by not interfering with the processes previously mentioned. The action of roots; earthworms; shrink-swell, wet-dry, and freeze-thaw periods reverse compaction in loamy and clayey soils (Figure 8). The benefits from these soil-forming processes begin and accumulate year by year when tillage ceases.

Sandy soils react differently to compaction. Many have the perfect proportion of sand and clay to be compacted to a high density, but do not have enough clay to swell when they are wet. Natural processes that keep sandy soils from packing are relatively large soil animals (i.e. gophers) and a more diverse population of plants with coarse roots.



Figure 7. Using a density tester to locate compacted zones in soil.



Figure 8. Density of corn roots in no-till, Reinach silt loam, Kay County, Oklahoma.

A strategy for decreasing compaction on sands may require more diverse crop rotations and toleration of a population of burrowing animals.

Tillage Planes and Hydraulic Boundaries

Closely related to high density are the boundaries created by normal tillage tools (disks, sweeps, and plows). As these tools move through the surface, they push down with enough weight to compact and smear the cut surface they create. Most producers perform tillage at the moisture content which allows maximum compaction. Over time, a soil will accumulate several of these surfaces at different depths, with very dense plates of soil between them. This platy structure and the compact, smeared boundary are very effective at stopping roots, water, and air infiltration. Note the horizontal roots at this boundary (Figure 9).

The processes that reverse compaction also operate to reverse tillage planes. Cracks, pores, animals, and roots begin to break up tillage planes when tillage ceases and can change the horizontal plates to natural structure in a few years in some cases. In loamy and clayey soils in Oklahoma, as the tillage planes disappear, roots begin to enter the subsoil and grow to surprising depths. The clayey subsoil did not limit the roots; the packed boundary at the bottom of the tillage layer did.

Erosion by Wind and Water

The rate of erosion by wind and water falls dramatically with no-till. Crop residue covering the sur-



Figure 9. Roots growing horizontally on bottom of tillage pan.

face protects the soil surface from the energy of wind and rain. The residue dissipates the kinetic energy of raindrops and wind. Soil particles are not detached and are not available for transport off the field. The additional aggregate stability resulting from organic 'glues' also help protect soil from erosion.

When soil particles stay in place, they contribute to clean air and water. Less dust is produced, less sediment enters streams, and chemicals attached to soil particles stay in the field instead of entering water bodies.

Conclusion

No-till enables rapid increases in soil quality simply by working with soil forming processes rather than against them. The product of improved soil is a system that is more productive because it is more able to provide for plant needs, which in general are water, nutrients, and oxygen. Biological activity and nutrient cycling is high. Macropores are created and maintained. Root density and depth of rooting increases. Plants have access to more volume of the soil, and the water and nutrients present there.

Improvements are not instantaneous, but the changes do begin immediately, and producers see signs in the first year. However, the soil goes through several phases and patience is important, especially in the first five years. Often, conditions seem to get worse in the third and fourth season, but improve quickly in the fifth to seventh. Producers in other regions and countries have observed that improvement continues for more than 20 years, depending on the soil, climate, and rotation used. Producers need more adaptable management than in a tilled system.

It is important to note that none of these components operates independently. Quality increase occurs simultaneously in many components, and improvement in one component affects the whole system. For instance, increased residue cover lowers soil temperature, increases water content, lowers erosion, supports the soil organism community, and leads to increased nutrient cycling.

References

- Brady, Nyle C., and Ray R. Weil. 1996. *The Nature and Properties of Soils*, 13th edition. Prentice Hall, Upper Saddle River, New Jersey.
- Daddow, R. L., and G. E. Warrington, 1983. Growth-limiting soil bulk densities as influenced by soil texture. USDA Forest Service, Watershed Systems Development Group, Fort Collins, CO.
- Derpsch, Rolf. 2005. The extent of conservation agriculture adoption worldwide: implications and impact. Paper presented to III World Congress on Conservation Agriculture, Nairobi, Kenya, October 2005.
- Gove, P. B. and the Merriam Webster Editorial Staff. 1993. *Webster's Third International Dictionary*. Merriam-Webster, Springfield, Massachusetts.
- Karlen D. L., M.J. Mausbach, J. W. Doran, R. G. Cline, R. F. Harris, and G. E. Schuman. 1997. Soil Quality: A concept, definition, and framework for evaluation. *Soil Science Society of America Journal* 61, 1, pp. 4-10.
- Larson, W. E., and F. J. Pierce. 1991. Conservation and enhancement of soil quality, in *Evaluation for sustainable land management in the developing world*. pp. 175-203. Bangkok, Thailand.
- Nadian, H., S. E. Smith, A. M. Alston, and R. S. Murray. 1997. Effects of soil compaction on plant growth, phosphorus uptake and morphological characteristics of vesicular-arbuscular mycorrhizal colonization of *Trifolium Subterraneum*. *New Phytology*, 135, 303-311.
- Sá, J. C. M., et al. 2004. Carbon sequestration in Brazilian no-tillage soils. Paper presented January 30, 2004 at the Agronomy Seminar, Kansas State University, Manhattan, KS.
- Seybold, C. A., M. J. Mausbach, D. L. Karlen, and H. H. Rogers. 1997. Quantification of soil quality, in B. A. Stewart and R. Lal (eds.) *Advances in Agronomy*. Proceedings from an international symposium on carbon sequestration in soil. Lewis Publishers.
- Tugel, Arlene, Ann Lewandowski, Deb HappevonArb, eds. 2000. *Soil Biology Primer*. Rev. ed. Ankeny, Iowa: Soil and Water Conservation Society.
- USDA-NRCS, NSSC, Soil Quality Institute, SWCS, and USDA-ARS, National Soil Tilth Lab, Soil quality information sheet series. 2007. <http://soils.usda.gov/sqi/>.
- Wright, S. F., M. Franke-Snyder, J. B. Morton, and A. Upadhyaya. 1996 Time-course study and partial characterization of a protein on hyphae of arbuscular mycorrhizal fungi during active colonization of roots. *Plant and Soil* 181:193-203.
- Young, I. M., and J. W. Crawford. 2004. Interactions and self-organization in the soil-microbe complex. *Science*, 304: 1634-1637.

Effects of No-till on Water Quality

Mike Smolen

Extension Water Quality Specialist
Oklahoma State University

The Clean Water Act of 1972 recognized point source and nonpoint sources of pollution. The point sources were defined as those issuing from a pipe or manmade conveyance. Nonpoint sources were defined as everything else, including runoff from agricultural cropland. Point sources were addressed by an aggressive nationwide campaign of permits and regulations. This program was so effective that by 1992, most pollutants were deemed to be from nonpoint sources (EPA 1994). Although a wide variety of pollutants remain a problem, the agricultural issues are primarily pathogens, eroded soil, plant nutrients, particularly nitrogen and phosphorus, and pesticides. In Oklahoma, approximately 71 percent of assessed streams were deemed to be impacted by agricultural sources (EPA 2002).

“Saving more water in the soil allows you to withstand the dry spells longer...less runoff erosion...if you rely on runoff to fill your ponds for livestock (or fishing) you had better pray for floods.”

James Wuerflein
Kremlin, OK

Eroded soil from cropland is a pollutant that smothers aquatic habitats and carries other pollutants such as fertilizer nutrients, herbicides, and insecticides into waterways. Aquatic plants thrive on these fertilizer nutrients, particularly phosphorus, which is typically limiting in aquatic systems. Thus, agricultural runoff may result in

Water Quality

Water quality improvement is the biggest benefit of a no-till production program resulting from:

- Reduced run-off
- Reduced sediment loss
- Greater soil retention of herbicides and fertilizers

stimulation and excessive growth of algae and other aquatic vegetation, causing severe water quality problems. Overgrowth of algae, in particular, causes taste and odor problems for drinking water supplies and oxygen depletion that may kill fish. Sediment from cropland erosion may also increase the turbidity (cloudiness) of water, impairing fisheries.

Perhaps the biggest water quality benefit from no-till production systems is the resulting reduced soil erosion and runoff. These benefits, however, may be offset somewhat by increased use of certain herbicides and nitrate contamination of ground water. A particular concern is the problem of herbicides like atrazine in runoff water.

No-till significantly reduces sediment loss from cropland. As shown in Table 1, Hill and Mannering (1995) found that increasing residue cover from zero to 93 percent reduced the amount of runoff, runoff velocity, and soil loss almost to zero. The crop residue, present in no-till systems, protects the soil surface from the impact of raindrops and acts like small dams to slow the flow of runoff across the surface (Hill and Mannering, 1995). Consequently, surface runoff stays in the field, allowing more opportunity for infiltration and saving water.

Seventy-five to 90 percent of the phosphorus that moves into surface waters is attached to eroded soil particles. No-till systems can control this source very effectively, but the remaining 10 to 25 percent is dissolved in runoff water (Devlin et al., 2000).

Table 1. Effects of surface residue cover on runoff and soil loss.

| <i>Residue Cover %</i> | <i>Runoff % of runoff</i> | <i>Runoff Velocity Feet/minute</i> | <i>Soil Loss Tons/acre</i> |
|----------------------------|-------------------------------|--|--------------------------------|
| 0 | 100 | 26 | 12.4 |
| 41 | 89 | 14 | 3.2 |
| 71 | 58 | 12 | 1.4 |
| 93 | 1 | 7 | 0.3 |

Modified from Hill and Mannering, 1995.

For this reason it is especially important in no-till systems that P fertilizers and manure be applied carefully, following soil test recommendations and using Best Management Practices (BMPs) like banding to reduce runoff losses. Because infiltration occurs more readily in no-till systems, it is also very important to use BMPs for nitrogen application like splitting nitrogen applications and matching nitrogen rates closely to crop needs. Likewise, it is important to utilize all available herbicide BMPs to assure minimal impact on water quality.

References

Devlin, D.L., D.A. Whitney, and K.A. McVay. 2000.

Phosphorus and water quality in Kansas. Kansas State Univ. Ag. Exp. Station and Coop. Ext. Service. MF-2463. Manhattan, KS.

Hill, P.R. and J.V. Mannering. 1995. Conservation tillage and water quality. Coop. Ext. Purdue Univ. West Lafayette, IN.

U.S. Environmental Protection Agency. 1994. The quality of our nation’s water. A summary of the 1992 National Water Quality Inventory. Office of Water, Washington, D.C.

U.S. Environmental Protection Agency. 2002. 305b Report. Assessment Data for the State of Oklahoma Year 2002. Available on the web at http://iaspub.epa.gov/waters/w305b_report_v2.state?p_state=OK#total_assessed_waters

Chapter 4

No-Till Equipment

Randy Taylor
Extension Agricultural Engineer
Oklahoma State University

Mark Schrock
Professor Emeritus
Biological and Agricultural Engineering
Kansas State University

Once the decision has been made to start no-till, planting the crop seems to be a major concern. Obtaining good stands in no-till conditions requires planters and drills that can penetrate firm soil and cut or move heavy surface residues without plugging. Planting seed at a uniform depth and in firm contact with moist soil assures a good stand (Figure 1). There are many planters and drills on the market that can accomplish this task. There are also some older seeders available that perform quite well with the proper adjustments and/or attachments.



Figure 1. No-till corn in wheat residue.

No-Till Drills

No-till seeding of corn and other drilled crops differs from conventional till in many ways. More residue must be cut or moved out of the path of the opener. This is a challenge for the narrow 6- to 12-inch row spacing used for grain drills, and some of the solutions used for row crop planters are simply too expensive or the attachments are too large to be used on drills. On the positive side, soil moisture is

Seeding Equipment

No-till seeding of crops differs from conventional tillage with respect to the equipment needed. Considerations include:

- Row spacing
- Types of openers
- Press wheels
- Depth control
- Residue management
- Topography of fields

usually closer to the surface in no-till than in conventional till. This means that seeding depths can often be shallower with no-till, provided the seeding depth is still sufficient for adequate early season plant growth. Also, heavy residue slows the rate of soil drying and reduces the tendency of the soil to crust before the plant emerges.



Figure 2. A no-till drill ready to seed into wheat stubble.



Figure 3. No-till drilling soybeans into milo stubble.

Component/Design Features

When looking at no-till drills there are some items that are worth comparing. Row spacing, types of openers, linkage, press wheels, and depth control are just a few of these. Consider all crops that will be seeded with the drill and choose the best options for your environment (Figure 3).

Row Spacing

The standard row spacing for most drills is 7.5 inches. For wheat, this row spacing tends to be much wider than the theoretically ideal square plant zone (equal distance in all directions to nearest plant). A bushel of wheat typically contains between 800,000 and 1,000,000 seeds, so achieving the square plant zone would require approximately 2-inch row spacing at a 1.5 bushels per acre rate. The concept of ultra-narrow row openers has been investigated in Oklahoma. A research study compared 3-, 6-, and 9-inch row spacings for two years at several locations. The study predicted a yield increase of about eight percent and nine percent for 6-inch and 3-inch rows compared with 9-inch rows. The yield response to the narrower rows occurred in both cheat-free and cheat-infested fields. The study concluded that the optimum row spacing for seeding rates commonly used in Oklahoma was about 6.6 inches. Thus, 6-inch and 7.5-inch row widths appear to be appropriate for wheat in Oklahoma.

For producers whose primary use of a no-till drill is soybeans and grain sorghum, a 10-inch spacing may be the most economical compromise, if wheat acreage is low. Grain sorghum growers who use seeding rates in the range of 30,000 to 60,000 seeds per acre can block half of the openers in the raised position to achieve satisfactory (12- to 20-inch) row spacing while eliminating unnecessary opener wear. The same technique can also be used for soybeans.

Naturally there is added cost of narrow row spacing on drills. A drill with 7.5-inch spacing has a third more openers than a drill with 10-inch spacing. However, the narrower row spacing may provide better weed control by allowing the crop to canopy sooner.

Types of Drills

The type of seed slot openers typically categorizes drills. There are three primary types of openers used in Oklahoma. They are the single-disk, double-disk, and hoe.

Single Disk Openers

For conventional tillage, single-disk openers were the standard grain drill in Oklahoma for more than 50 years. These openers usually consisted of a single concave 13-inch disk suspended by a simple swing arm. Depth control was acceptable in conventional tillage seedbeds without using an attached press wheel for depth control. Although these single disk drills are still available, the market for conventional till to reduced till drills has been largely captured by double disk openers during the last two decades.

No-till single-disk openers are available from several manufacturers (Figure 4). Designed for no-till, these openers are equipped with large (16- to 22-inch), heavy, flat disks with a heavy duty disk hub and bearing. These openers use a swing arm suspension, with depth controlled by a gauge wheel

Figure 4. A single disk opener on a Flexi-Coil air seeder. Note the tilted opener disk.





Figure 5. A single-disk opener operating in wheat stubble.

beside the opener. A narrow press wheel is typically operated directly in the seed furrow to create seed-to-soil contact and a furrow closing wheel typically follows (Figure 5). Although the single disk is subject to hairpinning when planting in tough residue, these openers can place seed at the desired depth with minimal disturbance of crop residues. They may be equipped with hydraulic down force adjustment (sometimes called “active” down force). The hydraulic down force system keeps a nearly constant force on the opener to maintain more consistent depth control over rolling terrain.

Double Disk Openers

Double disk openers usually have a press wheel attached directly behind the opener for depth control, seed-to-soil contact, and furrow closing. Double disk openers move less soil laterally than the concave single disk drill, allowing them to operate at higher speeds than the concave single disk. However, they have more lateral soil movement than the newer single disk no-till drills.

Double disk openers may be suspended by a swing arm, parallel arms, or a strut and swing arm combination (Figures 6, 7, and 8). Down force may be applied by springs, hydraulics, or a combination of the two. Most double disk openers that are intended for no-till have the disks offset slightly (0.5 to 1.5 inches), so only the leading disk edge cuts residue. In some cases, the trailing disk is a smaller diameter than the leading disk. The leading disk may also be notched, which should help cut residue better (Figure 9).

Coulter/double-disk combinations are a popular style of no-till drill, sometimes known as the “fluff-and-plant” system (Figure 10). These machines use coulters (usually rippled or wavy) aligned to run directly in the path of the double-disk openers. The coulters cut the residue and till the soil in front of the opener. Depth of the coulters



Figure 6. A Sunflower no-till drill with parallel linkage system.



Figure 7. A Great Plains no-till drill with parallel linkage system.



Figure 8. A Great Plains no-till drill with a swing arm linkage system.

and speed of operation have a major impact on the function of this concept. The addition of the coulters will cause more soil and residue disturbance than single disk and double disk no-till drills operating without coulters.



Figure 9. A double disk opener on a no-till drill with staggered disks and a notched leading blade.



Figure 10. Tillage action of coulters on a no-till drill.



Figure 11. A Great Plains no-till drill operating in milo stubble.

Hoe Openers

Hoe openers generally require much less down force to penetrate firm soil, and they usually move more soil laterally than disk openers. A hoe tends to lift the residue and allow it to fall to the side, whereas disk openers tend to push residue into the soil as they cut it. These features have made hoe drills more popular in western Oklahoma than in the east (Figure 12). The challenge of planting in dry conditions is to place the seed into moist soil without covering it too deeply. The hoe opener, operated on



Figure 12. A Haybuster no-till hoe drill. Note the under frame clearance for residue flow.

relatively wide spacing (10 to 14 inches), can move a layer of dry soil into a ridge between the rows. This can allow the seed to be placed 4 inches below the original soil surface, while covering the seed with about 2.5 inches of soil.

Hoe openers are usually used with gangs of “full press” wheels, which can carry much of the drill or air seeder frame weight. Full press wheels can apply heavy down force, forming well-defined furrows and ridges on the soil surface.

Though the hoe opener may require less down force for soil penetration, it will pull harder than most disk type no-till drills. Also the greater lateral soil movement created by hoe openers tends to limit the maximum speed of operation. At high speeds, the second (and third) ranks of openers tend to cover the front rank with additional soil. This may produce a noticeable stand reduction produced by the front rank. Attachments have been marketed to limit lateral soil movement from the rear rank.

On hoe drills, the openers are usually attached to the frame via a swing arm. There are a few examples of hoe openers having depth control/press wheels. With hoe-type air seeders, the opener is often rigidly attached to the seeder frame (the opener may be equipped with a spring linkage for shank protection). Such seeders rely on good frame flexibility to allow the machine to comply with lateral terrain features. Floating hitches, used with support wheels in front of the main frame, allow the frame to follow the ground independently from the tractor. Hoe openers may be selected to apply seed in narrow or wider bands and dual place fertilizer.

Older-model hoe drills do not function well in heavy residue. There are typically three dimensions that dictate how well a hoe drill will operate in residue: clearance, rank spacing, and spacing between openers on a rank. Increasing any of these dimensions improves the operation characteristics of hoe drills in no-till systems. Current hoe drills have much greater clearance than previous generation hoe drills. Three-rank hoe drills are available with

26-inch vertical clearance and 20-inch longitudinal spacing between ranks. Coulters are available on some models for operation in very heavy residue.

Depth Control

Depth control is a concern with any seeding system. A survey of conventional grain drills conducted in 1994 by Oklahoma State University researchers indicated a strong tendency for farmers to plant wheat much deeper than they intended. Only about 20 percent of producers were at or near the intended depth, and 68 percent of the fields were planted too deep. Excessive depth delayed emergence and reduced stands. In more than half of the fields examined, emergence was less than 60 percent. Kansas State University research in no-till wheat indicated that each half-inch of excess depth reduced the stand by six to 22 percent, depending on location.

“Start with the right equipment, talk to experienced no-tillers, check your planter settings, and constantly adapt, adapt, adapt!”

**Larry Davis
Miami, OK**

It is critical that depth be checked, especially when changing fields or planting conditions. This can be time consuming, especially in grain sorghum, where the seeds are small and more widely spaced than wheat. The objective is to place the seed in contact with moist soil, with an acceptably shallow covering depth. Because soil moisture varies with both location in a field and the time of planting, depth is usually a compromise between the need to place the seed into moisture and the need to plant shallow for quick and uniform emergence.

With most disk-type openers, the two primary adjustments affecting depth are a) the down-force applied to the opener, and b) the relative position of the disk and the depth-control wheel. Understanding how these two adjustments affect depth control is important. The down-force applied to the opener is balanced by the up-force of the soil on the disk itself and on the depth control wheel. In some cases, a seed firming wheel or runner also applies force to the soil.

As the opener moves through the field, the force on the disk changes in response to soil hardness and residue conditions. Any down-force not used to make the disk penetrate to the desired depth is fed

into the depth control wheel. No-till seedbeds usually require more down-force for disk penetration. If an opener is planting too shallow, check to see if the depth control wheel (in some cases the press wheel) is carrying a load. If the depth control wheel is not supporting down-force, depth will not be increased by raising the wheel. The solution is more down-force. Conversely, when moving a drill from firm soil to looser conditions, down-force should be reduced to prolong the life of the opener suspension, the depth control tire, and the bearing. In general, use just enough down-force to consistently force the disk to the desired depth, with enough left over to let the press wheel do its job. Depending on the drill, down-force may be adjusted by changing spring preload, hydraulic pressure, or even the operating height of the drill frame. Check the operator’s manual for specific instructions on depth and down-force adjustment. Also, many disk openers have more than one style of down-force springs available. Heavier springs are used for reduced or no-till seedbeds.

Residue Management

There are two basic options with residue management. One option is to cut through the standing residue and leave as much as possible still standing. Another option is to use coulters to mulch the residue ahead of the openers. If the residue is left standing, the risk of hair-pinning into the seed trench is possible.

Naturally, residue disturbance is a function of opener spacing, but the following generalities can be made regarding opener design. Residue disturbance is least with single disk openers. Double disk openers disturb more residue than single disk openers, but still leave a substantial amount of residue attached and standing (Figure 13). Drills with coul-



Figure 13. The area on the left was seeded with a single disk opener drill and the area on the right was planted with a double disk drill equipped with coulters.



Figure 14A. A single disk Flexi-Coil air seeder.



Figure 15. No-till planting of corn in milo stubble.



Figure 14B. A single disk Flexi-Coil air seeder.



Figure 16. No-till planting of soybeans in milo stubble.

ters will leave very little residue attached and standing, but the surface generally has ample residue to protect the soil from erosion.

Air Seeders

Air Seeders are now available with both disk and hoe openers, plus sweep and paired-row openers (Figures 14A and 14B). Using air to convey the seed (and fertilizer) from a central tank offers at least three basic advantages over conventional grain drills. First, the central hopper of an air seeder eases filling. Secondly, wings can be folded vertically for road transport like a tillage tool. These two advantages become more important as the width of the seeder increases. The third major advantage is the ability of the air seeder to transport seed horizontally under the soil. This allows one opener, such as a small sweep, to seed multiple rows of seed. It also facilitates the concept of the paired row.

A wide variety of openers are available for air seeders. Knife-type openers cut a narrow slot for seed placement with minimal soil disturbance, while sweep-type openers accomplish some mechanical

weed control at seeding time. Double-shoot openers use separate tubes for seed and fertilizer, allowing a heavy rate of nitrogen to be placed a safe distance from the seed. Openers are available to dual place dry, liquid, and even anhydrous ammonia fertilizer with the seed. Some air seeder openers split the seed stream into two rows, 3 to 7 inches apart, and place the fertilizer between the seed rows. The paired row concept is intended to give the crop preferential access to the fertilizer.

Topographical Conditions

Tillage tends to even out or “level” a field. Conversely, for reduced and no-till farming, unevenness is often more extreme and may increase with time. Erosion may be a major cause, especially for steep slopes, but terraces and contour farming are also causes of topography variations. With larger machinery and farming more marginal land, there is a greater requirement for machine flexibility. Most new planters have flex linkages that allows each row to move up and down independently of each other. This feature allows the planters to accommo-

date the soil unevenness. Flexing of the frame will be required for wide planters or uneven topography.

Planting on the contour often requires sharp turns. The distance from front to back (coulters to opener and press wheels) determines how well the planter will follow the row. The shorter front-to-back distance, the better the planter will stay on the row. Pull-type planters will follow curves better than mounted planters, but keeping spacing on steep side slopes may be a greater challenge.

No-Till Row Crop Planters

Row crop planters can be used to obtain good stands in no-till conditions even if the planter was not originally equipped for no-till. Most late model planters are heavy enough to be set up for no-till. They may require additional, or heavier, down-force springs to help penetrate firmer seedbeds. Coulters to slice through heavy residues or row cleaners that move residue from the seed slot may also be needed. Selecting the correct optional equipment and a good knowledge of planter adjustment are important for best planting in heavy residue and firm soil. If the planter is adjusted properly, it can operate in most no-till conditions without coulters or row cleaners.

Adjustments

For optimum planter performance, the frame should be leveled. Leveling the planter allows the row unit to stay parallel to the soil surface throughout its full range of motion. When a planter is level, the row unit will operate parallel to the ground. If the planter is not level, it will be more difficult to 'fine tune' the adjustment for operating in crop stubble. Making adjustments at the drawbar typically levels pull-type planters. Leveling of mounted planters is accomplished by adjusting the third link, while adjusting the carrying wheels levels semi-mounted planters.

Seed Metering

A well-controlled and evenly distributed plant population is essential for high yields. The metering mechanism should drop the same number of seeds per unit length regardless of variation in seed size and shape, travel speed, and slopes. Planter plates with individual openings for each seed are much more precise in spacing than feed cups used on drills. The spacing should be the same in all rows. Changing seeding rate (number of seeds per acre) should be simple. Plateless seed mechanisms are helpful in achieving uniform spacing with unsized seeds, especially for corn. A survey of planters in Nebraska showed a decrease in spacing uniformity when coulters-driven planters were used in tilled

fields and when press wheel-driven units were used with less tillage.

Seed Depth Uniformity

A planter should place seed at a uniform depth regardless of soil or residue conditions. Tillage tends to mask soil variations, which help improve uniform seed placement on old style planters. In no-till and reduced-till planting systems, the variations in soil conditions will usually be greater than with conventional tillage. Variations in soil texture are common, especially in alluvial soils, where they may range from clay to sandy soil in the same field. Surface residue retards soil drying so uniform residue conditions are especially important for no-till planting. Obtaining uniform residue spreading with wide combine platforms is especially challenging, but large spreaders and some straw choppers generally improve residue uniformity.

"You must be willing to commit to no-till and buy a drill made for no-tilling. You can add attachments and make a normal planter work in normal conditions."

**Greg Leonard
Afton, OK**

Variations in soil conditions make design of a planter that will perform equally well under all conditions difficult. New planters with depth gauge wheels at the side of each opener can drop seed at a uniform depth under a wide range of soil texture and moisture conditions. This feature, plus heavier weight and heavy-duty coulters enable accurate seed placement in difficult soil and residue conditions.

Press wheel or coulters controlled depths are generally more variable than gauge wheels beside the opener. Press wheels are adjacent to the opener rather than leading or following the opener as with press wheels or coulters.

Openers

The primary items of interest on row crop planters are the slot openers and presswheels. The opener forms a slot or groove in the soil for seed placement and one or more press wheels compact soil around the seed. Openers on row crop planters are typically double disks or runners. Because runner openers re-

quire looser soil for adequate penetration, the fluted coulter may be required. Double disk openers will usually penetrate following a coulter that has cut residue and penetrated firm soil.

Openers shape a groove for the seed and provide a bed for seed-to-soil contact. The runner opener shapes a sharp 'V' groove, which centers the seed. The double disk alone provides a less accurate flat or slightly raised center seed slot. Some double disks also have a small chisel or runner in the center to shape a rounded or 'V' groove. The shape of the seed opening is probably not as important as depth control, which provides seed placement in firm contact with moist soil.

Double disks and runners may press residues and dry soil into the seed opening which can delay germination and emergence. In a reduced tillage condition, buried residue and large soil clods can be serious detriments to obtaining good seed-to-soil contact for all planters.

Attachments

Though adjustments are probably the most critical item affecting row crop planter performance, there are several attachments that can help improve performance. These attachments help planters operate in heavy crop residue and improve seed-to-soil contact.

Coulters

Coulters are used to cut residue and penetrate firm soil planting conditions (Figure 17). The amount, condition, and distribution of previous crop residue as well as soil conditions affect proper operation of the coulter. Fresh, damp, wheat straw is tough and difficult to cut. Dry, decayed straw can be cut easily with sharp coulters.

Sod crops, such as grass or alfalfa, or stubble grazed by livestock on wet soil may result in very firm soil, especially when dry. Coulters in front of the planting units are essential to cut through sod and firm soil. In other conditions, such as moist soil



Figure 17. A bubble coulter on an older John Deere planter.

and little residue or following soybeans, the same soil may be quite soft and easily penetrated. Some coulter units are adjustable for down pressure and some have provisions for adding weight to increase penetration and cutting capability. When the soil is firm and dry, these features may be essential to ensure penetration.

Many types of coulters are available to cut residue and penetrate the soil. Each have advantages and disadvantages, so choosing one can be confusing. Large diameter coulters will mount residue but require more weight (or down pressure) to cut residue and penetrate soil.

Smooth or rippled coulters are preferred for cutting residues. Coulters with a smooth surface can be rolled to ensure a sharp edge for cutting heavy, tough residue. The rippled coulter with a smooth edge cuts well, loosens a narrow band of soil, and helps the coulter rotate.

Fluted and wavy coulters are available in a variety of widths and designs. They are ideal for tilling a narrow strip of soil ahead of the row opener. In some soil conditions this tillage may be required, but most often for spring planting the soil is soft and crumbly and requires little or no tillage. The need for tillage is partly dependent on the opener type and weight of the row units. The amount of tillage that fluted or wavy coulters provide is dependent on coulter width and number of waves. Wider coulters and less waves typically means the coulter will till the soil more. Wider coulters usually require more weight for cutting and penetration.

Row Cleaners

Row cleaners can be used on disk-opener type planters to move residue from in front of the opening disks and gauge wheels. Moving the residue means that the opener no longer needs to cut through it. This should increase the life of the opener disks by reducing wear.

Moving residue also provides gauge wheels a smoother operating surface, which allows more uniform depth control. Row cleaners can provide earlier emergence when planting crops in early spring. By moving residue off the seed slot, the soil in the row warms more quickly since it is a darker color than the residue covered soil between the rows. For later planted crops this is probably not an issue.

Row cleaners also have some disadvantages. If preplant herbicides are broadcast on the field, row cleaners can move them out of the row with crop residue. This can be disastrous. Row cleaners can have some problems operating in wet wheat straw and fields with heavy weeds. When these conditions exist, row cleaners tend to clog and stop turning.

Types of row cleaners vary widely (Figures 18, 19, and 20). They typically consist of concave disks

or spoke wheels, and may also have some type of a coulter mounted with them. In general, the disk type row cleaners move more soil than the spoke type. The disk type row cleaners are adequate for some no-till applications, but the spoke type units work better in more conditions.



Figure 18. A spoke-type row cleaner on a Kinze planter.



Figure 19. A combination coulter/row cleaner.



Figure 20. A 'saw' or 'shark tooth' type row cleaner.

Press Wheels

There are many current options for press wheels when ordering a planter or retrofitting an older planter (Figure 21). These range from cast iron to plastic in construction. Though many options exist, proper adjustment is still a necessity. Remember the primary function of press wheels is to provide good seed-to-soil contact for uniform emergence. When properly adjusted, factory press wheels generally provide adequate seed-to-soil contact. However in some no-till conditions where the soil may be wet, obtaining good seed-to-soil contact is challenging. The side walls of the seed trench may be smeared or compacted. Some of the spoke type press wheels, used with a seed firmer, can break up the tight soil around the seed to create a better environment for early season root development (Figure 22). The seed firmer becomes a key component in this arrangement because it provides most of the seed-to-soil contact.



Figure 21. A spike closing wheel used with a standard John Deere closing wheel.



Figure 22. Spoked closing wheels on a John Deere planter.

Seed Firming Devices

Several companies are offering devices to firm the seed in the slot (Figure 23). These may be plastic rods or small wheels that operate in the furrow or small closing disks that force the sidewall closed. The devices are intended to improve seed-to-soil



Figure 23. A Keaton seed firmer on a John Deere planter.

contact, reduce seed bounce, and ensure the seed is placed in the bottom of the furrow. While all these items typically work well, experience in Oklahoma has found the conditions most needed are where some of these do not perform well. Wetter soils with higher clay content tend to stick to small wheels operating in the seed furrow, reducing their ability to operate as designed. Plastic seed firming devices that slide in the seed furrow seem to be more effective. Research in Kansas has indicated the plastic devices help stand establishment to a certain degree.

References

This material was adapted from the Chapter 11 – Seeding Equipment for No-till, *Kansas No-till Handbook*, Kansas State University. November, 1999.

Photos courtesy of Randy Taylor, Oklahoma State University



Chapter 5

Sprayers for No-Till Crop Production

Robert E. Wolf

Extension Specialist, Application Technology
Kansas State University

Randy Taylor

Extension Agricultural Engineer
Oklahoma State University

No-till requires some adjustments in pesticide application equipment over intensive tillage systems. Because soil incorporation of herbicides can destroy crop residue, no-till systems typically use contact herbicides and/or residual herbicides that are carried into the soil by rainfall or irrigation. Applying herbicides in heavy residue does not require additional active ingredients but may require higher spray volumes for coverage and penetration of crop residue. The use of herbicide resistant crops has reduced the need for many soil-incorporated herbicides and increased the amount of foliar or postemergence herbicides.

Proper equipment adjustment and product selection is critical for satisfactory performance. Inaccurate pesticide application is expensive. It can result in wasted pesticide, marginal pest control, and excessive carryover contributing to water contamination and/or crop damage. Better application equipment and new techniques that allow for smaller dosages of crop protection products and reduce drift and residue have become increasingly important in minimizing harmful effects of crop protection products on the environment.

Low-Pressure Field Sprayers

Sprayers are available in various types and sizes, each designed for a specific application. For applying crop protection products in agriculture, applicators use low-pressure sprayers more than any other kind of application equipment. Tractor-mounted, pull-type, and self-propelled low-pressure sprayers are available in many models and for a wide range in cost. Spray pressures typically range from 15 to 70 pounds per square inch (psi) and application rates can vary from less than 5 to 30 gallons per acre (GPA). All low-pressure sprayers have several basic components: a pump, tank, agitation system, flow-control assembly, and a distribution system.

Sprayers for No-till Crop Production

Optimal use of sprayers for No-till crop production requires:

- Understanding proper equipment types for specific applications
- Understanding variables affecting application rates
- Performing accurate calibrations to determine chemical application
- Calculating the gallons of spray to be applied per acre

At the end of the distribution system is the spray nozzle.

Keep spray equipment in good condition; calibrate frequently, and operate as recommended for specific field conditions. Manufacturers' manuals include tables to show application rates in GPA for various nozzles, pressures, nozzle spacing, and ground speeds under ideal conditions. Use this information to adjust the sprayer; then calibrate and fine-tune the sprayer for accurate application.

Nozzle Types

Selecting the correct type and size of spray nozzle is essential for each application. The nozzle determines the amount of spray applied to an area, the uniformity of the application, the coverage of the sprayed surface, and the amount of drift. Although nozzles have been developed for practically every kind of spray application, only a few types - extended range flat-fans (Figure 1), Turbo flooding flat-fans, Turbo flat-fans, venturi flat-fans, and drift reduction pre-orifice flat-fans are commonly used in the application of crop protection products. An em-

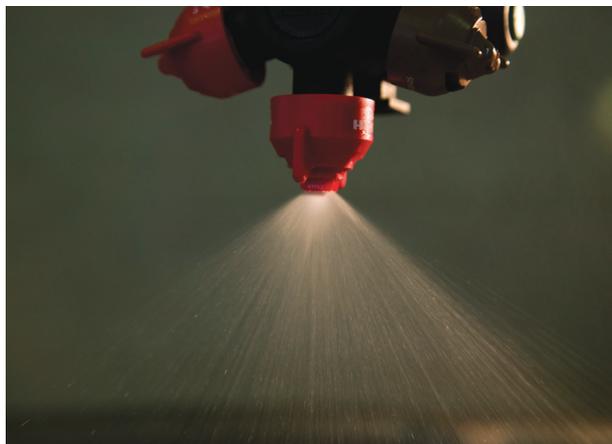


Figure 1. Flat fan nozzle.

phasis in nozzle design over the past few years has resulted in a vast improvement in spray quality. You can minimize drift by selecting nozzles that give the largest droplet size while providing adequate coverage at the intended application rate and pressure.

Spray nozzle assemblies consist of a body, cap, check valve, and nozzle tip (Figure 2). Various types of bodies and caps (including color-coded versions) and multiple nozzle bodies are available with

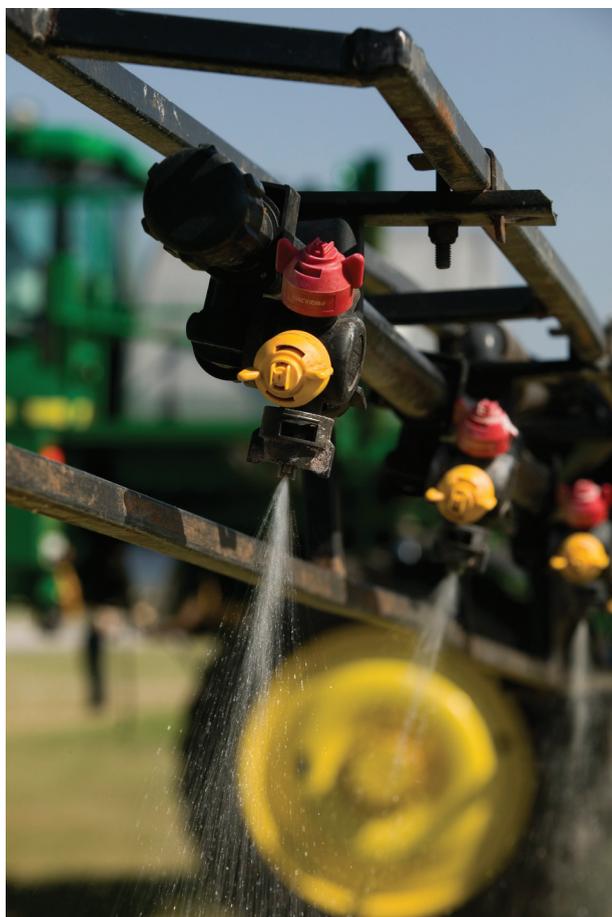


Figure 2. Spray nozzle assemblies consist of a body, cap, check valve, and nozzle tip.

Table 1. ASABE Standard S-572.

| <i>Spray Quality Categories</i> | |
|---------------------------------|--------------|
| <i>Category</i> | <i>Color</i> |
| Very Fine (VF) | Red |
| Fine (F) | Orange |
| Medium (M) | Yellow |
| Coarse (C) | Blue |
| Very Coarse (VC) | Green |
| Extra Coarse (EC) | White |

threads as well as quick-attaching adapters. Nozzle tips are interchangeable in the nozzle cap and are available in a wide variety of materials, including hardened stainless steel, stainless steel, brass, ceramic, and various types of plastic. Hardened stainless steel and ceramic are the most wear-resistant materials, but they are also the most expensive. Stainless steel tips have excellent wear resistance with either corrosive or abrasive materials. Plastic tips are resistant to corrosion and abrasion, and are proving to be very economical tips for applying crop protection products. Brass tips have been very common, but they wear rapidly when used to apply abrasive materials, such as wettable powders, and are corroded by some liquid fertilizers. Other types should be considered for more extensive use. See Table 1 for information about nozzle nomenclature.

Variables Affecting Application Rate/Volume (GPA)

Three variables affect the amount of spray material applied per acre: (1) the nozzle flow rate, (2) the ground speed of the sprayer, and (3) the width sprayed per nozzle. To calibrate and operate a sprayer properly, you must understand how each of these variables affects sprayer output.

The nozzle flow rate varies with the size of the tip, the nozzle pressure, and the density of the spray liquid. Installing a nozzle tip with a larger orifice, increasing the pressure, and decreasing the density of the spray liquid all increase the flow rate. To increase the nozzle output, you must multiply the pressure by the square of the desired increase in flow rate. In other words, doubling the pressure will not double the nozzle flow rate. To double the flow rate, you must increase the pressure four times. For example, to double the flow rate of a nozzle from 0.2 gallons per minute at 10 psi to 0.4 gallons per minute, the pressure must be increased to 40 psi (4 x 10).

Pressure changes should not be used to make major adjustments in the application rate. To obtain a uniform spray pattern and minimize drift, you should maintain the operating pressure within the

recommended range for each nozzle. The pressure can be changed, however, to correct for minor variations in flow rate resulting from nozzle wear.

The spray application rate varies inversely with the ground speed. Doubling the ground speed (MPH) of the sprayer reduces the application rate (GPA) by one-half. For example, a sprayer applying 20 GPA at 4 MPH would apply 10 GPA if the speed were increased to 8 MPH while the pressure remained constant.

Many low-pressure field sprayers have a metering control system that maintains a constant application rate while operating over a range of travel speeds. All metering systems now in use, such as ground-driven piston pumps, electronic feedback control systems, and various centrifugal pump arrangements, vary the nozzle pressure to compensate for changes in travel speed, keeping the application rate constant. Although all the systems work over a wide range of travel speeds, the spray nozzle limits the range of speeds at which precise application can be obtained. Because of the possibilities for dramatic pressure increases while using such systems, a serious potential for spray drift could occur through a fixed orifice nozzle.

To regulate the flow in proportion to travel speed, the rate of increase in nozzle pressure must vary with the square of the rate of increase in speed. For example, if the sprayer is traveling at 4 MPH at a nozzle pressure of 30 psi, increasing the speed to 8 MPH will require increasing the nozzle pressure to 120 psi to maintain the same flow volume. Remember, a fourfold change in pressure drastically reduces the droplet size, which may result in increased drift. The pattern width and distribution pattern may also be affected. For uniform application, the travel speed should be held as nearly constant as possible, even when using controlled metering systems.

To apply crop protection products accurately, you must maintain the proper ground speed. Do not rely on a conventional speedometer as an accurate indicator of speed. Slippage of the drive wheels can result in speedometer errors exceeding 20 percent. Electronic wheel speed sensors, radar guns, and GPS give more accurate readings since they do not depend on the drive wheels for speed measurements. Changes in tire size also affect speedometer readings, and the accuracy of all speedometers should be checked periodically.

The effective width sprayed per nozzle also affects the spray application rate. Doubling the effective width sprayed per nozzle decreases the gallons per acre (GPA) applied by one-half. For example, if applying 20 GPA with flat-fan nozzles on 20-inch spacings, changing to flooding nozzles with the same flow rate on 40-inch spacings will decrease the application rate from 20 GPA to 10 GPA.

Calibration

Accurate calibration is the only way to know how much chemical is applied. Even with the widespread use of electronics to monitor and control the application of crop protection products today, a thorough sprayer calibration procedure is essential to ensure against misapplication. Failure to calibrate a sprayer can injure the crop, cause potential pollution, and waste money. In addition to calibrating the sprayer at the start of the season, recalibrate regularly. Abrasive pesticide formulations can wear nozzle tips resulting in increased nozzle flow rate and the development of poor spray patterns.

To obtain uniform coverage, you must consider the spray angle, spacing, and height of the nozzle. The height must be readjusted for uniform coverage with various spray angles and nozzle spacings. Do not use nozzles with different spray angles on the same boom for broadcast spraying. Be sure the nozzle tips are clean. If necessary, clean with a soft bristle brush. A nail, wire, or pocket knife can damage the tip and ruin the uniformity of the spray pattern. While the sprayer is running, observe each spray tip for any distortions in the patterns.

Worn or partially plugged nozzles produce non-uniform patterns. Misalignment of nozzle tips is a common cause of uneven coverage. The boom must be level at all times to maintain uniform coverage. Skips and uneven coverage will result if one end of the boom is allowed to droop. A good method for determining the exact nozzle height to produce the most uniform coverage is to spray water on a warm surface, such as a road, and observe the drying rate. Streaks in the spray pattern should be obvious. Replace nozzles that not performing correctly.

Once the sprayer is operating properly, you are ready to calibrate. There are many methods for calibrating low-pressure sprayers, but they all involve the use of the variables discussed in the following section. Any technique for calibration that provides accurate and uniform application is acceptable. No single method is best for everyone.

The calibration method described below has four advantages. First, it allows you to select the number of gallons to apply per acre and to complete most of the calibration before going to the field. Second, it provides a simple means for frequently adjusting the calibration to compensate for changes due to nozzle wear. Third, it can be used for broadcast, band, directed, and row crop spraying. This method requires knowledge of nozzle types and sizes and the recommended operating pressure ranges for each type of nozzle used. Finally, when using the method below, the applicator will have a better understanding of how each variable will affect the application rate. As each of the variables change,

the influence on the rate (gallons per acre) is apparent.

The gallons of spray applied per acre can be determined by using the following equation:

$$\text{(Equation 1) GPA} = \frac{\text{GPM} \times 5,940}{\text{MPH} \times W}$$

GPA = gallons per acre or desired output
 GPM = output per nozzle in gallons per minute
 MPH = ground speed in miles per hour
 W = effective width sprayed per nozzle in inches
 5,940 = a constant to convert gallons per minute, miles per hour, and inches to gallons per acre

The size of the nozzle tip will depend on the application rate (GPA), ground speed (MPH), and effective width sprayed (W) planned. Some manufacturers advertise “gallon-per-acre” nozzles, but this rating is useful only for standard conditions (usually 30 psi, 4 MPH, and 20-inch spacing). The gallons-per-acre rating is useless if any one of the conditions varies from the standard.

Most applications will begin with reading the label to decide what carrier volume (GPA) is recommended with the chosen product. With a selected GPA, a more exact method for choosing the correct nozzle tip is to determine the gallons per minute (GPM) required for the conditions. Then select nozzles that provide this flow rate when operated within the recommended pressure range. By following the five steps described below, the nozzles required for each application can be selected well ahead of the spraying season.

Step 1. From the label information, select the spray application rate in gallons per acre (GPA). Pesticide labels recommend ranges for various types of equipment. The spray application rate is the gallons of carrier (water, fertilizer, etc.) and pesticide applied per treated acre.

Step 2. Select or measure an appropriate ground speed in miles per hour (MPH) according to existing field conditions. Do not rely on speedometers as an accurate measure of speed. Slippage and variation in tire sizes can result in speedometer errors of 20 percent or more. If you do not know the actual ground speed, you can easily measure it. (Instructions for measuring ground speed are given below.)

Step 3. Determine the effective width sprayed per nozzle (W) in inches.

For broadcasting spraying, W = the nozzle spacing
 For band spraying, W = the band width
 For row-crop applications, such as spraying from drop pipes or directed spraying,

$$W = \frac{\text{row spacing (or band width)}}{\text{number of nozzles per row (or band)}}$$

Step 4. Determine the flow rate required from each nozzle in gallons per minute (GPM) by using a nozzle catalog, tables, or the following equation. Using Equation 2 allows the applicator to determine flow rates for each application scenario needed for the application season. This can be done before the application season begins, thus not interfering with critical time available during the application time.

$$\text{(Equation 2) } \frac{\text{GPA} \times \text{MPH} \times W}{\text{GPM}} = 5,940$$

GPM = gallons per minute of output required from each nozzle

GPA = gallons per acre from Step 1

MPH = miles per hour from Step 2

W = inches sprayed per nozzle from Step 3

5,940 = a constant to convert gallons per minute, miles per hour, and inches to gallons per acre

Step 5. Select a nozzle that will give the flow rate determined in Step 4 when the nozzle is operated within the recommended pressure range. You should obtain a catalog of available nozzle tips or view on-line. These catalogs and on-line information can be obtained free of charge from equipment dealers or nozzle manufacturers. If you decide to use nozzles you already have, return to Step 2 and select a speed that allows operation within the recommended pressure range.

Herbicide Band Applications for Cost-Effective Weed Control

Band applications of herbicides can reduce costs for postemergent and preemergent weed control treatments. In band applications, the treated acre is the acres actually sprayed, and depending on the row spacing and the band width, is some fraction of the total field acres. Remember, herbicides are applied in bands at the same rate of active ingredients per treated acre as in broadcast applications. Treating a field with 30-inch rows in 15-inch bands has the effect of reducing the herbicide cost by one-half.

When banding soil-applied herbicides to control weeds in row crops, use spray tips designed for band application. They are commonly referred to as ‘even flat spray’ tips and are designated in the nozzle nomenclature with the letter ‘E.’ Even flat spray tips are designed to apply a uniform pattern on the target across the width of the angle with no overlap required. Extended range flat spray tips on the other hand are designed to apply a tapered edge pattern, and thus would not uniformly cover the targeted band width requiring 50 to 60 percent overlap (25 to 30 percent on each edge). For even spray tips, the nozzle spray angle and height above the target will determine the spray width.

Band applications can also be used to apply postemergence materials. To obtain thorough cov-

erage to all plant material, it may be necessary to direct the spray in a multi-nozzle arrangement around and over the top of the plant. Special band-application row kits or drops are available for this purpose. Special attention should be given when using a multiple nozzle kit to properly calibrate for the correct nozzle orifice size.

Now that you have selected and installed the proper nozzle tips (Steps 1 to 5) you are ready to complete the calibration of your sprayer (Steps 6 to 10 below). Check the calibration every few days during the season or when changing the crop protection products being applied. New nozzles do not lessen the need to calibrate because some nozzles ‘wear in,’ increasing their flow rate more rapidly during the first few hours of use. New nozzles can also come from the factory with flow or pattern defects. The electronics component of the spray system does not necessarily alert you to these problems. Once you have learned the following method, you can check application rates quickly and easily.

Step 6. Determine the required flow rate for each nozzle in ounces per minute (OPM). To convert GPM (Step 4) to OPM, use the following equation:

(Equation 3)

$$\text{OPM} = \text{GPM} \times 128 \text{ (1 gallon} = 128 \text{ ounces)}$$

Step 7. Collect the output from one of the nozzles in a container marked in ounces. Adjust the pressure until the ounces per minute (OPM) collected is the same as the amount determined in Step 6. Check several other or all of the nozzles to determine if their outputs fall within five to 10 percent of the desired OPM.

If it becomes impossible to obtain the desired output within the recommended range of operating pressures, select larger or smaller nozzle tips or a new ground speed, then recalibrate. It is important for spray nozzles to be operated within the recommended pressure range. The range of operating pressures is indicated at the nozzle tip. Line losses, nozzle check valves, etc., may require the main pressure gauge at the boom or at the controls to read much higher.

Step 8. Determine the amount of pesticide needed for each tank or for the acreage to be sprayed. Add the pesticide to a partially filled tank of carrier (water, fertilizer, etc.). Then add carrier to the desired level with continuous agitation.

Step 9. Operate the sprayer in the field at the ground speed measured in Step 2 and at the pressure you determined in Step 7. The application rate selected in Step 1 will be spraying. After spraying a known number of acres, check the liquid level in the tank to verify that the application rate is correct.

Step 10. Check the nozzle flow rate frequently. Adjust the pressure to compensate for small chang-

es in nozzle output due to nozzle wear or variations in other spraying components. Replace the nozzle tips and recalibrate when the output has changed five to 10 percent or more from that of a new nozzle, or when the pattern has become uneven.

To apply crop protection products accurately, proper ground speed must be maintained. Because speedometers do not always provide an accurate measure of speed, check the accuracy of the speedometer with an electronic kit or radar gun. If the sprayer does not have a speedometer, or if the speedometer is not accurate, measure the speed at all of the settings planned in the field. By measuring and recording the ground speed at several gear and throttle settings, remeasuring speed each time you change settings will be unnecessary.

To measure ground speed, lay out a known distance in the field you intend to spray or in another field with similar surface conditions. Suggested distances are 100 feet for speeds up to 5 MPH, 200 feet for speeds from 5 to 10 MPH, and at least 300 feet for speeds above 10 MPH. At the engine throttle setting and in the gear you plan to use during spraying with a half-loaded sprayer, determine the travel time between the measured stakes in each direction. Average these speeds and use the following equation to determine ground speed.

$$\text{Speed (MPH)} = \frac{\text{distance (feet)} \times 60}{\text{time (seconds)} \times 88}$$

$$1 \text{ MPH} = 88 \text{ feet per } 60 \text{ seconds}$$

Once speed is decided, record the throttle setting and drive gear used.

Droplet Size Considerations

Droplet size will influence coverage and drift. The nozzles typically used to apply herbicides produce droplets that vary greatly in size (Figure 3). Large droplets, which will help mitigate spray drift, may not provide good coverage. Very small droplets lack the momentum needed toward the target and are prone to drift under windy conditions. The range of droplets from a nozzle is also affected by liquid flow rate (size of nozzle orifice), liquid pressure, and physical changes to nozzle geometry and operation.

To help applicators select nozzles and use them at the most optimum droplet size range for a given situation, ASABE (American Society of Agricultural and Biological Engineers) has developed a classification system. According to this system, spray quality from a nozzle can be classified as: Very Fine; Fine, Medium, Coarse, Very Coarse, and Extremely Coarse (Table 1).



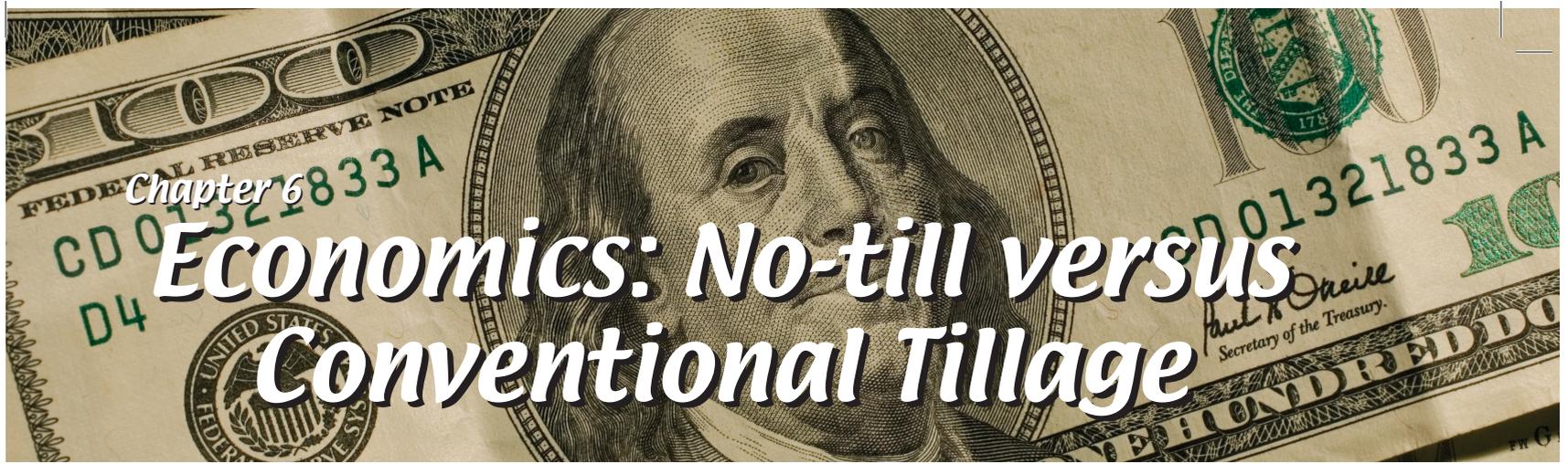
Figure 3. Different nozzles create droplet patterns used for a variety of purposes. (Refer to Table 1 for droplet size categories.)

Currently, medium to coarse spray droplets (approximately 300-500 microns) are recommended by nozzle manufacturers for application of herbicides. In fact, company labels may specify the droplet size suggested based on the above classification system. Contact herbicides may need to be on the smaller end of the range to achieve better surface coverage, while translocated materials are expected to work effectively at the upper end of the range. Since most nozzle sizes will span a range of droplets sizes, dependent on the operating pressure, it is important to select the nozzle type and pressure option that closely matches the 300 to 500 micron size recommended. To achieve this, calibration to determine needed flow rate or orifice size must be done in conjunction with matching pressure, nozzle type, orifice size, and speed to the desired droplet size.

It will be necessary to add this step to the set-up of the sprayer to optimize the herbicide application for increased coverage and minimized drift.

Consulting the nozzle manufacturer's droplet sizing charts is essential. Websites and manufacturer's literature is available for additional help. Nozzle manufacturer's charts can help you determine what pressure to use for the nozzle type selected to produce the mid-fine to mid-medium quality spray.

Though sprayers have become more complex than their predecessors, there are a lot of similarities. The keys to successful sprayer operation are to select appropriate nozzles and calibrating for desired operating conditions. Following the simple tips presented here will enable accurate and effective chemical application.



Francis M. Epplin

Professor, Agricultural Economics
Oklahoma State University

The most economical tillage system depends upon a number of factors, and the most economical system for one farm may not be the most economical for an adjacent farm. In this chapter, we identify factors that may tip the scales in favor of one system over another.

Prior to the implementation of the 1996 Farm Bill (Freedom to Farm Bill), the vast majority of Oklahoma dry-land crop acres were seeded to continuous monoculture hard red winter wheat. In 1975, more than 96 percent of the cropland in Garfield County was seeded to winter wheat. By 1995, the proportion seeded to wheat, excluding land in the Conservation Reserve Program, had increased to more than 99 percent (Oklahoma Agricultural Statistics Service, 2006).

“The no-till operation continues to have higher yields on average. We have split a farm in half, tilling one side and no-tilling the other side...the side that was no-tilled raised 10 to 15 bushels more per acre than the tilled side.”

**C. Trojan
Bison, OK**

The USDA found in a 1998 survey that less than three percent of the wheat farms in the Prairie Gateway, the region that includes Western Oklahoma, Kansas, Eastern New Mexico, Eastern Colorado, Southern Nebraska, and Northern Texas, used no-till to produce wheat (Ali, 2002). These findings included wheat produced in rotations as well as wheat in monoculture.

Economics of No-Till

Economic considerations will vary from farm to farm and are dependant upon:

- Types of cultivation systems
- Weed control programs
- Equipment and cost considerations
- Federal policy

Previous studies have identified several impediments to the adoption of no-till for continuous monoculture winter wheat production. First, the lack of an inexpensive and effective herbicide program necessary to control weeds throughout the summer from harvest in June until planting in October has been a major obstacle. A no-till budget prepared in 1994 included 4.5 pints per acre of glyphosate (4 pounds of emulsifiable concentrate per gallon) at \$6 per pint (\$48 per gallon) for a cost of \$27 per acre (Epplin, Al-Sakkaf, and Peeper, 1994). The 1994 study found that the reduction in tillage costs when switching from conventional tillage to no-till was insufficient to offset the expected increase in herbicide costs. Tillage was the most economical way to control cheat and other similar species and volunteer wheat in a continuous wheat system. A 1998 survey found two-thirds of the farms that produced wheat in the Prairie Gateway used no herbicide (Ali 2002).

Second, some of the first generation no-till grain drills did not always result in successful stands of wheat. Third, wheat yields obtained from continuous monoculture wheat in a no-till system were often lower than yields obtained from conventional till systems (Bauer and Black, 1992; Epplin et al., 1983; Epplin, Al-Sakkaf, and Peeper, 1994; Heer and Krenzer, 1989; Williams et al., 2004). Given the higher production costs combined with lower yields, the fact that few farmers in the region used no-till to

produce continuous monoculture wheat was understandable.

Fourth, federal policy penalized growers who planted crops other than wheat on wheat base acres. Therefore, the vast majority of the acres were seeded to continuous monoculture winter wheat, and the most economical wheat production system required tillage to control cheat and volunteer wheat.

During the last decade, several changes provide justification for reevaluating the economics of no-till production for the region. These factors include a change in federal policy, a reduction in the price of glyphosate, improvements in no-till seeding equipment, and an increase in the price of diesel fuel. The change in federal policy, beginning with the 1996 Farm Bill that eliminated the requirement of seeding wheat base acres to wheat in order to maintain eligibility for program payments is important. The policy change enabled farmers to plant crops other than wheat on wheat base and enabled them to rotate crops with wheat. Crop rotations are often useful tools for managing weeds and diseases.

The second factor is a reduction in the price of glyphosate. Generic glyphosate became available in 2000 after the original patent expired. The price of glyphosate (four pounds of emulsifiable concentrate per gallon) has declined from a U.S. average of \$45.50 per gallon in 1999 to less than \$20 per gallon in 2007. This reduction in cost for controlling summer weeds in continuous monoculture no-till winter wheat is less than half of what it was in 1990 and substantially less when adjusted for price inflation. The development and adoption of glyphosate-resistant varieties of corn, soybeans, canola, and cotton has also advanced the adoption of no-till. The development and improvement of no-till grain drills and air seeders that increase the likelihood of good soil-to-seed contact in a variety of residue and soil condi-

tions has also advanced the adoption of no-till. An additional factor is the price of diesel fuel increased from less than \$1 per gallon in 2002 to more than \$2 per gallon in 2006. This price change increases the relative cost of tillage, and tips the economic balance scales in favor of no-till.

Case Study: Cost of No-Till versus Conventional Tillage for Continuous Wheat for Four Farm Sizes

A case study was conducted by Stock (2004) to determine the production costs for both conventional tillage and no-till (direct seeded with a no-till drill or air seeder) continuous monoculture wheat production in Oklahoma on four farms. More specifically, the objectives were to determine the costs of conventional tillage and no-till management farm practices for each of four farm sizes (320; 640; 1,280; and 2,560 acres) from monoculture wheat used to produce grain (Stock 2004; Epplin et al. 2005). In this section, revised results of that study are presented.

Stock used an economic engineering approach. Costs for each system and farm size were computed, based upon field operations and operating inputs that were defined from results of small plot research conducted over three years on three Oklahoma farms (Morley 2006).

The number and type of field operations (tillage, seeding, herbicide application, insecticide application, fertilizer application, and harvest) for both conventional tillage and no-till production systems are listed in Table 1. For the conventional tillage system, the assumption was made that the field

Table 1. Field Operations Budgeted for Conventional Tillage and No-till Wheat Production Systems.

| <i>Field Operations</i> | <i>Month</i> | <i>Conventional</i> | <i>No-till</i> |
|---------------------------------------|--------------|---------------------|----------------|
| Moldboard Plow (Used on 20% of acres) | June | ✓ | |
| Chisel (Used on 80% of acres) | June | ✓ | |
| Apply Herbicide (Glyphosate) | June | | ✓ |
| Apply Herbicide (Glyphosate) | August | | ✓ |
| Secondary Tillage | August | ✓ | |
| Broadcast Fertilizer (46-0-0) | August | ✓ | ✓ |
| Secondary Tillage | September | ✓ | |
| Apply Herbicide (Glyphosate) | October | | ✓ |
| Tertiary Tillage | October | ✓ | |
| Band Fertilizer with Drill (18-46-0) | October | ✓ | ✓ |
| Plant Wheat (Conventional Till Drill) | October | ✓ | |
| Plant Wheat (No-till Drill) | October | | ✓ |
| Apply Pesticide (Dimethoate) | April | ✓ | ✓ |
| Harvest Wheat Grain | June | ✓ | ✓ |

Table 2. Operating Inputs Budgeted for Conventional Tillage and No-till Wheat Production Systems.

| <i>Operating Inputs</i> | <i>Date</i> | <i>Unit</i> | <i>Price (\$)</i> | <i>Conventional</i> | <i>No-till</i> |
|----------------------------------|-------------|--------------|-------------------|---------------------|----------------|
| Glyphosate Custom Application | June | Pt. Acre | 2.25 4.00 | | 1.5 1 |
| Glyphosate Custom Application | August | Pt. Acre | 2.25 4.00 | | 2 1 |
| Urea (46-0-0) Custom Application | August | Lbs. Acre | 0.16 3.75 | 196 1 | 196 1 |
| Glyphosate Custom Application | October | Pt. Acre | 2.25 4.00 | | 1 1 |
| Diammonium Phosphate (18-46-0) | October | Lbs. | 0.14 | 50 | 50 |
| Wheat Seed | October | Bu. | 9.00 | 1.5 | 1.5 |
| Dimethoate Custom Application | April | Pt. Acre | 4.00 4.70 | 0.75 1 | 0.75 1 |

^a Custom application of herbicide, fertilizer, and insecticide was budgeted for the 320- and 640-acre farms. Custom application of these inputs is not assumed for the two large farms. The machinery complements of the 1,280- and 2,560-acre farms include fertilizer applicators and sprayers.

would be tilled after harvest in June with either a moldboard plow (20 percent) or chisel (80 percent). Another assumption was that 20 percent of the farm would be plowed each year, so each field is plowed with a moldboard once in five years. A tillage operation was budgeted for August followed by urea (46-0-0) application and tillage operation in September. A final tillage operation was budgeted for October prior to seeding with a conventional drill or conventional air seeder. For the no-till system, glyphosate applications were budgeted for June, August, and prior to planting in October. A no-till drill or no-till air seeder was budgeted to plant the wheat in October. An April insecticide application was budgeted for both systems. Table 2 includes a list of the operating input prices and application rates for both systems. Applications of fertilizer, seed, and insecticide were assumed to be the same across systems.

Machinery Selection

Available tractors and machines were determined from personal interviews and discussions with dealers and confirmed by information posted on manufacturers' websites. These discussions resulted in three important assumptions. The first assumption was that all wheat produced would be custom harvested and hauled. The machinery costs

did not include costs of combines and trucks. The second assumption was that herbicide, fertilizer, and insecticide would be custom applied on the two smaller farms, but farmer applied on the two larger farms. The machinery complements for the 1,280- and 2,560-acre farms included fertilizer applicators and sprayers. The third assumption was that air seeders rather than grain drills would be budgeted for the 2,560-acre farm.

The list prices used for drills and air seeders as reported in Table 3 show that the relative cost difference between conventional and no-till seeding equipment depends upon machine size. A 10-foot no-till drill costs almost three times as much as a 10-foot conventional drill. A 20-foot no-till drill costs more than twice as much as a 20-foot conventional drill. However, a 36-foot no-till air seeder costs only 30 percent more than a 36-foot conventional air seeder.

MACHSEL, a machinery complement selection software program developed by Kletke and Sestak (1991), enables a user to assemble a set of tractors and machines that can perform the budgeted field operations in the expected time available. Candidate machines were selected based on farm size, estimated fieldwork days, machines available, and required field operations. Table 3 includes a list of the selected machines for each farm size for both

Table 3. Machinery Complements Budgeted for Conventional Tillage and No-till Wheat Production Systems for Alternative Farm Sizes.

| <i>Machine</i> | <i>List Price (\$)</i> | <i>Machine Width (Feet)</i> | <i>Conventional</i> | <i>No-till</i> |
|--------------------------------------|----------------------------|---------------------------------|---------------------|----------------|
| 320-Acre Farm | | | | |
| 95 hp Tractor | 58,167 | | ✓ | ✓ |
| Moldboard Plow | 13,921 | 4.75 | ✓ | |
| Chisel | 5,555 | 8.55 | ✓ | |
| Disk | 7,543 | 10.48 | ✓ | |
| Conventional Till Drill | 9,239 | 10 | ✓ | |
| No-till Drill | 27,053 | 10 | | ✓ |
| Machinery Labor (hrs/ac) | | | 1.21 | 0.29 |
| Average Machinery Investment (\$/ac) | | | 160 | 134 |
| Diesel fuel (gal. per acre) | | | 5.0 | 1.2 |
| 640-Acre Farm | | | | |
| 155 hp Tractor | 81,707 | | ✓ | ✓ |
| Moldboard Plow | 15,812 | 7.75 | ✓ | |
| Chisel | 9,673 | 18.6 | ✓ | |
| Disk | 20,231 | 17.1 | ✓ | |
| Conventional Till Drill | 23,957 | 20 | ✓ | |
| No-till Drill | 51,992 | 20 | | ✓ |
| Machinery Labor (hrs/ac) | | | 0.68 | 0.14 |
| Average Machinery Investment (\$/ac) | | | 128 | 106 |
| Diesel fuel (gal. per acre) | | | 4.6 | 1.0 |
| 1,280-Acre Farm | | | | |
| 95 hp Tractor | 58,167 | | | ✓ |
| Sprayer | 5,564 | 40 | | ✓ |
| Fertilizer Spreader | 11,200 | 40 | | ✓ |
| 155 hp Tractor | 81,707 | | ✓ | ✓ |
| No-till Drill | 51,992 | 20 | | ✓ |
| Conventional Till Drill | 23,957 | 20 | ✓ | |
| Sprayer | 7,372 | 60 | ✓ | |
| Fertilizer Spreader | 11,200 | 40 | ✓ | |
| 170 hp Tractor | 101,198 | | ✓ | |
| Moldboard Plow | 18,337 | 8.5 | ✓ | |
| Chisel | 16,469 | 20.4 | ✓ | |
| Disk | 22,049 | 18.75 | ✓ | |
| Machinery Labor (hrs/ac) | | | 0.72 | 0.43 |
| Average Machinery Investment (\$/ac) | | | 119 | 85 |
| Diesel fuel (gal. per acre) | | | 5.2 | 2.2 |
| 2,560-Acre Farm | | | | |
| 95 hp Tractor | 58,167 | | ✓ | ✓ |
| Sprayer | 5,564 | 40 | ✓ | ✓ |
| Fertilizer Spreader | 11,200 | 40 | ✓ | ✓ |
| 255 hp Tractor | 156,404 | | ✓ | ✓ |
| Disk | 29,022 | 28.13 | ✓ | |
| Chisel | 21,982 | 30.6 | ✓ | |
| Conventional Till Air Seeder | 105,000 | 36 | ✓ | |
| No-till Air Seeder | 137,500 | 36 | | ✓ |
| 255 hp Tractor | 156,404 | | ✓ | |
| Moldboard Plow | 24,516 | 12.75 | ✓ | |
| Chisel | 21,982 | 30.6 | ✓ | |
| Disk | 29,022 | 28.13 | ✓ | |
| Machinery Labor (hrs/ac) | | | 0.51 | 0.37 |
| Average Machinery Investment (\$/ac) | | | 131 | 75 |
| Diesel fuel (gal. per acre) | | | 4.9 | 2.1 |

production systems. Parameters, including field efficiency, draft, speed, repair factors, and depreciation costs, were based upon Agricultural Machinery Management Data Standards as published by the American Society of Agricultural and Biological Engineers (2001). Diesel fuel price was budgeted at \$2.25 per gallon.

The machinery complement for the 320-acre conventional tillage farm included a 95 horsepower tractor matched with a plow, chisel, disk, and conventional drill. The 320-acre no-till farm included a 95 horsepower tractor and a 10-foot no-till drill. For the 640-acre conventional tillage farm a 155 horsepower tractor was matched with a plow, chisel, disk, and conventional drill. The 640-acre no-till farm included only a 155 horsepower tractor and a 20-foot no-till drill.

The machinery complement for the 1,280-acre conventional tillage farm included two tractors (155 and 170 horsepower), sprayer, fertilizer spreader, plow, chisel, disk, and conventional drill. The 1,280-acre no-till farm machinery complement included two tractors (95 and 155 horsepower), sprayer, fertilizer spreader, and no-till drill. The complement assembled for the 2,560-acre conventional tillage farm included three tractors (one 95 horsepower and two 255 horsepower tractors), a sprayer, fertilizer spreader, plow, two chisels, two disks, and a conventional air seeder. The 2,560-acre no-till farm complement included two tractors (one 95 horsepower and one 255 horsepower), a sprayer, fertilizer spreader, and a no-till air seeder.

Results of Case Study

Table 4 includes estimates of production costs for both systems across the four farm sizes. Figure 1 includes a chart of the average machinery investment per acre. The difference in average machinery

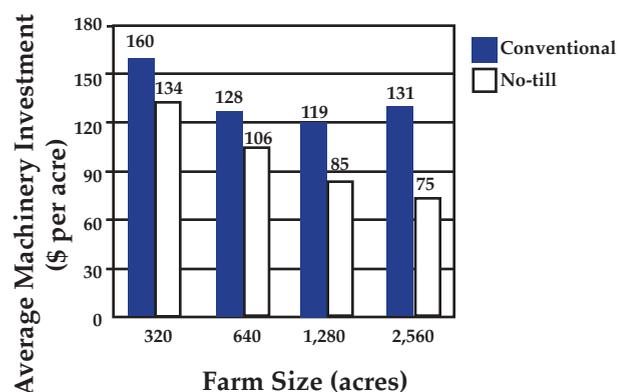


Figure 1. Average machinery investment (\$/acre) for both conventional tillage and no-till monoculture winter wheat for four farm sizes.

investment between the conventional tillage and no-till machinery complements ranges from \$22 per acre for the 640-acre farm to \$56 per acre for the 2,560-acre farm. The machinery cost estimates depend upon the type and set of machines selected to include in the complement for a particular farm size. For example, economies of size in average machinery investment are more evident across the range of farm sizes for the no-till system. The list price for the 36-foot no-till air seeder budgeted only for the 2,560-acre farm is 2.6 times as much as the 20-foot no-till drill budgeted for the 1,280-acre farm. However, the list price for the 36-foot conventional till air seeder budgeted only for the 2,560-acre conventional tillage farm is more than four times as much as the list price for the 20-foot conventional till drill selected for the 1,280-acre conventional tillage farm. This difference explains much of the relative difference in size economies across the two production systems when the farm size increases from 1,280 to 2,560 acres.

Machinery fixed costs (depreciation, insurance, interest on average investment, and taxes) for both systems across the four farm sizes are included in Table 4 and graphed in Figure 2. The estimates are similar across farm size. They range from \$25 to \$35 per acre for the conventional tillage farms and from \$16 to \$28 per acre for the no-till farms. For the four farms, the estimated difference in machinery fixed costs between conventional tillage and no-till range from \$6 to \$12 per acre. The chart in Figure 2 illustrates the potential economies of size in machinery fixed costs per acre especially for the no-till production systems. Machinery fixed costs per acre is greater for the 2,560-acre conventional tillage farm than for the 1,280-acre conventional tillage farm primarily because an air seeder rather than conventional drill was budgeted for the larger farm.

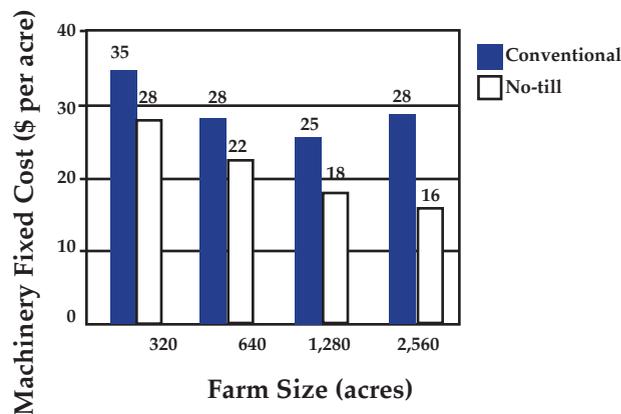


Figure 2. Machinery fixed costs (\$/acre) for both conventional tillage and no-till monoculture winter wheat for four farm sizes.

Table 4. Estimates of Machinery Labor, Machinery Investment, and Production Costs for Conventional Tillage and No-till Wheat Production Systems.

| | <i>Units</i> | <i>Conventional</i> | <i>No-till</i> |
|--|--------------|---------------------|----------------|
| All Farms | | | |
| Wheat Seed | \$/ac | 13.50 | 13.50 |
| Fertilizer | \$/ac | 38.36 | 38.36 |
| Herbicide | \$/ac | 0.00 | 10.13 |
| Pesticide | \$/ac | 3.00 | 3.00 |
| Custom Harvest and Hauling | \$/ac | 24.00 | 24.00 |
| 320-Acre Farm | | | |
| Machinery Labor | hrs/ac | 1.21 | 0.29 |
| Average Machinery Investment | \$/ac | 160 | 134 |
| Interest on Operating Capital | \$/ac | 2.60 | 3.39 |
| Diesel Fuel | \$/ac | 11.25 | 2.70 |
| Lubricants | \$/ac | 1.69 | 0.41 |
| Repairs | \$/ac | 3.85 | 1.67 |
| Custom Application Charge | \$/ac | 8.45 | 20.45 |
| Total Operating Cost | \$/ac | 106.69 | 117.61 |
| Machinery Fixed Cost | \$/ac | 34.58 | 27.88 |
| Total Operating Plus Machinery Cost | \$/ac | 141.27 | 145.49 |
| 640-Acre Farm | | | |
| Machinery Labor | hrs/ac | 0.68 | 0.14 |
| Average Machinery Investment | \$/ac | 128 | 106 |
| Interest on Operating Capital | \$/ac | 2.61 | 3.37 |
| Diesel Fuel | \$/ac | 10.35 | 2.25 |
| Lubricants | \$/ac | 1.55 | 0.34 |
| Repairs | \$/ac | 4.64 | 1.57 |
| Custom Application Charge | \$/ac | 8.45 | 20.45 |
| Total Operating Cost | \$/ac | 106.47 | 116.96 |
| Machinery Fixed Cost | \$/ac | 28.09 | 22.49 |
| Total Operating Plus Machinery Cost | \$/ac | 134.56 | 139.45 |
| 1,280-Acre Farm | | | |
| Machinery Labor | hrs/ac | 0.72 | 0.43 |
| Average Machinery Investment | \$/ac | 119 | 85 |
| Interest on Operating Capital | \$/ac | 2.53 | 2.76 |
| Diesel Fuel | \$/ac | 11.70 | 4.95 |
| Lubricants | \$/ac | 1.76 | 0.74 |
| Repairs | \$/ac | 7.96 | 4.71 |
| Custom Application Charge | \$/ac | 0.00 | 0.00 |
| Total Operating Cost | \$/ac | 102.81 | 102.15 |
| Machinery Fixed Cost | \$/ac | 25.37 | 17.92 |
| Total Operating Plus Machinery Cost | \$/ac | 128.18 | 120.07 |
| 2,560-Acre Farm | | | |
| Machinery Labor | hrs/ac | 0.51 | 0.37 |
| Average Machinery Investment | \$/ac | 131 | 75 |
| Interest on Operating Capital | \$/ac | 2.61 | 2.89 |
| Diesel Fuel | \$/ac | 11.03 | 4.73 |
| Lubricants | \$/ac | 1.65 | 0.71 |
| Repairs | \$/ac | 9.79 | 7.35 |
| Custom Application Charge | \$/ac | 0.00 | 0.00 |
| Total Operating Cost | \$/ac | 103.94 | 104.66 |
| Machinery Fixed Cost | \$/ac | 28.45 | 16.07 |
| Total Operating Plus Machinery Cost | \$/ac | 132.39 | 120.73 |
| Budgeted Diesel fuel price of \$2.25 per gallon. | | | |

As shown in Table 4, wheat seed (\$13.50 per acre), fertilizer (\$38.36 per acre), insecticide (\$3.00 per acre), and custom harvest and hauling (\$24 per acre) costs are assumed to be the same for both systems across all farm sizes. The budgeted cost of the herbicide program for the no-till system is \$10.13 per acre. No herbicide was budgeted for the conventional tillage system.

Figure 3 includes a chart of total operating costs (\$/acre) for both production systems across the four farm sizes. Operating costs are very similar for the two large farms. For these farms, no-till required \$10 per acre more for herbicide and saved \$10 to \$11 per acre in fuel, lube, and repairs. For the two small farms, no-till required \$10 per acre more herbicide and \$12 per acre more for custom application, but saved about \$12 per acre in fuel, lube, and repairs. The estimated operating costs for the two small farms are approximately \$11 per acre greater for the no-till system.

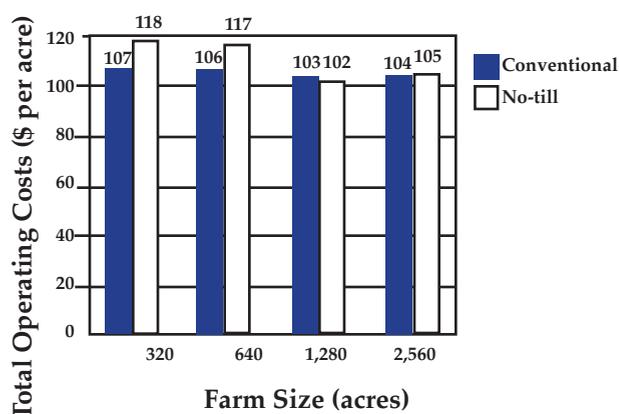


Figure 3. Total operating costs (\$/acre) for both conventional tillage and no-till monoculture winter wheat for four farm sizes.

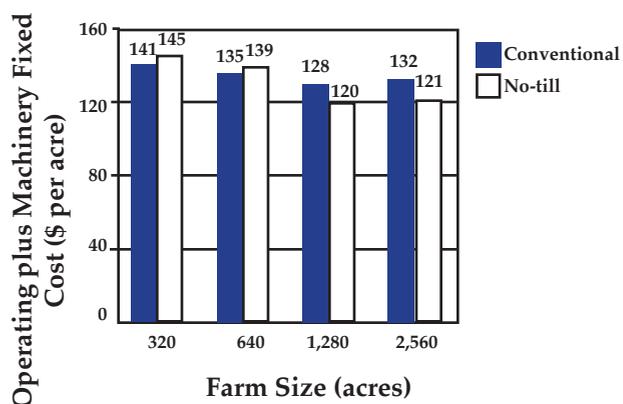


Figure 4. Total operating plus machinery fixed costs (\$/acre) for both conventional tillage and no-till monoculture winter wheat for four farm sizes.

Figure 4 includes a chart of total operating plus machinery fixed costs for both production systems across the four farm sizes. The estimated total operating and machinery costs are \$4 per acre greater for the 320- and 640-acre no-till farms than for the corresponding conventional tillage farms. However, estimated costs are \$8 to \$11 per acre greater for the conventional tillage 1,280- and 2,560-acre farms. These estimates do not include differences in the opportunity cost of labor across farm sizes and production systems.

The estimated savings in diesel fuel for the no-till relative to conventional tillage 320- and 640-acre farms is 3.7 gallons per acre. For the small farms, the assumption was made that herbicide and pesticide would be custom applied. Custom harvest was assumed for all farms. For the 1,280- and 2,560-acre farms, the estimated savings in diesel fuel for the no-till relative to conventional is approximately 2.9 gallons per acre.

Differences in labor costs are not reflected in Figures 3 and 4. Savings in time differ across farm size and across assumptions relative to the application of herbicides and pesticides. For the 320- and 640-acre farms, the average difference in estimated machinery labor requirement between the conventional and no-till systems is approximately 0.75 hours per acre. For the 1,280- and 2,560-acre farms, the estimated difference is approximately 0.25 hours per acre. The value of 0.25 to 0.75 hours per acre is farm and farm family specific. The opportunity cost of family labor, and the cost to hire labor, may differ substantially across farms. Some farm families may have access to relatively inexpensive labor. However, other families may struggle to find time to complete field activities in a timely manner. Some families may be able to use the time saved by switching to no-till, to farm additional acres, or to expand livestock production activities.

Cost differences between the two systems as budgeted are minimal. For the 640-acre farm the budgeted no-till system required an additional 4.5 pints per acre of glyphosate (\$10.13 per acre) and an additional \$12 per acre in custom application charges. The no-till system saved 3.6 gallons of diesel fuel (\$8.10 per acre), \$5.60 per acre in machinery fixed costs, and 0.54 hours of labor per acre. If the farm family's labor was valued at \$9.06 per hour the two systems would have equal costs.

Case Study Conclusions

Several general conclusions can be made from the results of the case study. The reduction in the price of glyphosate after the original patent expired and the increase in the price of diesel fuel has improved the relative economics of no-till for continuous winter wheat, but economic advantages or

disadvantages are still farm specific. The economics of no-till relative to conventional tillage depend on farm size. The list prices of effective no-till grain drills are from two to three times greater than the list prices of conventional drills. No-till equipped air seeders list for 30 to 40 percent more than conventional air seeders of the same width, but the difference in drill/seeder cost decreases as the size of the drill/seeder increases.

A general finding of the case study is that if 4.5 pints of glyphosate per acre can successfully control weeds, no-till for continuous wheat production is cost-competitive with conventional tillage. While the costs may be similar between the systems, producers must also consider potential differences in yield and revenue. For a field that is relatively free of weeds, the glyphosate system as budgeted may work for one or two years. However, most experiment station trials conducted in Oklahoma of no-till versus conventional tillage for continuous wheat managed to produce grain, have found that weeds often become a very serious problem after two or three years. Most studies have also found that in a continuous wheat system in regions with annual rainfall in excess of 26 inches, wheat grain yields are often less in the no-till plots. The cost savings from switching to no-till may be insufficient to offset the expected yield loss. For these reasons (weeds and yields), no-till is not currently recommended for continuous monoculture wheat managed to produce grain. However, some growers have been able to manage weed problems by using a rotation that includes wheat for forage-only (graze out) along with wheat for grain.

Other Considerations

No-till is more likely to be economical in farm/soils/climate situations in which no-till enables farmers to increase the number of harvested acres per year on the farm. For example, in some regions of the U.S., a no-till system enables the successful double cropping of soybeans or grain sorghum after wheat. The probability of a successful double crop with conventional tillage is not as great due to timing and loss of soil moisture. In some situations, no-till enables the cropping of land too steep for conventional tillage. In effect, a no-till system may enable the conversion of pastureland to cropland. In both of these situations, the appropriate economic comparison is not between no-till and conventional tillage. In the first case, it is between growing a crop and fallow, and in the second case, it is between producing a crop and pasture. In both cases, no-till enables an increase in the number of harvested acres for a given farm size, and the investment in either a no-till drill, a no-till planter, or a no-till air seeder may be weighed against the investment in additional land.

The following questions may be useful to assist with determining whether no-till may be an economical alternative for your farm situation.

1. Do you currently, or do you plan to use crop rotation?

If Yes: consider no-till. Currently, because of the inability to control weeds, no-till is not likely to be the most economical system for continuous monoculture wheat for grain.

2. Do you plan to double crop by planting grain sorghum or soybeans immediately after wheat harvest?

If Yes: consider no-till.

3. Would a no-till drill/planter permit you to crop fertile pasture land that is currently not cropped because of potential for erosion?

If Yes: consider no-till.

4. Do you have the opportunity to use the potential labor savings (0.25 to 0.75 hours per acre) either to farm additional land, or to earn additional income from an alternative use for your labor?

If Yes: consider no-till.

5. Are you planning to replace your grain drill?

If Yes: consider no-till.

If the answers is yes to one or more of the above questions, then farm-specific economic analysis could be used to determine if no-till is likely to be an economical choice for your farm. The economics of no-till are farm and farm situation specific. In addition to the cost of tillage relative to the cost of herbicides and the cost of no-till drills and air seeders relative to the cost of conventional drills and seeders, the economics of no-till depends upon farm size, soils, climate, crops grown, and the opportunity cost of the farm family's labor.

The Oklahoma Cooperative Extension Service has a program specifically designed to assist Oklahoma farm families that are in the process of considering a change in the farm business. In addition to an attitude adjustment, switching to no-till will require either a no-till drill or no-till air seeder or dependable access to timely custom no-till planting. Also, no-till requires a sprayer or dependable access to timely custom application of herbicides. Oklahoma farm families who are considering a change to no-till are encouraged to take advantage of the services provided by the Oklahoma Cooperative Extension Service. The Intensive Financial Management and Planning Support (IFMAPS) program provides specially trained financial specialists to work one-on-one with Oklahoma farm families to develop sound financial plans in a confidential

manner. Specialists arrange a mutually convenient time and place (often the producer's home) to meet. To determine if a change in tillage system is likely to be economical for your farm, contact your county Extension office, or call 800-522-3755 and ask to participate in the IFMAPS program.

References

- Ali, M. B. 2002. Characteristics and Production Costs of U.S. Wheat Farms. United States Department of Agriculture Statistical Bulletin number 974-5.
- American Society of Agricultural Engineers Standards. 2001. Agricultural Machinery Management Data. ASAE D497.
- Bauer, A. and A.L. Black. 1992. Effect of Management Method of Erect Stubble at Spring Planting on Performance of Spring Wheat. North Dakota State University Agricultural Experiment Station Research Report No. 524.
- Epplin, Francis M., Ghazi A. Al-Sakkaf, and Thomas F. Peeper. 1994. Impacts of Alternative Tillage Methods for Continuous Wheat on Grain Yield and Economics: Implications for Conservation Compliance. *Journal of Soil and Water Conservation* 49-4:394-399.
- Epplin, Francis M., Curtis J. Stock, Darrel D. Kletke, and Thomas F. Peeper. 2005. Cost of Conventional Tillage and No-till Continuous Wheat Production for Four Farm Sizes. *Journal of the American Society of Farm Managers and Rural Appraisers* 69:69-76.
- Epplin, Francis M., Thomas F. Tice, Steven J. Handke, Thomas F. Peeper, and Eugene G. Krenzer, Jr. 1983. Economics of Conservation Tillage Systems for Winter Wheat Production in Oklahoma. *Journal of Soil and Water Conservation* 38:294-297.
- Heer, W.F., and E.G. Krenzer, Jr. 1989. Soil Water Availability for Spring Growth of Winter Wheat (*Triticum aestivum* L.) as Influenced by Early Growth and Tillage. *Soil and Tillage Research* 14:185-196.
- Kletke, D., and R. Sestak. 1991. The Operation and Use of MACHSEL: A Farm Machinery Selection Template. Department of Agricultural Economics Computer Software Series CSS-53. Oklahoma State University, Stillwater.
- Morley, Deena Leigh. 2006. Effects of Tillage System, Grazing, and Seeding Date on Grain Yield of Hard Red Winter Wheat (*Triticum aestivum*) and Effect of Production Objective and Tillage System on Forage Production. Oklahoma State University M.S. thesis.
- Oklahoma Agricultural Statistics Service. 2006. Oklahoma Agricultural Statistics 2006. Available at: http://www.nass.usda.gov/Statistics_by_State/Oklahoma/Publications/Annual_Statistical_Bulletin/index.asp
- Stock, Curtis J. 2004. Winter Wheat Cropping and Tillage Systems. Oklahoma State University M.S. thesis.
- Williams, J.R., R. G. Nelson, M. M. Claassen, and C.W. Rice. 2004. Carbon Sequestration in Soil with Consideration of CO₂ Emissions from Production Inputs: An Economic Analysis. *Environmental Management* 33-:S264-S273.

Economics: No-till versus Conventional Tillage

Chapter 7

Soil Fertility and pH Management for No-till

Hailin Zhang
Extension Soil Fertility Specialist
Oklahoma State University

A successful no-till production system starts with proper management of soil pH and fertility. The acidification process and nutrient distribution in a no-till soil are somewhat different from those of a conventional tillage system due to limited mixing of soils under no-till; therefore, prior to adopting a no-till system, soil pH and nutrient levels should be tested and proper adjustments should be made to be successful.

Soil Testing: the Right First Step

It is possible to apply unneeded fertilizer or animal manure if the nutrient status of a field is unknown. This not only costs more money, but the excess nutrients applied may also enter water supplies and cause environmental problems. It is especially important to have a soil test done when fertilizer prices are high. On the other hand, applying inadequate fertilizer could reduce yields, decreasing profits. Soil testing helps determine the nutrient status of the soil. Fine-tuning nutrient management will result in more efficient fertilizer use, which can increase yields, reduce costs, and potentially reduce environmental pollution.

Careful soil sampling is essential for an accurate fertilizer recommendation. A sample must reflect the overall or average fertility of a field, so subsequent analyses, interpretations, and fertilizations accurately represent the nutrient status of the soil. Soil fertility varies by location, slope, and past management. Consider each of the following steps to obtain a good soil sample (Figure 1):

1. **Sampling Area:** A composite soil sample should represent a uniform field area. Each such area should have a similar crop and fertilizer history. A soil survey map may be helpful in identifying sampling area. Exclude small areas within a field that are obviously different. These can be sampled separately if they are large enough to warrant special treatment. One sample in gen-

Soil Fertility and pH Management

Soil Testing is important to monitor levels of:

- Nitrogen
- Phosphorus
- Potassium
- Acidity

eral should represent no more than 40 irrigated acres or 80 dryland acres.

2. **Sampling Procedure:** Follow a random zig-zag pattern to get a minimum of 15 to 20 cores from the sample area. Mix these subsamples thoroughly and save one pint for analysis. Fewer subsamples taken in a given area results in less accuracy of evaluating the nutrient status of the soil.
3. **Sampling Depth:** Take the surface sample to tillage depth or about 6 inches, for routine fertility analysis.
4. **Sampling Time:** Typically, the best time to soil test is before each cropping season, but be sure to allow enough time for analysis and fertilizer recommendation. It generally takes less than two weeks (in Oklahoma) to have a sample tested.
5. **Sample Handling:** OSU soil sample bags, probe, and other information related to soil testing are available at your local county Extension office. County Extension educators will mail your samples to the OSU Soil, Water, and Forage Analytical Laboratory and assist you in interpreting test results.

A routine soil test including pH, nitrate-nitrogen, plant available phosphorous, and potassium is needed for most crops, but secondary and micro-nutrient analyses may also be important for a success-

Table 1. Soil pH Preference of Selected Crops.

| <i>Legumes</i> | <i>pH Range</i> |
|---|-----------------|
| Cowpeas, crimson clover, mungbeans, vetch | 5.5-7.0 |
| Peanuts, soybeans | 5.8-7.0 |
| Alsike, red, and white (ladino) clovers, arrowleaf clover | 6.0-7.0 |
| Alfalfa, sweet clover | 6.2-7.5 |
| <i>Nonlegumes</i> | <i>pH Range</i> |
| Bluestem, fescue, native hay, weeping lovegrass | 4.5-7.0 |
| Buckwheat | 5.0-6.5 |
| Corn, oats, orchardgrass, ryegrass, sorghum, sudangrass, winter wheat | 5.5-7.0 |
| Bermudagrass | 5.7-7.0 |
| Barley | 6.5-7.0 |
| Cotton | 5.7-7.0 |

placing N fertilizer just below the soil surface with a coulter can effectively reduce volatilization loss.

Additionally, some N may be temporarily used by microorganisms as they decompose crop residue with a high C:N ratio. This may reduce N available to plants during the early stage of plant growth, but applying 1/3 to 1/2 of the total N preplant, preferably injected into the soil, should avoid residue decay-induced N deficiency. Ultimately, if managed properly, the amount of N needed for no-till should be similar to that for conventional tillage system.

The sensor-based N management strategy developed by Oklahoma State University and marketed by NTech, Inc. has proven to be practical and efficient. If used correctly, it can increase nitrogen use efficiency (NUE) by 10 to 20 percent and save farmers more than \$10 per acre in addition to environmental benefits. The sensor-based N management uses a 'Nitrogen Rich Strip' or Nitrogen RAMP and a 'GreenSeeker' sensor to predict site-specific yield goal and prescribe the right amount of top dress N at an appropriate growth stage in season. It addresses the point-to-point variability within a field (spatial variability) and year-to-year variability over time (temporal variability). The sensor-based N management technology has been calibrated for wheat, corn, rice, and bermudagrass, and research is underway to extend this technique to other crops. Several states and foreign countries are currently using this new invention for crop production. More information about this crop-sensing-based technology to improve N use efficiency can be found at www.nue.okstate.edu.

Phosphorous Management

The method used to determine phosphorus (P) availability in soil is called Mehlich 3. It is expressed in an index. An index of 65 is desired for all crops, which is considered 100 percent sufficient. A soil test with 40 percent sufficiency means 40 percent of plant phosphorus needs will be supplied by the soil. The remainder must be provided by adding fertilizer. If no phosphorus is added, the yield will only be 40 percent of the potential yield. If P is deficient, apply adequate amount of fertilizers before switching to a no-till system. Similar to conventional till, banding P fertilizers is advantageous over broadcasting in a no-till system. In fact, banding may be even more advantageous in a no-till system because P movement in the soil is very slow. Furthermore, P applied on the surface may be subject to erosion or runoff loss more easily than when (or if) it is band applied.

Research has shown that no-till crops responded to starter fertilizers containing both N and P very well even in soils with high soil test P levels. This is probably due to the fact that no-till soils with increased residue cover are cooler and wetter early in the growing season than conventionally tilled soils, which may decrease soil P availability.

Potassium Management

Like phosphorus, potassium (K) soil test estimates K availability in the soil and the test indicates a certain percent sufficiency. The optimum level will vary with crops, soil type, and other soil related factors, but an index of 250 is considered adequate for all crops except for alfalfa. Alfalfa requires 350 to have adequate K supply from the soil. Potassium can be surface applied or in a band. However, the amount of K and N in the starter (banding) is determined by the distance of the fertilizer band and the seed, since both nutrients contribute to the salt index. Some crops are more sensitive to salt injury than others. Soluble fertilizers placed in a band may cause germination and/or seedling injury if rates are too high. In general, the salt index (applied N + K₂O) should not exceed 30 pounds per acre for wheat and 7 pounds per acre for corn. In extremely arid regions and/or where rapid drying takes place, salt rates less than these can adversely affect wheat and corn seed germination.

Summary

- Soil test at the beginning and on a regular basis.
- Lime to adjust soil pH before switching to no-till practices. Once in no-till, monitor surface pH frequently and lime to maintain proper pH if needed.

Soil Fertility and pH Management for No-till

- Residue can reduce N efficacy and tie up N during decay. Adjustment may be needed on N fertilization.
- Base P and K fertilization rates on regular soil test recommendations.
- Pay attention to salt index when band-applying fertilizers.



Chapter 8

Weed Management

Case Medlin

Extension Weed Specialist
Oklahoma State University

Switching from a conventional tillage weed control system to a no-till weed control system is similar to a mechanic loosening their open-end adjustable wrench (i.e. Crescent® wrench). The open-end adjustable wrench is often the wrench of choice for many jobs, or those jobs that require a metric wrench that you never have purchased. Likewise, tillage is a reliable method to combat weed populations regardless of the species and is still an option for controlling weeds whose chemical control options do not exist. Just like the mechanic loosening the wrench, crop producers should remember there are four other methods of weed control besides mechanical control (e.g. preventative, cultural, biological, and chemical). In general, the reliance on these four methods will increase in no-till crop production systems.

Cultural Control Practices

A Healthy Crop is a Competitive Crop

Cultural weed management should not be overlooked when planning for a crop. Too often, producers forget the basics of 'crop health,' which leads to weed problems. The best weed control tool we have is a healthy, actively growing crop. Therefore, getting a no-till system off to a good start in terms of proper adjustment of soil pH and nutrients will benefit the health of a crop and also improve weed management practices. A healthy crop is more likely to out-compete weeds than a crop lacking proper fertility.

Small Changes May Drastically Ease Weed Control

Narrower row spacing and higher seeding rates result in quicker canopy closure and a denser crop canopy, which enables the crop to shade out weeds. Likewise, planting into good soil moisture, planting

Successful weed control for no-till production systems will ensure:

- A healthy, actively growing crop.
- Timely applications of an appropriate herbicide.

at uniform depths across the field, and closing the seed furrows ensures uniform crop emergence, improves crop competitiveness, and lessens chances of herbicide injury to the crop.

Crop Rotations Complement Weed Control Strategies

A summer rotational crop will help kill infestations of winter annual grasses that may have plagued winter wheat production. Similarly, rotating to a summer broadleaf crop may help address the control of summer annual grasses that may infest the corn or grain sorghum planned the following year.

Chemical Control Considerations

Burndown Programs For a Good Start

Planting a crop into growing weeds is not a good practice. Significant crop competition occurs when crops and weeds emerge at the same time, however, the crop is damaged even more if the weeds are established prior to planting the crop. Too often when the crop is planted into actively growing weeds

rainfall, mechanical problems, or other issues delay burndown efforts, which result in early-season weed competition and the use of more expensive, and often less efficacious, herbicides for early in-season weed control that may result in crop injury, negatively impacting the health of the crop.

Consider Soil Residual Herbicide Programs

The use of soil residual herbicides is one way to lessen the potential of early-season weed competition and to help manage problematic weeds difficult to control with current postemergent herbicide options. If planned appropriately, these soil residual herbicides will diversify the herbicide chemistry in the field and prolong or prevent weed resistance from occurring. A possible downside of using residual herbicides is potential herbicide carryover into the following crop. For this reason, it is always important to read herbicide labels to determine rotational provisions prior to its application.

“Probably the greatest obstacle is weed control...it is hard when your fields look like they are full of trash, plus the neighbors want to know if you have quit farming... strange thing is the ones that gave me fits are now beginning to do the same thing!”

David Shultz
Altus, OK

Herbicide Selection can Impact Crops Planted up to Three Years Later

Chemical carryover occurs when an herbicide applied to a crop remains active in the soil long enough so it impacts the growth of following crop(s). For this reason, one must consider not only the crop to plant, but also the herbicides that will be sprayed to control the major weed pest in the field, and the rotational interval required by the label prior to planting the next crop in the rotation.

Timely Herbicide Applications are Critical

Early season weed interference can significantly lower crop yields and make chemical control of weeds much more difficult. To maximize your yield, weeds that emerge with the crop should be controlled during the third to fifth week after crop emergence. In order to achieve acceptable control, postemergent herbicides should be applied to small, actively growing weeds. The application timings should correspond to weed height ranges indicated on the herbicide labels. Consider purchasing your own sprayer if timely application from your commercial applicator has been a problem. Another consideration is to purchase one with a neighbor and share the cost.

Prolong Herbicide Resistance Problems at all Cost

Alternating herbicide modes of action may prevent or at least prolong the development of herbicide resistance. Avoid sole reliance on an herbicide resistant cropping system where the same mode of action is used application after application, but rather incorporate other herbicide modes of action to compliment this program and have more activity on potential problematic weeds (e.g. Palmer amaranth, horseweed, Italian ryegrass, tall waterhemp, etc.)

Some Misperceptions that Should be Avoided

No-till Will Save me a lot of Money

Perhaps the most common misperception is, “changing to no-till will save a lot of money.” Although changing to no-till should not increase your

“All growers should be ready for a shift in their weed species the longer they leave a field in a no-till system...but also observe a great increase in their soils the longer it is no-tilled.”

Greg Leonard
Afton, OK

“The additions of herbicide-tolerant soybeans and corn have greatly aided in dealing with undesirable vegetation in the fields, but it still presents a challenge.”

Brent Rendel
Miami, OK

expenses drastically, the money you may save in fuel costs will likely be used in chemical weed control during both the crop and fallow periods.

Going No-till is Simple With the Use of Herbicide-resistant Crops

Herbicide-resistant crops (HRC) (i.e. Roundup Ready®, Liberty Link®, and Clearfield® crops) have

made the conversion from conventional tillage to no-till production systems a lot easier, but there are still pitfalls to avoid. Several weeds in Oklahoma have become resistant to one or more of the herbicides used in these HRC.

Any Field can be Switched to No-till

Although this is a correct statement, one should also consider the expense it will take for each field. Fields with excessive weed pressure may be more trouble to convert to no-till. One should first concentrate on the cleaner fields before tackling the “weed patch.” When the decision to convert the problematic field has been made, get the perennials and other bad weed problems under control for a couple of years prior to conversion to no-till.

Also, one should consider any herbicide resistant weeds you or your neighbors may have.

Weed Management



Chapter 9

Disease Management

Robert M. Hunger
State Extension Pathologist
Oklahoma State University

John P. Damicone
State Extension Pathologist
Oklahoma State University

There are many organisms (pathogens) that can cause plant disease, but it takes a combination of a pathogen along with a susceptible host and a favorable environment to result in disease. The combination of these three factors is known as the disease triangle (Figure 1), and unfortunately combinations of these three factors that are favorable for disease frequently occur with the cultivation of genetically similar crops covering large areas. In corn for example, epidemics of southern corn leaf blight swept across the corn belt in the 1970s when corn hybrids were planted that all contained the same male-sterile trait that unfortunately was linked to susceptibility to the disease. An example closer to home is the 4 to 6 million acres of wheat that are typically planted in Oklahoma each year. In the 2005-2006 crop season, approximately 54 percent of this acreage was planted in two varieties (Jagger at 38 percent and

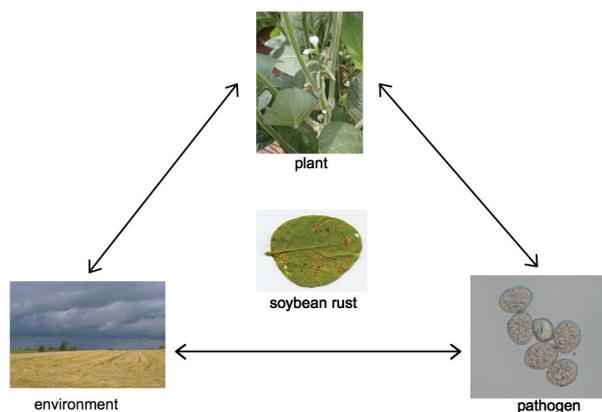


Figure 1. Disease triangle: A susceptible host plant, favorable environment, and the presence of the pathogen interact to produce disease. Soybean rust occurs during early reproductive growth stages, cloudy and rainy weather, and the presence of airborne spores.

Disease Management

Effective disease management requires understanding:

- The relationship between pathogen-host-environment that make-up the disease triangle
- Effects of reduced tillage and increased residue on plant diseases
- Genetic resistance
- Proper application of chemicals
- Cultural practices

Jagalene at 16 percent) that have similar genetic backgrounds. Such cultivation definitely contributes to the corner of the disease triangle related to the presence of a susceptible host since both Jagger and Jagalene are susceptible to wheat leaf rust.

Another corner of the disease triangle is related to the actual pathogens that cause plant disease. These pathogens represent several types of organisms including fungi, bacteria, viruses, and nematodes to name a few. The relationship between these pathogens and their hosts is often quite complex, and in many cases (for example wheat rusts), has coevolved over thousands of years. Some of these pathogens have an extremely narrow host range and are able to adapt quickly to genetic resistance incorporated into a new variety (again for example, wheat rusts). Others have an extremely broad host range and are able to infect and cause disease not only on several crops, but also on many weeds. A good example of this type of pathogen is the fungus *Sclerotium rolfsii*, which has been reported to have a

host range of at least 500 plant species in 100 plant families.

The final corner of the disease triangle is related to the environment. It is in this corner where variation from year to year and from location to location can have a tremendous effect on presence of disease and its level of occurrence. With a disease such as wheat leaf rust, there often is a susceptible variety and sufficient levels of the rust fungus (inoculum) to start the disease, but in a crop season such as 2005-2006 there was insufficient moisture to allow the disease to develop and spread. Similarly, foliar diseases of soybean such as frogeye leaf spot are more of a problem in the southeastern U.S. where rainfall and humidity levels are higher than in Oklahoma.

Agriculture typically has employed tillage to bury or hasten the decomposition of crop residue in order to prepare a clean seed bed that is considered beneficial for proper seeding and crop establishment, and to manage residue-borne diseases. In contrast to clean tillage, reduced tillage practices, such as no-till, leaves significant amounts of residue on or near the soil surface that has the benefits of increasing soil moisture conservation, reducing energy use associated with tillage operations, and reducing soil erosion. However, reduced tillage and associated surface residues also can have the adverse effect of increasing some diseases by, one) increasing levels of residue-borne diseases, and two)

“Positive point to no-till... less disease from crop rotation.”

**C. Trojan
Bison, OK**

inducing changes in the environment that include cooler soil temperatures, increased soil moisture, and leaving soil undisturbed (Bockus and Shroyer, 1998). Table 1 describes the potential impact of increased wheat residue resulting from reduced tillage on subsequent wheat crops. As indicated in the table, wheat pathogens and the diseases they cause may be reduced, unaffected, or favored in reduced tillage systems. For example, the inoculum to initiate a disease such as tan spot of wheat (Figure 2) comes directly from residue left on the soil surface. Hence, tan spot of wheat is a disease that would likely increase under reduced tillage systems. In fact, this occurred in the mid 1980s when there was an emphasis to switch to reduced tillage production along with the wide-spread cultivation of a wheat variety (TAM-101) highly susceptible to tan spot. Another similar example is take-all of wheat, where

Table 1. Effect of increased wheat residue* on the incidence and severity of various wheat diseases.

| <i>Disease</i> | <i>Effect of increased residue* on incidence and severity of disease</i> | <i>Explanation for effect</i> |
|--|--|--|
| Tan spot (<i>Pyrenophora tritici-repentis</i>) | Increases disease | Increases pathogen inoculum |
| Septoria leaf blotch (<i>Septoria tritici</i>) | Increases disease | Increases pathogen inoculum |
| Stagonospora glume blotch (<i>Stagonospora nodorum</i>) | Increases disease | Increases pathogen inoculum |
| Powdery mildew (<i>Blumaria graminis</i> f. sp. <i>tritici</i>) | Increases disease | Increases pathogen inoculum |
| Take-all (<i>Gaeumannomyces graminis</i> var. <i>tritici</i>) | Increases disease | Increases pathogen inoculum |
| Aphid:barley yellow dwarf virus | Decreases disease | Fields with increased residue are less attractive to aphids |
| Strawbreaker [also called eyespot, foot rot] (<i>Pseudocercospora herpotrichoides</i>) | Decreases disease | Related to modification of environment and inhibition of spore dispersal resulting in a reduction of infected plants |
| Other root rots including dryland root rot, common root rot, sharp eyespot, Pythium root rot | Increase or decrease, depending on the pathogen | Effect is through multiple factors including soil moisture, temperature, etc. |

*In this table, “residue” indicates straw from a previous crop of wheat as opposed to residue from a rotated crop such as canola or legumes, which would be non-hosts for these pathogens and diseases of wheat.

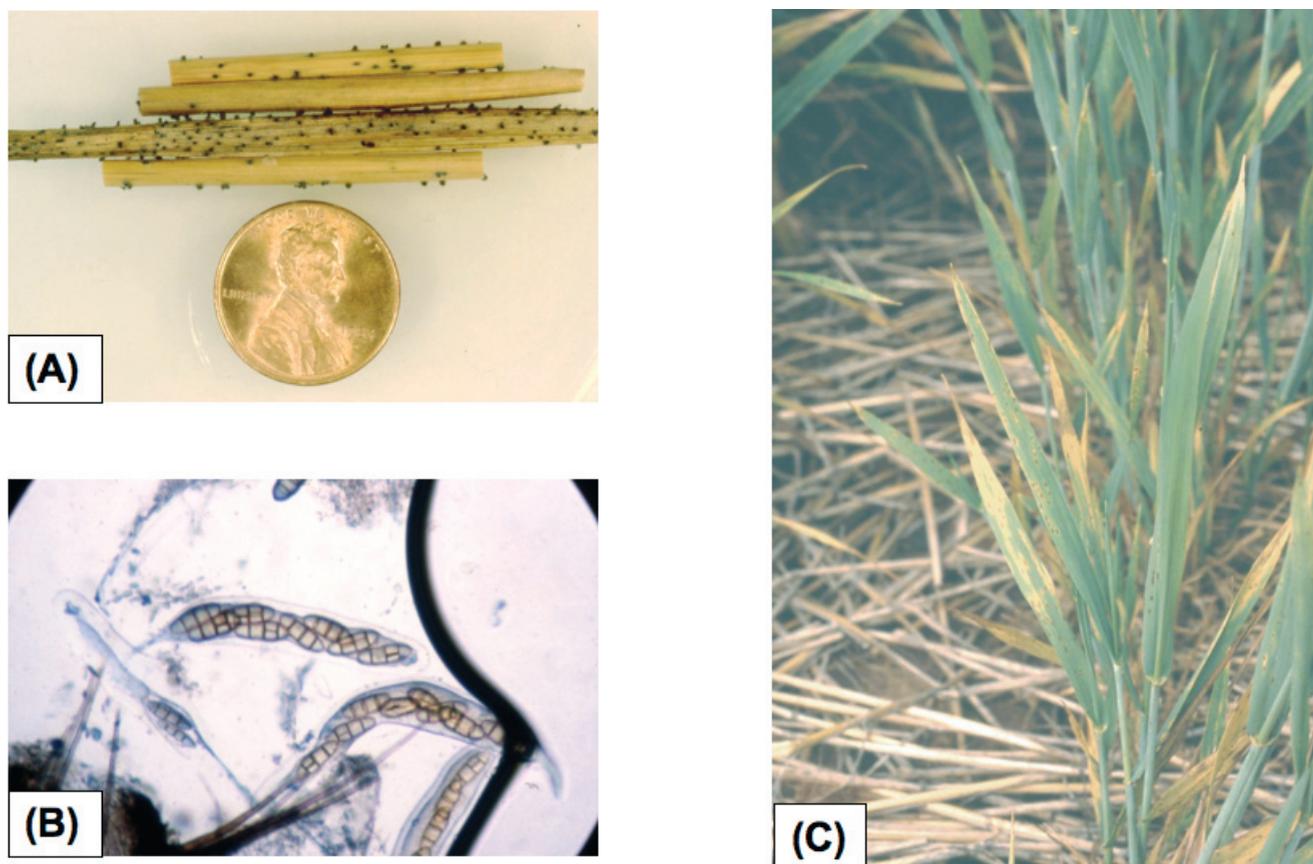


Figure 2. The fungus that causes tan spot of wheat survives during the summer on wheat residue on the soil surface producing small, black fruiting structures (A); during the fall and winter it contains spores of the fungus (B). These spores spread from the residue onto wheat in the winter and spring, causing tan spot (C).

the pathogen (again, a fungus) survives in the upper root and crown tissue. If that residue is destroyed by clean tillage, the inoculum is also destroyed. However, if residue is left undisturbed, pathogen survival and resulting disease development increases. Take-all is also favored by reduced tillage because residue conserves soil moisture and decreases soil temperature that favors take-all. A few diseases, such as *Rhizoctonia* root rot on wheat, are favored in reduced tillage systems not only because the fungus causing this root rot survives on the residue, but also because of a reduction in soil disturbance. This allows the fungus to form a large growth mat that serves as a base from which infection of wheat plants can occur.

In contrast, there are a number of diseases that are reduced by reduced tillage. Again, this is often related to environmental conditions resulting from the increased residue. As described, soil moisture increases and soil temperature decreases in reduced tillage systems. These changes, although favorable to some pathogens, are unfavorable to others such as common root rot and dryland root rot of wheat, and various stalk rots of corn. The pathogens that cause these diseases are favored in drier and warm-

er environments and tend to cause the most damage under conditions of moisture stress. Another disease that decreases in incidence and severity with reduced tillage is foot rot (strawbreaker) of wheat. The pathogen that causes this disease survives on residue, which would seem to favor an increase in eyespot. However, this pathogen also requires cool temperatures and high humidity/free moisture to move from infected straw to young wheat plants. It is thought that increased residue reduces the density of the foliage that in turn leads to a less favorable environment for infection.

In addition to the considerations related to the effects of reduced tillage and increased residue on plant diseases, the question of how to manage diseases in a reduced tillage system also arise. The answer to this question revolves around the same considerations that have been used over the years to manage diseases, and primarily involve use of genetic resistance, application of chemicals, and the use of cultural practices such as crop rotation.

For many years, Oklahoma and other states have generated tables that compare the performance and disease reactions of various crop varieties (for an example, see: <http://www.wit.okstate.edu/varietyin->

fo/index.html). Similar publications and/or charts have been developed that describe reduced tillage impacts on the diseases of specific crops. Examples include:

1. For corn, <http://www.extension.iastate.edu/Publications/PM1096.pdf>, and
2. For wheat, <http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-7561/PSS-2132web/pdf> and <http://www.oznet.ksu.edu/Topic2.asp>.

If a switch is being made to reduced tillage, then such a chart will be helpful in selecting varieties with resistance to a disease (or diseases) that are favored by increased residue.

Fungicides are a second approach to help control diseases in many commodities and are useful in both reduced and clean tillage systems. Finally, the use of various cultural practices may also be used to help control diseases that cause concern related to reduced tillage. For example, planting wheat later in the fall can reduce the incidence and severity of some diseases that are 'residue-borne' such as *Cephalosporium* stripe in wheat, but will have minimal or no effect on a disease such as tan spot of wheat. Another possible cultural control is the type of fertilizer used as demonstrated by the reduction in take-all of wheat following application of ammoniacal forms of nitrogen as compared to nitrate forms of nitrogen. However, the single most important cultural control to employ in management of diseases in reduced tillage operations is rotation with an unrelated crop. This type of rotation breaks the cycle of continuous residue of a given crop and nearly always significantly reduces the inoculum

of a pathogen. This is most reliable if the rotation is during a two or three year period as compared to double cropping within the same season. There are a few instances where care must be taken. For example, a corn-wheat rotation would appear to fit this scenario quite well as these are quite unrelated hosts. However, in the Midwest, corn-wheat or corn-barley rotations can contribute to epidemics of head scab caused by *Fusarium* spp. because both crops are hosts for this pathogen. This, however, is the exception to the rule, and rotation with an unrelated crop generally will contribute greatly to the success of reduced tillage operations.

Summary

In summary, reduced tillage is attractive for a number of benefits including, conservation of energy and moisture, and reducing soil erosion. However, reduced tillage increases crop residue left on or near the soil surface, which can impact the incidence and severity of diseases primarily by maintaining pathogen populations in the increased residue, increasing soil moisture, decreasing soil temperature, and leaving soil undisturbed. Therefore, disease management programs that use disease resistant varieties, crop rotation, and fungicides when necessary should be considered for managing diseases that are likely to increase in reduced tillage operations.

References

- Bockus and Shroyer. 1998. *Ann. Rev. Phytopath.* 36:485-500.

Chapter 10

Insect Management

Tom A. Royer

IPM Coordinator and Extension Entomologist
Oklahoma State University

Conservation tillage practices, such as no-till, are receiving renewed interest among Oklahoma wheat producers. As producers adopt conservation tillage, they may see shifts in the insect pest complex that infest their crops and will need to adjust their pest management strategies to account for them. Fortunately, control tactics are available regardless of the type of tillage used. What is important is to develop a management strategy based on fundamental principles of Integrated Pest Management (IPM).

How can conservation tillage affect insect pest populations? Tillage practices directly affect soil, which provides shelter and resources for many arthropods that live there, so tillage can affect insect populations as well:

1. Direct effects:

- a. Some insects live in or on the crop residue, or in the soil at some point in their lifecycle. Tillage can disturb these insects by killing them, by destroying the residue that the insects rely on for shelter, or by physically disturbing the soil habitat. For example, Hessian flies overwinter and over-summer as a puparia on wheat stubble. If the wheat stubble is buried deep enough in the soil with tillage, emerging Hessian flies die in the soil.
- b. Some insects such as May/June beetles prefer to lay their eggs in fields that are covered with plant residue, while others, such as the army cutworm, prefer bare soil.
- c. Soil temperatures are often cooler and soil moisture higher in fields with crop residue, which can affect the survival and development rate of insects that live in the soil. For example, Illinois researchers found that emergence of corn rootworm adults is delayed in no-till fields, and survival of rootworm eggs is actually increased in no-till because such fields tend to have less fluctuation in temperature during the winter.

Insect Management

Tillage systems greatly impact the insect populations present in the environment. Considerations should include an Integrated Pest Management Program for:

- Winter Wheat pests
- Corn/Sorghum pests
- Cotton pests
- Soybean pests

2. Indirect effects:

- a. Tillage can change the type and density of weeds that are present, which in turn can affect the populations of both beneficial and pest insects. Poor weed management can make a field more attractive to insects such as the black cutworm or the May/June beetle. Volunteer crops may serve as reservoirs for pests. Wheat curl mite, the vector of wheat streak mosaic virus, often builds in volunteer wheat, then moves into the wheat crop once it emerges from the soil. On the positive side, the presence of wheat stubble in the soil has been shown to deter greenbugs from colonizing and building in numbers compared to tilled fields. In general, increased diversity in the physical environment from crop residue may also add stability and diversity to the agricultural ecosystem, including a more diverse population of beneficial insects.
- b. Crop rotations are often an important component for successful crop production with conservation tillage. Rotations can affect the potential insect pests that might occur. For example, continuous cultivation of the same

crop may allow pests of that crop to build. The lifecycle of some pests can be disrupted by rotating into a nonhost crop for one or more years. Some insects are pests of several crops and can cause problems if the crop rotation sequence is favorable for them. In general, crop rotations are beneficial for effective crop production using conservation tillage, but producers should become aware of the pests associated with the rotation program they implement.

With a couple of exceptions, effective management tactics are available to control insect pests regardless of the tillage system. In fact, most control recommendations are not contingent on the type of tillage system in place. Tillage can be an effective management tactic for some insects, and by removing it as a potential tool, other tactics need to be identified and used to compensate for that loss. Some tactics that are important for managing insect pests of small grains include:

- Biological control
- Crop rotation
- Planting date selection
- Resistant varieties
- Weed control
- Chemical control

The following section will discuss some of the more important insect and mite pests of individual crops as they relate to conservation tillage.

Winter Wheat

Aphids

Cereal aphids are the most important pests of winter wheat in Oklahoma (Figure 1). The most common include the greenbug, the bird cherry-oat aphid, and the Russian wheat aphid. Published research has provided mixed results with regard to the effects of conservation tillage. Oklahoma research has shown that the presence of crop residue inhibits greenbug infestations. Research in the northern Great Plains showed that bird cherry-oat aphids survived better in spring wheat grown under no-till. At best, we can say conservation tillage either has little effect or that aphid numbers will be less abundant in fields grown under conservation tillage. Fortunately, control recommendations for aphids in winter wheat are based upon the number of aphids present at any given time. Scouting procedures are not altered because of the tillage system. An area of research that needs attention is the effect of crop residue on some important natural enemies of cereal aphids, including the lady beetle complex and the parasitic wasp, *Lysiphlebus testaceipes*.



Photo courtesy USDA.

Figure 1. Aphids.

Armyworms

Several different insects are referred to as “armyworms.” There are three important armyworms that are pests in winter wheat, the armyworm, the fall armyworm, and the army cutworm. Each has a different biology and habits, and conservation tillage would potentially have different impacts on each of them. Very little research has been published on the effects of tillage systems as it relates to infestations by armyworms in winter wheat.

The armyworm over-winters in Oklahoma and typically causes problems during the spring after wheat has jointed (Figure 2). Adult armyworm moths prefer to lay eggs in fields with dense plant populations, or in fields with lodged plants. Tillage probably does not have much affect on armyworms.

Figure 2. Armyworm.



Photo courtesy Tom Royer.

Army cutworms occur during the winter and early spring. Adult army cutworm moths prefer to lay eggs in bare fields, thus wheat grown under conservation tillage would probably be at less risk of being damaged by army cutworms.

Fall armyworms do not over-winter in Oklahoma. They typically infest wheat during the fall after it emerges. Populations die following the first killing frost in the fall. Little research-based information exists on what effects conservation tillage would have on fall armyworm infestations.

Hessian fly

The Hessian fly over-winters and over-summer in wheat stubble (Figure 3). Two major periods of egg-laying activity occur, one in the spring, and one in the fall. They seem to be stimulated by favorable temperatures and precipitation events. Hessian fly populations carry over in wheat stubble and can build from volunteer wheat. Therefore, they can be expected to be more of a problem in areas where continuous wheat is grown under conservation tillage. Since tillage can be a major factor in reducing Hessian fly, it becomes more important to utilize other management tactics to reduce the threat of Hessian fly damage. They include: use of resistant varieties, planting after established fly-free dates, destruction of volunteer wheat, and use of insecticide seed treatments.

Mites

Three species of mites commonly attack winter wheat. The winter grain mite prefers cool, moist growing conditions and the brown wheat mite thrives in the hot, dry conditions seen in drought. Both mites are associated with continuous wheat cropping, and are likely to be found in conservation tillage. However, they can be controlled with insecticides regardless of the tillage system.

The wheat curl mite is a vector of wheat streak mosaic virus. They can live in other grasses, but thrive in corn and wheat. Of most concern is their

Figure 3. Hessian Fly.



Photo courtesy Tom Royer.

potential to build in volunteer wheat in fallowed land. Since they can maintain themselves in volunteer wheat, they can be a source of virus disease in the fall. There is no effective chemical control of wheat curl mite, so they must be managed through control of volunteer wheat at least two to three weeks before the fall crop is planted.

Wheat Stem Maggot

Wheat stem maggot is not a serious pest of winter wheat in Oklahoma, but it does maintain populations in volunteer wheat and other grasses. It is not known how conservation tillage would affect wheat stem maggot infestations, but delayed planting is an option for decreasing infestations.

Wireworms and White Grubs

Wireworms, false wireworms, (Figure 4) and white grubs (Figure 5) are stand-reducing insects that are affected by tillage. Adults of these insects are attracted to fields with volunteer plants, germinated weeds, and crop residue to deposit their eggs. Wireworm and false wireworm damage can be minimized with the use of insecticide seed treatments, but white grubs are not effectively controlled with insecticide seed treatments. It becomes imperative to control volunteer plants and weeds during the egg-laying periods to minimize damage from these



Photo courtesy Tom Royer.

Figure 4. False Wireworm.



Photo courtesy Tom Royer.

Figure 5. White Grubs.

pests.

Corn/Sorghum

Cutworm

Cutworms damage seedling plants by cutting them below their growing point, which results in stand loss. Some cutworms, such as the army cutworm and the variegated cutworm over-winter as larvae. Other cutworms, such as the black cutworm, lay eggs in early spring on winter annual weeds. Conservation tillage often allows for more winter annual weeds to germinate and grow until a burn-down herbicide is applied before planting. Such fields are attractive to black cutworms. Crop residue in general provides suitable habitat for survival of over-wintering cutworm larvae. Generally, the risk of cutworm damage can be reduced by applying a burn-down herbicide application to a field three weeks before the field is actually planted.

Corn rootworms over-winter as eggs in soil. Most of the research on the effects of tillage on rootworm egg survival suggests that tillage combined with cold dry winters may increase rootworm egg survival, but often does not significantly impact rootworm egg survival. Undisturbed soil may actually allow for increased natural enemy activity against rootworm eggs. Thus, rootworms would not likely be affected favorably or unfavorably by conservation tillage.

Corn Borers (Southwestern and European)

European and southwestern corn borers are significant pests of corn. Both insects overwinter as larvae in the corn stalk. Conservation tillage systems likely would encourage survival of southwestern corn borer larvae. Fortunately, transgenic corn varieties that control corn borers are widely available, and growers should select hybrids that aid in management of southwestern corn borers.

Other insects, such as stalk borer, stinkbug, and wireworms are more likely to be a problem in conservation tillage. All are difficult to control because they often damage plants before the producer is aware they are a problem. Stalk borers can be discouraged by controlling grassy weeds two to three weeks before planting. Wireworms are effectively controlled with one of the neo-nicotinoid insecticides such as imidacloprid, thiamethoxam, or clothianidin.

Cotton

Generally, insect pests of cotton tend to be favored by conservation tillage, with the exception of

bollweevil, cotton fleahopper, and tarnished plant bug. In the Southwest (Texas, New Mexico, and Oklahoma), there appears to be less of a buildup of thrips, cotton aphid, bollworm, and tobacco budworm associated with conservation tillage if cotton is planted into a winter grain crop that previously has been killed with an herbicide.

Cutworms

Cutworm numbers appear to increase in conservation tillage. The increased incidence of injury from cutworms is likely related to the presence of winter cover crops and the presence of weeds in conservation tillage fields. A key practice for reducing cutworm injury in conservation tillage systems is to destroy the cover crop/vegetation at least three weeks before planting.

Thrips

Thrips can utilize other host plants that might be present in the field and enable them to invade seedling cotton as it emerges. Results from research in the southwestern portion of the Cotton Belt suggest that thrips populations are no more abundant in cotton grown in conservation tillage systems compared to conventional tillage systems. However, higher thrips populations may occur in cotton if the surrounding vegetation is destroyed through an herbicide application.

Cotton Aphids

In south Texas, research shows that early season aphid numbers were higher in conservation tillage cotton compared to conventional tilled cotton, but numbers of the more damaging late-season cotton aphid infestations were lower in conservation tilled plots.

Soybean

Considerable research regarding the influence of tillage practices on soybean insects has been conducted in the north central states. Results suggest that densities of grasshoppers, Japanese beetles, and damsel bugs (a predator) were greater in mulch-till systems. Densities of potato leafhoppers were greater in plowed fields. Densities of green cloverworms were unaffected by tillage practices. Slug problems may increase as conservation tillage becomes more common because of the residue and inclusion of soybeans in no-till rotational systems.

Another study showed that cover crops and residues dramatically affected populations of seedcorn maggots. Population densities of seedcorn maggots did not increase in no-till systems, but more seedcorn maggots were found in tillage systems that incorporated live, green cover crops into

the soil compared to systems that used dead crop residue.

Grasshoppers

Population densities of grasshoppers (Figure 6) vary widely from year to year and seem to be regulated primarily by weather, natural enemies, and diseases. Most grasshopper species over-winter as eggs buried about 2 to 3 inches in the soil. Most species deposit egg pods in the soil of uncultivated field



Photo courtesy USDA.

Figure 6. Grasshoppers.

margins, roadsides, ditch banks, fence rows, pastures, alfalfa, and clover fields in late summer and early fall. Eggs over-winter and hatch from late May through July. Grasshopper nymphs usually feed for two to three weeks near their hatching site. When their food source becomes scarce or when feeding sites are mowed or otherwise destroyed, nymphs move to nearby crops, where they feed and become adults. There is usually one generation of each grasshopper species each year. While tillage can affect grasshopper populations, such impact would have to occur over large areas to cause any significant reductions because grasshoppers are very capable of migrating long distances as adults.

Seedcorn Maggot

Seedcorn maggot adults (flies) emerge early in the season and seek decaying organic matter on which to lay eggs. The larvae (maggots) feed on seeds and underground portions of soybean seedlings. As stated previously, potential for seedcorn maggot injury increases if green cover crops and crop residues are incorporated into the soil or liquid or solid animal wastes are used as fertilizer.

References

- Buntin, G. D, K.S. Pike, M.J. Weiss and J.A. Webster. 2007. Handbook of Small Grain Insects. Entomological Society of America, APS Press, St. Paul, MN.
- Royer, T.A., B. R. Leonard, R. Bagwell, J. Leser, K. Steffey, M. Gray and R. Weinzier. 2000. Insect Management, pp 139-154 in. Conservation Tillage Systems and Management, MWPS-45, 2nd Edition. Iowa State University, Ames.

Insect Management



No-till Crops

Jeff Edwards
Small Grains Extension Specialist
Oklahoma State University

J.C. Banks
Extension Cotton Specialist
Oklahoma State University

Chad Godsey
Extension Cropping Systems Specialist
Oklahoma State University

Rick Kochenower
Area Agronomy Specialist
Oklahoma State University

Wheat

Wheat occupies the largest acreage of any grain crop in Oklahoma, so it is likely that any no-till production system in the state will include wheat at some time. In the presence of a crop rotation, the agronomic and managerial requirements for no-till wheat production are similar to those of a conventional till system. Without a rotation, however, no-till wheat production requires much more planning and management than a conventional till system.

The level of planning and management required for no-till wheat will vary by producer, region, and production objective. There are, however, some 'universal truths' regarding no-till wheat production and no-till crop production in general. Even distribution of the previous crop's residue, for example, is critical for no-till farming. Wheat farmers, especially those using custom harvesters, may not be accustomed to closely monitoring combines to



Photo courtesy Jeff Edwards.

Figure 1. Winter crops, such as canola, often serve as good rotational crops for wheat farmers wishing to transition to no-till.

No-till Crops

Important crops for no-till consideration include:

- Wheat
- Soybeans
- Cotton
- Sorghum
- Corn

ensure that straw choppers are engaged and working properly and that chaff spreaders are covering the entire header width. These farmers will quickly discover that incorrect residue management can negatively affect crops for years to come.

Another management technique that will likely apply to all no-till wheat production systems is the need for starter fertilizer. Numerous experiments at OSU have revealed the benefit of in-furrow application of phosphorus fertilizers. The benefits to starter fertilizer are greatest in low pH and/or low phosphorous fertility situations, but researchers have seen advantages to starter fertilizer in dual-purpose wheat even when soil phosphorus is already at sufficiency levels. It is likely that, because of cooler soils and nutrient stratification, the benefits of starter fertilizer will be even greater in a no-till system than in conventional till wheat.

How Important is Rotation?

As stated earlier, the difficulty associated with no-till production of wheat will depend largely on whether or not crop rotation is used (Figure 1). If a crop rotation is incorporated into the production system, then no-till wheat production techniques will be very similar to those of conventional till

wheat. In fact, since most Oklahoma farmers are familiar with wheat production, wheat will likely be the easiest part of the cropping system. The challenge will be in production and marketing the rotational crops incorporated into the cropping system.

In contrast to farmers using a rotation, farmers wishing to grow no-till continuous wheat will likely encounter many challenges they did not face when growing conventionally tilled continuous wheat. Paramount among these issues will likely be weed and/or disease control, but other issues such as fertility, compaction, and residue management can also create challenges.

Most Oklahoma farmers know of someone who has tried to no-till wheat and then reverted back to conventional tillage due to poor weed control. With proper planning and management, however, this does not have to be the case. Perhaps one of the most important components of this planning process is to begin with clean fields. If wheat fields are already infested with hard-to-control weed species such as *Italian ryegrass*, then these weed problems will likely only become worse in a no-till system.

Another part of the weed control planning process for wheat farmers is to become familiar with rotation restrictions. Many of the most popular wheat herbicides have restrictions regarding the planting of rotational crops. Planning for crops one or two years ahead of time will likely be a new experience for most wheat farmers, but with careful attention to label restrictions and good recordkeeping, wheat farmers will likely find this task easier than they first thought.

It is also important for new no-till farmers to realize that summer weed control is critical to moisture savings and long-term weed control. A good rule of thumb to use is to ask yourself “are there enough weeds in my field that I would normally till right now?” If the answer is yes, then you probably need to spray for weeds in a no-till wheat production system.

Using Graze-out as a Rotation

Graze-out is a management system in which cattle are allowed to graze wheat pasture well into the spring and no grain is harvested from the field. There is some evidence that graze-out can successfully be used as a rotation in a continuous wheat production system. Under this management strategy, farmers would typically graze-out 2/3 of their acreage and harvest 1/3 for grain. The advantage of this system is the intensive grazing pressure can reduce the amount of wheat residue carried over from year to year, thereby reducing the amount of inoculum present for disease the following year. The commonality among farmers that have made this system work seems to be they are more cattle-oriented



Photo courtesy Jeff Edwards.

Figure 2. Cattle traffic creates compaction regardless of the tillage system. The soil compaction from hoof traffic in the conventional till wheat field pictured will likely affect grain yield. Compaction such as this may be reduced in no-till systems over time due to greater load-bearing strength of the soil.

than crop-oriented and the wheat yield potential on their farm is typically less than 30 bushels per acre.

There are also many forage-only producers who have found success with continuous no-till wheat production. In this system, the majority of wheat residue is removed during grazing, so diseases are not generally as much of a problem in these systems as in grain only or dual-purpose systems. Likewise, since the emphasis is on forage production, weed control is generally not an issue. Producers using this system are often cattle-oriented and may enjoy the flexibility and simplicity that a no-till system provides.

What about Compaction?

Cattle create compaction, and dual-purpose and forage-only wheat producers are often concerned about soil compaction in a no-till system. In conventional till systems, compaction from hoof traffic is normally alleviated via tillage operations; however, this compaction is quickly reintroduced once wheat fields are stocked with cattle in the fall. As a result, conventional till and no-till fields have similar amounts of compaction by the following spring. So, the primary difference in compaction between the two systems is during planting and forage establishment in the fall. The effect of this compaction on forage production is probably minimal and should not deter someone from no-till wheat production. In fact, a properly managed no-till system might actually have less compaction in wet years due to greater load bearing strength of the soil.

Variety and Seeding Rate

If incorporating a rotational crop into a no-till strategy, there probably is little difference in variety

performance under no-till or conventional till management. It is best to review current variety trial results and variety comparison charts (www.wheat.okstate.edu).

As long as high-quality seed is sown, seeding rates for no-till wheat production should be similar to those for conventionally tilled wheat. High-quality seed is characterized as being free from weed seed and foreign material, having good vigor, and having greater than 80 percent germination. High-quality seed is necessary to ensure adequate germination in cool, wet soil conditions that can be prevalent in no-tilled soils. This is especially true when planting after October 15.

Soybeans

Soybean production in no-till cropping systems is relatively simple and gives producers flexibility. Reasons for growing no-till soybean are similar to other crops: no-till conserves soil moisture and prevents soil erosion. Improved planting equipment and herbicides have made no-till production easier, and it offers several advantages for double-cropping. Double-crop soybean production is often practiced in Oklahoma when soil moisture is available after wheat harvest. Planting directly into wheat stubble reduces the risk associated with double-cropping. A double-crop soybean-wheat rotation is often an excellent way to begin practicing no-till. This system provides an easy transition into no-till.

Production of soybeans in no-till systems should involve a crop rotation. Since soybean is a legume (fixes N), it is an excellent crop to incorporate in a rotation. Planting soybeans prior to wheat, corn, or grain sorghum are all excellent choices for most parts of Oklahoma. Rotation will help control soybean cyst nematode populations. Any rotation including both broadleaf and grass crops is ideal because weed populations are easier to control.

Planting

One advantage soybeans have compared to other crops is the ability to plant soybeans in several different row widths. Recommended row width for no-till planting is 30 inches or narrower. Consistent yield response to row width less than 30 inches is hard to document. If any advantage is observed, it is usually with early/short season varieties responding more often (early MG IV). With row width not being an important yield determining factor, planting width decisions are often based on producer preference.

Soybean seed should be planted at a depth of 1 to 2 inches. Depth control needs to be precise; oth-

erwise seed is more likely to be damaged by soil applied herbicides. Plant populations should be planted around 110,000 seeds per acre. This should allow for a final plant population of 100,000 plants per acre, which is considered ideal. Drills provide less accurate seed metering than row planters. Several seed metering mechanisms are available including fluted, double-run, and wobble-slot and all require repeated adjustments to obtain the correct seeding rate. Typically, drills provide less uniformity in seed spacing and seeding rates than planters. Some adjustments will cause a grain drill to be closer in performance to a unit planter. Refer to Chapter 4 No-till Equipment on page 11 for more details on planting options and adjustments.

- a. Adjust the metering mechanism to drop two to three viable seeds per foot in 7.5-inch rows or four to six viable seeds per foot in 15-inch rows. Generally, less seed damage occurs with 15-inch rows due the large flute openings. Using a wider gate opening and slower rotation of the flute will usually give better distribution of seed in the row. Always calibrate the drill on the basis of seeds per row foot. Seeds per pound can vary tremendously between varieties and even within varieties depending on growing conditions under which the seed was produced.
- b. Whenever possible, avoid large seed. Seed damage increases as seed size increases. Use seed having at least 2,400 seeds per pound and increase the seeding rate to compensate for the seed damaged by the metering mechanism.
- c. Increase seeding rate by 10 percent for a poor seedbed.
- d. Increase seeding rate by 10 percent for early maturing varieties.
- e. Increase seeding rate by 10 percent when planting late or after wheat.

“ The no-till system is ideal for double-cropping soybeans behind wheat, since time is very limited to get the soybeans planted after the wheat is harvested.”

Brent Rendel
Miami, OK

Weed Control

Failure to control weeds is often the reason producers have a negative experience with no-till soybean production. Herbicides used in no-till soybean production fall into three categories: burndown, preemergence, and postemergence. Burndown herbicides kill existing weeds or grasses that are present at the time of application. The size of weeds is influenced by mulch quantity and the time of year when soybeans are planted. In harvested small grain stubble, weeds may be as tall as the stubble left by the combine. Harvesting removes most of the foliage from both broadleaves and grasses, reducing the amount of surface area for herbicides to contact. This may reduce herbicide effectiveness because less chemical is absorbed and translocated to other parts of the plant. This is particularly true of weeds that emerge early, such as smartweed and giant ragweed. A burndown herbicide is recommended on all no-till fields. The most common herbicides used are glyphosate and paraquat.

Cotton

Due to the sensitivity of young cotton to wind and blowing soil, cotton is a natural for reduced tillage or no-till system. Recent developments in transgenics, varieties, equipment, and techniques have allowed no-till cotton.

Reduced tillage systems in cotton were developed in the mid 1960s in Washita County in southwest Oklahoma, but due to difficulty in terminating the wheat or rye cover crops, and weed control problems, they were not used by many producers. When row-till equipment and spinning blade cultivators were developed in the 1980s more producers in this area started row-till or strip till programs. In the 1990s a program was developed that was referred to as the "Oklahoma Interseeded Residue Management Program." This program utilized a shielded drill to interseed wheat or rye between the cotton rows in late August or early September prior to cotton harvest. The small grains germinated, and when cotton was harvested, the cover crop was already established. In late winter or early spring, a row-till unit consisting of a ripper shank, coulters to move soil into the depression left by the ripper, and a rolling basket to firm the soil was used to till a strip of soil approximately 12 to 14 inches wide. The cover crop was allowed to continue to grow until it reached the hollow stem stage of growth and was then terminated with a glyphosate herbicide. At the hollow stem stage, the residue would remain standing and provide better protection from wind, heavy rainfall, and blowing soil. Cotton was then planted

"I have had some success in planting dryland cotton following harvested wheat. It has reduced, and in most cases, eliminated wind damage to young cotton."

Clint Abernathy
Altus, OK

in the strips with a normal cotton planter. Weed control was accomplished by incorporating a dinitroaniline herbicide in the strips, and by cultivation between the rows. This cultivation was achieved with a spinning disk cultivator that would not be clogged by the high residue. This technique was a vast improvement over other strip till systems, but weed control remained a season-long problem.

In 1996, transgenic cotton was introduced to the market and Roundup Ready® cotton was available to the producer. During this time, planter attachments were developed that would allow accurate placing of seed into residue. Higher prices for tillage equipment, diesel, and labor also encouraged less tillage and made no-till systems more feasible. Boll weevil eradication reduced the cost of growing cotton and cotton yields increased. Transgenic varieties were developed utilizing Roundup Ready Flex® that allowed over-the-top applications of glyphosate throughout the growing season and Bollgard® to decrease or eliminate yield loss due to bollworms. Improved planters were developed, which allowed much more accurate seed placement and allowed seeding in high residue conditions. No-till cotton quickly became the preferred technique for cotton production in dryland and pivot irrigated systems.

Producers planning to start no-till production systems need to develop a program that is specific for their individual areas and equipment systems. Crop rotation programs, soil texture, and rainfall patterns all contribute to the decision making process. Most equipment that producers already have on hand can be modified for no-till production by adding attachments to allow planting into residue. Immediate money savings result from less wear on equipment and less time spent per acre in producing the crop. Soil benefits build up over a four or five year period, but increased organic matter and crop rooting conditions are a definite long term benefit of no-till production. Producers should have a good sprayer, and preferably a hooded sprayer as well.

No-till tips and techniques will be discussed in the following paragraphs:

Residues

One of the keys to successful no-till cotton production is having sufficient residue available during the early part of the season to protect the young cotton plants. Many cover crops have been tried, but wheat or rye seemed to work best. The cover crop needs to be planted either prior to large green boll development in late August, or as soon as possible following harvest. If planting is delayed until large green bolls are developed, or if any open bolls are on the cotton, damage to the cotton can result. If the cover crop is interseeded in late August or early September, under favorable fall conditions, the cover crop can oftentimes be grazed. The cover crop should be terminated as soon as possible following jointing to eliminate water use by the cover crop. If the crop is terminated prior to jointing, it will not remain standing, nor provide as much protection to the cotton seedlings.

Planting

Planters should be equipped with coulters, residue managers, or disks to move surface residue from the row. When dealing with residue, equipment needs to cut and roll to avoid buildup on the planter. Disks on the planter that are normally used for clean till can be used if the residue is left standing, soil is mellow, and if planting following small grain harvest. The combine needs to have a good straw chopper and spreader. Heavy duty down pressure springs should be available for use on the planter under hard soil conditions, but these will often not be needed. Spike tooth closing wheels or a combination of one spike tooth wheel and a normal press wheel should be used in high residue conditions. Residue is always more easily handled when left standing. It is surprising how much residue can be planted into when a planter is properly equipped. Seeding rate will vary if the area is dryland or irrigated, but 35,000 to 40,000 seeds per acre is a good rate for dryland areas, and 40,000 to 55,000 seeds per acre is adequate for irrigated production.

Weed Control

Roundup Ready® and Roundup Ready Flex® genetic traits have greatly reduced weed control problems in no-till cotton production. Under heavy weed pressure, a preemergent herbicide can be used at planting, or an herbicide containing metolachlor can be used for annual weed control over the top of the crop. Staple® herbicide is another option as a banded over-the-top spray for control of broadleaf weeds in the row. Varieties containing the Roundup

Ready Flex® gene can have Roundup® applied over the top at any time from emergence to shortly prior to harvest. If for some reason the crop is cultivated, the soil mixing will bring more weed seed to the soil surface and increase germination of weeds. Cultivation will also cause some root pruning of the cotton, and can increase mid season stress to the plant.

Harvest

Cotton harvest in no-till conditions should not be different from conventionally tilled fields. Under most conditions, the wheat or rye cover crop is almost completely degraded and will not be picked up by the stripper. In the strip till systems, no wheat or rye is planted in the row and therefore cannot be picked up by the harvester.

In summary, conservation tillage will reduce weather injury to the young, developing cotton. It is well documented that the first 30 to 40 days in the production season set the potential for maximum yield. When soil is not tilled, more water will infiltrate rather than wash off the field, soil erosion is greatly decreased, and over time, organic matter is increased. The system might require more herbicide applications the first year or two, but after this period, weed control costs will likely decrease. With recent advances in transgenic technology, boll weevil eradication, and modern equipment selection, adaptation to a no-till system is much more easily accomplished.

Sorghum

There are two important things to consider before switching to no-till grain sorghum, what the history of herbicide use has been and if a compacted layer (hard-pan) is present. Herbicide carryover in a wheat only system can have rotation restrictions for grain sorghum up to two years from application. Therefore planning is needed before trying sorghum in a rotation. For producers switching to no-till, taking care of a compacted layer should be the first step. The compacted layer will inhibit root growth and reduce yields in any production system. Shattering of the compacted layer by deep tillage or strip-till should be done before adopting no-till. Utilizing strip-till to break the compacted layer will also allow producers to apply fertilizer and prepare a seedbed similar to what conventional tilled would be. Research at Kansas State University has shown a 3° to 4° F increase in soil temperature for strip-till when compared to no-till. This increase in soil temperature may be important when planting sorghum during the last two weeks of April, although with row cleaners on today's no-till planters, the soil

temperature difference disappears in a week to 10 days.

Grain sorghum production utilizing no-till does not require drastic changes when compared to conventional till. The goal in both production practices is to obtain proper seed spacing and good seed-to-soil contact. For any successful production practice, getting proper seed-to-soil contact is the first step. This allows the seed to germinate and grow without undue stress. The same planter can be utilized in both no-till and conventional till, two major changes needed are row cleaners and more down pressure on the row units. The seeding rate for no-till is the same as for conventional till unless row cleaners are not used. If not using row cleaners, it is more difficult to get good seed-to-soil contact and therefore, the number of seeds germinating will be reduced. It is generally recommended to increase seeding rate by 5,000 seeds/acre when not utilizing row cleaners.

As reported in the popular press and journal articles, the benefits of no-till are not immediate. In a rotation study located at the Oklahoma Panhandle Research and Extension Center (OPREC), it was in year six before the first difference in grain sorghum yields was observed (Figure 3). One common misconception is that no-till means no yields, as observed there was no difference in yields between no-till and conventional till the first five years of the study. Although no-till will not increase yields when no precipitation has fallen as in 2002 when only 53 percent of long-term mean rainfall was received. Since 2004, yields for the no-till grain sorghum have been significantly higher than for conventional till, with 2004 and 2006 yields twice as high or more. In 2006, part of the yield difference is explained by the difference in test weights (Table 1). The difference for 2006 is explained by a short duration of drought stress observed in the conventional till grain sorghum that was not observed in the no-till. The duration of drought stress, although short and not very severe, delayed head emergence and flowering. The delay in flowering was long enough that grain fill and maturation was affected by a freeze, therefore more than 7 lb/bu difference in test weights was observed.

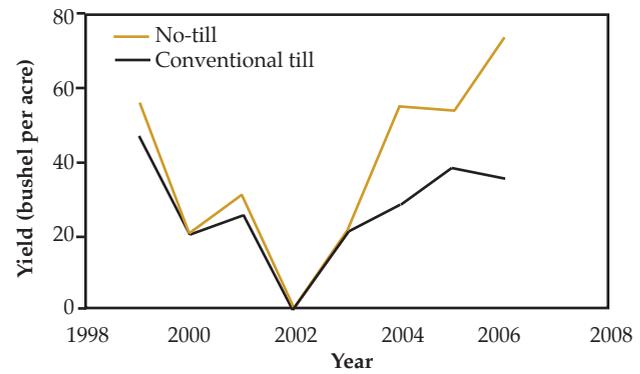


Figure 3. Grain yields of grain sorghum (bu/ac) for dryland tillage and crop rotation study at OPREC.

Table 1. Test weight of grain sorghum (lb/bu) for dryland tillage and crop rotation study at OPREC.

| Tillage | 2004 | 2005 | 2006 | Three-year |
|--------------|------|------|------|------------|
| No-till | 56.5 | 57.8 | 56.8 | 57.0 |
| Strip till | 56.7 | 57.0 | 52.9 | 55.5 |
| Minimum till | 55.8 | 56.9 | 49.6 | 54.1 |
| Mean | 56.3 | 57.2 | 53.1 | 55.6 |
| CV % | 0.8 | 1.6 | 4.2 | 3.7 |
| L.S.D. | NS | NS | 5.0 | 2.0 |



Photo courtesy Chad Godsey.

Figure 4. Double crop grain sorghum following canola.

Corn

Given all the benefits no-till can offer, there are challenges as well. Crops grown under conservation tillage are subject to many different early season stresses that may limit the plant from being able to take up essential nutrients. Crop residue acts as an insulating layer over the soil surface, which can contribute to lower soil temperatures in the upper soil profile (Johnson and Lowery, 1985). Soil temperature and soil moisture greatly influence the mineralization cycle, which controls N that is released from soil organic matter (Kolberg et al., 1999). Cool, wet soils slow down the mineralization process and contribute to poor early season growth due to the decreased amount of nutrients available to young plant roots. MacKay and Barber (1984) found the most profound effect of temperature on corn development was the rate of root growth. When soil temperature was increased from 64° to 77° F, root growth increased by a factor of five. To address slow early crop growth associated with no-till soils, the use of starter fertilizer at planting, usually containing N and P, has shown to be a key management tool for corn production throughout the U.S. These factors mentioned previously make starter fertilizer very important for no-till corn production.

Importance of Starter Fertilizer

Several researchers have documented yield responses to starter fertilizer in no-till systems in Kansas and Missouri (Gordon et al., 1997; Gordon and Whitney, 1995; Scharf, 1999). Advantages to using higher N containing fertilizers include providing additional N supplies earlier in the growing season, reducing potential of volatilization and other N



Photo courtesy Chad Godsey.

Figure 5. No-till corn – note previous years' grain sorghum and wheat residue.

losses, flexibility in timing for future N applications, and enhanced P absorption (Lamond and Gordon, 2001). In addition, the method of applying starters has become more critical as the potential of physical incorporation of materials into the soil profile with tillage decreases. Deficiencies in secondary nutrients such as sulfur (S) are becoming more common in no-till systems as well. As with N, S becomes available to plants mainly through soil organic matter and residue decomposition and mineralization. If this process is slowed down by cool, wet soils, the early season S needs of a developing crop could be affected.

Various placement methods have been adapted to provide options for starter fertilizer application. Some of the more common starter placements include in-furrow, banded near the seed, or dribble over the seed row. In-furrow placement of fertilizer, commonly referred to as *pop-up* fertilizer, is intended to promote more vigorous seedling growth due to an immediate supply of available nutrients to young plant roots. However, placing fertilizers in the seed furrow increases the salt concentration surrounding the seed (Figures 6 and 7). Under certain circumstances this can result in delayed seedling emergence, reduced seedling germination, and reductions in crop stand (Raun et al., 1986). With an increase in salt content, the plant's capacity to absorb water is reduced until it cannot extract water even in wet soils. Another possible problem with in-furrow placement of urea-containing starters is ammonia toxicity.

Alternative placement methods for starter fertilizer have been developed with the purpose of placing the fertilizer far enough away from the seed so germinating seeds and seedlings are not adversely affected, yet close enough to allow early uptake of essential nutrients. Many starter fertilizers are now placed in a band 2 inches below and 2 inches to the side of the seed row. This placement method is commonly referred to as *2 x 2 placement*. A band placement away from the seed allows more flexibility in the rates of fertilizer that can be safely applied, especially when higher N rates are desired. Subsurface band placements have generally been proven to be the most effective placement method for deriving the maximum benefit of the starter and greatest yield per unit of applied fertilizer in corn. A second option of a "safened" starter fertilizer application is a dribble placement (over the row). A dribble placement of starter fertilizer simply consists of dribbling fertilizer directly behind the closing wheel of the planter over the seed row on the soil surface.

Planting Considerations

In order to establish a good stand of no-till corn, close attention should be made to planting

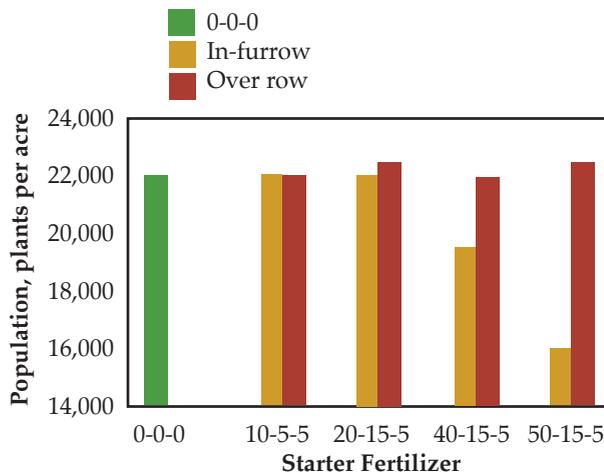


Figure 6. Modified from Niehues et al., 2004. Shows the effect of increased salt concentration from in-furrow applied fertilizer.

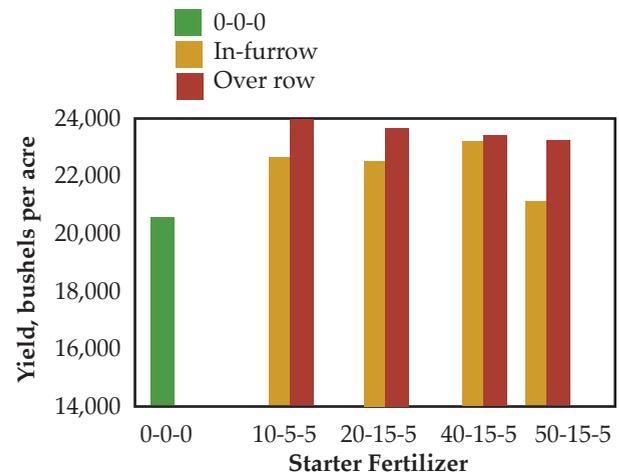


Figure 7. Modified from Niehues et al., 2004. Shows the yield response from in-furrow and over-row (drizzle) starter fertilizer.

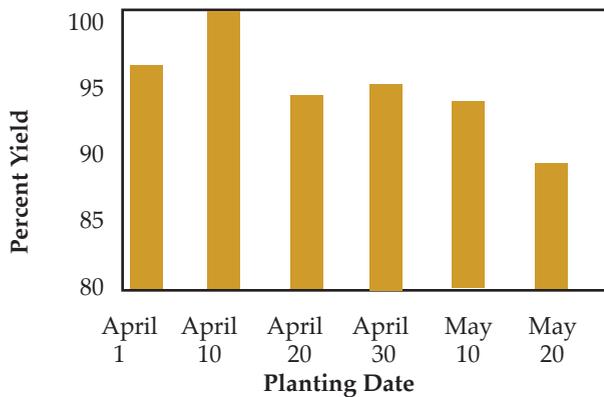


Figure 8. Four years of grain yields (114 Day Maturity) at Goodwell, Oklahoma.

date, population, and planting depth. Planting date should be based on soil temperature. The effect of delayed planting date on grain yield can be easily observed (Figure 8). Corn will germinate at soil temperatures as low as 50° F, but germination may be delayed up to 21 days. The basic recommendation for planting is a soil temperature of 55° F at the 2" depth. Also, check the forecast to be sure that for the next three to five days the forecast is favorable. Soil temperatures can be found on the Oklahoma Mesonet (<http://agweather.mesonet.org/soil/default.html>). This is the recommended method for determining optimal planting date.



Photo courtesy Chad Godsey.

Figure 9. No-till corn in Garfield County.

Dryland corn should be planted at a population from 19,000 to 25,000 seeds per acre. Corn planted in the western part of the state should be on the lower end of the range, while corn planted in the eastern half of the state should be on the upper end of the range. Keep in mind that water requirements of corn only decrease if population is less than 18,000 plants per acre. Also, hybrid selection may influence planting density, so ask seed company representatives if your selected variety performs better at a lower or higher plant population. Seed should be planted at a depth of 1.5 to 2 inches for a fine textured soil and at a depth of 2 to 2.5 inches for a coarse textured soil. Planting depth is critical for proper germination.

Table 2. Effects of starter application method and composition on corn grain yield, plant population and dry whole-plant dry matter at the V-6 stage, Experiment Field, Scandia, Kansas, 2000.

| | <i>Yield bu/ac</i> | <i>Population plants/ac</i> | <i>V-6 Dry Matter lb/ac</i> |
|---------------|------------------------|---------------------------------|-------------------------------------|
| Check 0-0-0 | 136 | 30,884 | 230 |
| Method Means | | | |
| In-furrow | 146 | 23,330 | 323 |
| 2x2 | 180 | 30,985 | 479 |
| Dribble 2x | 177 | 30,864 | 438 |
| Row band | 161 | 30,840 | 410 |
| LSD (0.05) | 11 | 840 | 32 |
| Starter Means | | | |
| 5-15-5 | 156 | 31,266 | 349 |
| 15-15-5 | 164 | 31,557 | 375 |
| 30-15-5 | 167 | 30,589 | 435 |
| 45-15-5 | 170 | 30,492 | 444 |
| 60-15-5 | 172 | 30,298 | 459 |
| LSD (0.05) | 10 | 849 | 33 |

*Source Barney Gordon Kansas State University

No-till Crops





Chapter 12

Cover Crops in No-till Systems

Chad Godsey
Extension Cropping Systems Specialist
Oklahoma State University

Introduction

In areas of western Oklahoma where precipitation (< 35 inches per year) is the main limiting factor in dryland cropping systems, the use of cover crops has generally been viewed as unacceptable due to limited precipitation. During the last quarter of a century, cropping systems have switched from a relatively diversified cropping system to a continuous winter wheat system. Wheat is often grazed, since many producers rely heavily on production of beef as their main source of income. The current general consensus of many producers in the western part of Oklahoma is that no suitable summer crops exist for their climate and no suitable alternative exists to replace wheat forage for cattle, so they are reluctant to grow anything except winter wheat. The quality of winter wheat has continued to decline in this area due to increased weed and insect populations as a result of minimal crop rotation. Another aspect of limited rotation is that no-till systems have not become popular in this region because of yield reduction under no-till with continuous winter wheat. In order for Oklahoma producers to successfully implement no-till in their cropping systems, they must be willing to rotate crops. One potential is through the use of cover crops, especially during the sum-

“Cash crops grown are wheat, cotton, corn, milo, cowpeas, canola, and hay, along with cover crops...use cover crops to start a no-till rotation.”

A. Mindemann
Apache, OK

Cover crops in a No-till cropping system can:

- Provide soil cover
- Prevent soil erosion by wind and water
- Be annual, perennial, or biennial plants
- Can be grown during all or part of the year
- Fix nitrogen in the soil
- Suppress weed, insect pests, and diseases

mer months when temperatures are high and rainfall is highly variable. Cover crops may be cheap, and if legumes are used, they may reduce nitrogen fertilizer costs for the following crop.

Cover crops contribute a variety of conservation benefits. For water conservation, they offer a triple bonus. A living cover crop traps surface water. When killed and left on the surface, cover crop residue increases water infiltration, lessens erosion, and reduces evaporation. Green manure cover crops involve incorporation for the purpose of soil improvement. Water storage efficiencies in traditional clean-till fallow systems usually are around 20 percent, while water storage efficiency in no-till systems is near 40 percent, but seldom exceeds this amount (Greb, 1983; Unger, 1984). This means 60 percent of the precipitation received during fallow is lost to evaporation.

In a no-till system, incorporation of residues is not possible, which makes it difficult to determine nutrient contribution from these crops. A cover crop is any crop grown to provide soil cover, regardless of whether it is incorporated later. Cover crops are grown primarily to prevent soil erosion by wind and water. Cover crops and green manures can be annual, biennial, or perennial herbaceous plants

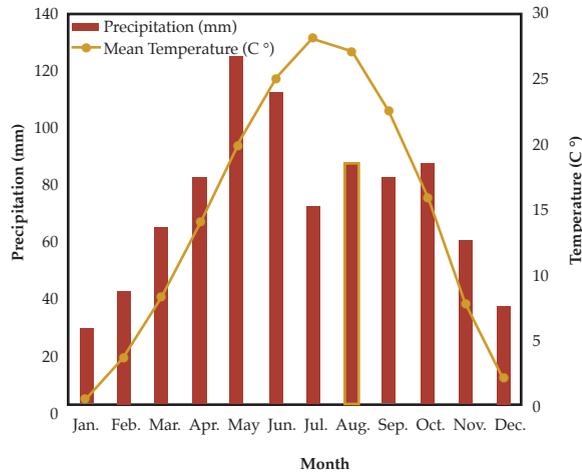


Figure 1. Average monthly precipitation and mean monthly temperature for Garfield County Oklahoma.

grown in a pure or mixed stand during all or part of the year.

Cover Crops in Rotation

Cover crops can fit well into many different cropping systems during periods of the year when no cash crop is being grown. In some areas even the simplest corn/soybean rotation can accommodate a rye cover crop following corn, which will scavenge residual nitrogen and provide ground cover and forage in the fall and winter. When spring-killed as a no-till mulch, rye provides a water-conserving mulch and suppresses early-season weeds for the following soybean crop. In Kansas, Claussen (2004) found late-maturing soybeans reached an average height of 24 inches, showed limited pod development, and produced 2.11 ton per acre of above-ground dry matter with an N content of 2.11 percent or 90 lb per acre. Sunn hemp averaged 72 inches in height and produced 3.19 ton per acre with 1.95 percent N or 125 lb per acre of N. Soybean and sunn hemp suppressed volunteer wheat to some extent, but failed to give the desired level of control ahead of the wheat. Also, when averaged over N rate, soybean and sunn hemp significantly increased grain sorghum yields, by 9.7 and 13.4 bu per acre, respectively.

Perhaps the greatest challenges for dryland producers in the southwestern part of the United States is storing and using the precipitation they receive throughout the year. Figure 1 illustrates the average monthly precipitation and mean monthly temperatures for western Oklahoma.

Production of continuous winter wheat is the common practice in the area so producers are not fully taking advantage of moisture they receive dur-

Table 1. Percent nitrogen in legume tops and roots. (McLeod, 1982)

| Crop | Tops %N | Roots %N |
|------------|---------|----------|
| Soybeans | 93 | 7 |
| Vetch | 89 | 11 |
| Cowpeas | 84 | 16 |
| Red Clover | 68 | 32 |
| Alfalfa | 58 | 42 |

ing the summer months. If we assume 40 percent water storage efficiency for a no-till systems, then 5.5 inches of water is lost during a given year or >15 percent of the precipitation they receive. Summer moisture has the potential to produce cover crops or leguminous cover crops to reduce their fertilizer costs and use the soil moisture that may otherwise be lost during the fallow period.

Nitrogen Contribution

One of the biggest obstacles with nitrogen contribution from cover crops is estimating or measuring the amount of nitrogen that a given cover crop will contribute to the following crops, especially in a no-till system. A review of the literature provides wide ranges of nitrogen contribution from various nitrogen fixing cover crops (McLeod, 1982; Claussen, 2004; Heer and Janke, 2004).

Nitrogen production from legumes is a key benefit of growing cover crops, especially with the recent increase in nitrogen prices. Nitrogen accumulations by leguminous cover crops typically range from 35 to 18 pounds of nitrogen per acre. The amount of nitrogen available from legumes depends on the species of legume grown, the total biomass produced, and the percentage of nitrogen in the plant tissue. Cultural and environmental conditions that limit le-

Figure 2. Cowpeas planted following wheat harvest in Major County.



Photo courtesy Chad Godsey.

gume growth, such as a delayed planting date, poor stand establishment, and drought will reduce the amount of nitrogen produced. Conditions that encourage good nitrogen production include getting a good stand, optimum soil nutrient levels, soil pH, good nodulation, and adequate soil moisture. Heer and Janke (2004) reported nitrogen contributions from 27 to 54 pounds per acre. Nitrogen contributions in a no-till system will no doubt be affected by lack of tillage operations. Table 1 shows percent nitrogen in above and below-ground root mass.

The portion of green-manure nitrogen available to a following crop is usually about 40 percent to 60 percent of the total amount contained in the legume. For example, a hairy vetch crop that accumulated 160 pounds N per acre prior to plowing down will contribute approximately 80 pounds N per acre to the succeeding grain or vegetable crop. Hoyt (1987) estimated that 40 percent of plant tissue nitrogen becomes available the first year following a cover crop that is chemically killed and used as a no-till mulch. He estimates that 60 percent of the tissue N is released when the cover crop is incorporated as a green manure rather than left on the surface as a mulch. Lesser amounts are available for the second or third crop following a legume, but increased yields are apparent for two to three growing seasons.

In addition to providing ground cover, and in the case of a legume, fixing nitrogen, they also help suppress weeds and reduce insect pests and diseases. Weeds flourish on bare soil. Cover crops take up space and light, thereby shading the soil and reducing the opportunity for weeds to establish themselves. Providing weed suppression through the use of allelopathic cover crops and living mulches has become an important method of weed control in sustainable agriculture. Allelopathic plants are those that inhibit or slow the growth of other nearby plants by releasing natural toxins, or “allelochemicals.” Cover crop plants that exhibit allelopathy include the small grains like rye and summer annual forages related to sorghum and sudangrass. The mulch that results from mowing or chemically killing allelopathic cover crops can provide significant weed control in no-till cropping systems. Claassen (2004) observed soybean and sunn hemp effectively suppressed volunteer wheat and, in the fall, reduced the density of henbit compared to areas having no cover crop.

Organic Matter and Soil Structure

A major benefit obtained from green manures is the addition of organic matter to the soil. During the breakdown of organic matter by microorganisms, compounds are formed that are resistant to decomposition, such as gums, waxes, and resins.

These compounds—and the mycelia, mucous, and slime produced by the microorganisms—help bind together soil particles as granules, or aggregates. A well-aggregated soil tills easily, is well aerated, and has a high water infiltration rate. Increased levels of organic matter also influence soil humus. Humus—the substance that results as the end product of the decay of plant and animal materials in the soil—provides a wide range of benefits to crop production.

Limitations of Cover Crops

The recognized benefits of green manuring and cover cropping—soil cover, improved soil structure, nitrogen from legumes—need to be evaluated in terms of cash returns to the farm as well as the long-term value of sustained soil health. For the immediate growing season, seed and establishment costs need to be weighed against reduced nitrogen fertilizer requirements and the effect on cash crop yields. Water consumption by green manure crops is a concern and is pronounced in areas with less than 30 inches of precipitation per year. Still, even in the fallow regions of the Great Plains and Pacific Northwest, several native and adapted legumes (such as black medic) seem to have potential for replacing cultivation or herbicides in summer fallow. Additional management is required when cover crops of any sort are added to a rotation. Turning green manures under or suppressing cover crops requires additional time and expense, compared to having no cover crop at all. Insect communities associated with cover crops work to the farmer’s advantage in some crops and create a disadvantage in others. For example, certain living mulches may enhance the biological control of insect pests but may serve as a host to non-beneficial pests.

Summary

The use of leguminous cover crops has gained attention due to increased nitrogen fertilizer prices. In western Oklahoma, the lack of precipitation has precluded producers from including cover crops in their rotations. It is believed that the use of cover crops can be effective in using soil moisture that would otherwise be lost during the fallow period.

References

- Claassen, M.M. 2004. Effects of late-maturing soybean and sunn hemp summer cover crops and nitrogen rate on no-till grain sorghum after wheat. Kansas State University, SRP928.
- Greb, B.W. 1983. Water conservation: Central Great Plains. p. 57–72. *In* H.E. Dregne and W.O. Willis (ed.) Dryland agriculture. Agron. Monogr. 23. ASA, CSSA, and SSSA, Madison, WI.



Cover Crops in No-till Systems

Heer, W.F. and R.R. Janke. 2004. Effects of termination date of Austrian winter pea cover crop and nitrogen rates on grain sorghum and wheat yields. Kansas State University, SRP928.

Hoyt, G.D. 1987. Legumes as a green manure in conservation tillage. p. 96-98. In: J.F. Powers (ed.) *The Role of Legumes in Conservation Tillage Systems*. Soil Conservation Society of America, Ankeny, IA.

McLeod, E. 1982. *Feed the Soil*. Organic Agriculture Research Institute, Graton, CA. p. 209

Unger, P.W. 1984. Tillage and residue effects on wheat, sorghum, and sunflower grown in rotation. *Soil Sci. Am. J.* 48:885-891.



Chapter 13

Personal Experiences

Interview with Robert Greenlee
Okmulgee County, Oklahoma

Robert Greenlee of Morris, Oklahoma, first tried no-till in 1980 with a Haybuster drill. The primary reason was to facilitate double-cropping soybeans after wheat, which was difficult using a moldboard plow and disc. Labor, fuel, and erosion were not an issue. Chemicals were expensive (Roundup® was \$80 per gallon) and not very good. He hit some exceptionally dry years and his first experience with no-till was pretty much a failure. The only good experience was with wheat for pasture. He just about went broke and sold the drill after three years.

Greenlee tried again in 1990, and switched to a planter for double crop soybeans. At the time, he was burning wheat stubble then discing, but this lost too much moisture. The soybeans would come up then die. The herbicide options had improved (Basagran®, Blazer®, and Poast®), but he continued to cultivate. This time he mastered getting a stand and the soybeans would flourish, but he was still having weed problems. He decided, "This will work if we can control the weeds." He attended the Milan, Tennessee no-till field day in 1993 or 1994. He started out experimenting with a few acres, maybe 10 percent of the total acres, and during the next few years increased the no-tilled acres.

In 1995, Greenlee started to no-till corn on a limited scale, seven acres the first year, 30 acres the second year, and continued to increase. Robert said he received his first yield monitor in 1992 or 1993 and that opened a new world. He found that no-till was yielding a little more than conventional tillage. He was getting a three to five bushels per acre increase where he did not cultivate and quit cultivating altogether in about 1997 or 1998. In the early 1990s, it was no-till that was the trial in a field, but by the late 1990s, conventional tillage had become the trial. In 1995, he planted his first Roundup Ready® soybeans, and weeds became a nonissue. Double crop beans became more feasible.



Photo courtesy Greenlee family.

According to Greenlee, "In 2002 I pretty much committed to 100 percent no-till on every acre." His partner (Mark White) threatened to cut the tongue out of the disc. He is no-tilling soils where he was told by the neighbors it would not work and has found it has improved yields on some hard-to-manage soils. He no longer needs to rebuild terraces. He did not experience a yield reduction with no-till, but it took three to four years for a yield increase. Interestingly, Greenlee now plants wheat no-till with a conventional drill. Greenlee and White are asking themselves if they really need the coulters on the planter. Greenlee said a key is getting a good stand and that requires good seed-to-soil contact. He recommends checking the neighbors, "know what's going on with the dirt, and if it's too wet, go fishing."

Greenlee stresses the following key points for success with no-till.

1. No-till works on any soil type.
2. It takes multiple years, as many as five, to condition the ground.
3. It takes some modification of planters and keep them in good shape.
4. Must keep the fields clean.
5. Harvest residue management is important, get it spread evenly, use spreaders not choppers.
6. 'No-till' is not 'No Management.'

Interview with Jimmy Wayne Kinder
Cotton County, Oklahoma

Rotation takes on several forms for no-till producers, but for Jimmy Wayne Kinder of Cotton County, it takes on the form of graze-out wheat.

"Forage is number one, wheat (grain) is number two," Kinder says. In any given year, when wheat is around \$3.00 a bushel, approximately 50 percent of his 2,000 acres is grazed-out. But if the grain price goes up, the graze-out percentage goes down.

Kinder feels his no-till wheat is able to produce more grain per acre than conventional production practices, because in wet years cattle bogging and trampling is not a significant problem on no-till. In dry years, there is little difference. He sees no difference in grain yield from his past conventional program and no-till today.

About a half mile north of his headquarters is a 25-acre field that has been in no-till production for nine years. It has been managed for wheat grain only until last year. The drought of 2005-2006 caused him to graze cattle on it. In continuous wheat production, Kinder has had some problems with grassy weeds, saying, "In no-till they haven't gotten any worse." He tries to graze-out his problem fields.

But in his other fields, he has seen a weed shift over the years in his no-till system. Purslane, thistles, and prairie cupgrass are specific weeds he notes finding.

The impact of no-till on Kinder's time came to the forefront. Farming conventionally, Kinder says, in the summer they "never had time to do anything but farm." Now he also has time for summer stockers. The conventional operation, including his father and brother's part of the operation, used to hire three to four youth during the summers and now one full-time hand is required. Kinder says that if not for the cattle, he probably would not need that hired hand. On the whole family's acreage, they used to spend as many as 10 days plowing terraces. When they farmed conventionally, they plowed and planted over terraces, but by using the no-till system, that terrace maintenance is no longer required. He also feels no-till should make the waterways last longer.

Looking around Kinders headquarters, very little equipment is seen. A few tractors, a couple of no-till drills, and a couple of sprayers is about all. He says the costliest are the drills. One of the main things that drove him to no-till was equipment. Kinder says, "tractors were worn out, equipment was worn out, and drills were worn out."



When planting, Kinder uses a fertilizer in the seed furrow that is about half urea and half 18-46-0. It comes out to be a 30-20-0 and he uses approximately 50 lbs per acre. He has been using the in-season sensor-based nitrogen management program for four years on about 50 fields. During the past five years, his operation has required very little nitrogen fertilizer.

His herbicide program centers around glyphosate, but includes 2,4-D when needed. He has noticed that in a no-till program, his weed control program works better when weeds are controlled at a young growth stage. Some of his neighbors who have tried no-till have had real difficulty with weed control because they were letting weeds get too large. Just from the cost of weed control, the dry summers are great for weed control in his no-till system.

Summers like 2006, the cost of chemical weed control was only about \$5/acre due to only one or two trips being necessary. His sprayers are pulled behind pickups, each carrying 85 foot booms and can be pulled up to 15 mph in the field. The sprayers are equipped with ground-driven pumps. Putting out eight gallons of water, he uses flat-fan nozzles, even though he has tried air induction nozzles. The sprayer wheels line up with the pickup wheels and weed control is slower in those tracks. The spray rigs are equipped with GPS.

In a couple of closing thoughts, Kinder said, "I'm glad to tell you that my boys don't know how to plow," which is what most farm boys have grown up doing. He also mentioned that to do no-till, a new 'skill set' was required. Weed identification can be very important in a no-till system, and relating to conventional tillage "when plants are killed with iron, ID is not very important."

Summary of Producer Responses

Below are questions and replies from eight experienced no-till producers in Oklahoma. Some of the following you may have seen throughout the publication, but below are their full response to questions we asked. The authors encourage you to read through them and learn from their experiences and what they see as some benefits of no-till.

With your own experiences in mind...

1. What convinced you to give no-till a chance?

The lack of labor and the time savings.

Greg Leonard, Afton, OK

High fuel prices and the need for soil and water conservation. Also Roundup® resistant cotton varieties makes no-till much easier to manage.

Clint Abernathy, Altus, OK

One of the main reasons we started no-till was to lower input cost due to rising prices of fuel, fertilizer, and maintenance. As well as the opportunity to raise a crop that may increase profits for the farm and put nutrients back in the soil.

C. Trojan, Bison, OK

It was an economic driven decision. I purchased a no-till drill and rented other equipment as needed until I could build up my operation and afford necessary equipment.

A. Mindemann, Apache, OK

I went to a field tour near Tyrone in 1995. Bob Detricks had spoken to the OALP class when we were in the panhandle area a couple of months earlier and he peaked my interest. After seeing the demonstrations and going to the No-till On the Plains Conference in Salina that winter, I was sold on its benefits.

James Wuerflein, Kremlin, OK

My father began experimenting with no-till back in the 1970s and was favorably impressed with the results. Part of my experience growing up on the farm was planting no-till soybeans into wheat stubble and harvesting them in the fall. For me, no-till farming was a normal part of the farm.

Brent Rendel, Miami, OK

Started no-till with cotton production mainly because I have sandy ground and was always trying to protect small cotton from sand burn. Last couple of years has been because of labor shortage and fuel costs.

Dave Shultz, Altus, OK

The best reason to consider no-till is...less investment in machinery, labor is drastically reduced, rotating crops usually pays, and conserving moisture.

Ernest Trojan, Bison, OK

2. How long have you been using no-till? Briefly describe your no-till program.

I have been no-till planting double crop soybeans into wheat straw for 17 years. No-till wheat planting 14 years and on and off no-till corn planting for six years.

Greg Leonard, Afton, OK



Five years. Most of my no-till acres are on pivot and drip irrigation where cotton is produced. I have also had some success in planting dryland cotton following harvested wheat. It has reduced, and in most cases eliminated wind damage to young cotton.

Clint Abernathy, Altus, OK

We have had several farms in no-till for more than ten years, we continue to have fields in conventional tillage operation. The no-till operation continues to have higher yields on average. We have even split a farm in half tilling one side that had been in no-till for three years and no-tilling the other side. The side that was no-tilled raised ten to fifteen bushels an acre more than the tilled side.

C. Trojan, Bison, OK

Since the early 70s. No-till wheat (2,500 acres) double cropped into No-till soybeans (2,600 acres) every year back to wheat.

Larry Davis, Miami, OK

Eleven years. Continuous no-till rotations are used on all farmed acres. Cash crops grown are wheat, cotton, corn, milo, cowpeas, canola, and hay along with cover crops.

A. Mindemann, Apache, OK

June 1996, on my first two fields. I started slowly at first, then expanded into other fields over the next several years. I had a JD 750 15-foot drill and as I did more acres it could not keep up. My brother and I decided we needed to either go back to all tillage or sell the equipment and go all no-till. No-till was the easy choice as we could already see benefits that were occurring on the fields we had been using it on the first few years. We have been totally no-till for six or seven years. We have a JD 1890 36-foot air drill and a JD 1770 12 row 30-inch conservation planter. With less tillage we now have time to do custom planting which helps pay the bills. We hire all spraying by the COOP.

James Wuerflein, Kremlin, OK

No-till has always been a part of my farm. In the past, virtually all of my no-till was limited to double-cropping soybeans behind wheat. The no-till system is ideal for that crop since time is very limited to get the soybeans planted after the wheat is harvested. No-till provides the fastest way to get the crop in the ground and it also provides the advantage of preserving soil moisture throughout the summer. In recent years, I have begun to incorporate no-till wheat and non-double-crop, no-till soybeans into my farm.

Brent Rendel, Miami, OK

Started 35 acres of no-tilling in row crops in 1998. We went all no-till row crop in 1999. Small acreage of wheat no-till in 2004, 500 acres in 2005, and total no-till in 2006. Total no-till 3,000 acres since wheat harvest 2005. On row crop, cotton, or sorghum usually plant cover crop of wheat, usually 30 to 35 pounds per acre. I usually plant around November 1 or immediately after seeding wheat for harvest, usually burn down in March to April, depending on size of wheat, before heading. If there is good moisture, I sometimes plant into wheat stubble after harvest for double crop. I usually put liquid fertilizer down when planting row crop. Roundup® for weed control as needed. On wheat production, I usually seed around October 15 to November 15, depending on moisture and weather conditions. I only do grain production, so no grazing. Last year, I put liquid down as sowed wheat and top-dressed in February. I usually sow 80 to 90 pounds. This year, I pulled harrow after harvest to spread straw from combine. I also spray as needed, usually first spraying a quart Roundup® and 1/4 oz Cimarron®. Then it is control weeds as needed summer and winter.

Dave Shultz, Altus, OK

We have been using no-till 10 years...have had success and also failures. We have success with beans for at least five years planted after wheat. One year we planted a variety of milo our seed advisor selected, which yielded one hundred bushels. We plant registered seed wheat with no additional fertilizer, which yields 60 bushels.

Ernest Trojan, Bison, OK

3. What was your greatest obstacle to overcome?

Waiting for the ground to dry out and warm up or finding the right attachment for planting corn.

Greg Leonard, Afton, OK



Difficulties are weed control and timeliness. Timeliness is for weed control, planting, and harvesting. Some of our best crops have been when we have the combine, sprayer, tractor, and drill all working in the same field at the same time. Getting the manpower to be able to do this is a challenge. Compaction and not being able to just turn cattle out on the field for grazing.

C. Trojan, Bison, OK

Fertilizing methods-especially phosphorous applications.

Clint Abernathy, Altus, OK

Stand!! Extreme heat in late June, July into wet soil causes soil to set up like concrete, breaking the neck of the soybean.

Larry Davis, Miami, OK

The "It Won't Work Here" syndrome from neighboring farmers.

A. Mindemann, Apache, OK

What would the neighbors think? Am I just too lazy to be on a tractor all summer?

James Wuerflein, Kremlin, OK

Weed control has been and remains the greatest obstacle to no-till farming. The additions of herbicide-tolerant soybeans and corn have greatly aided in dealing with undesirable vegetation in the fields, but it still presents a challenge.

Brent Rendel, Miami, OK

Probably the greatest obstacle is weed control. It is a never ending challenge with resistance, weather, etc. Also, when you have been a conventional farmer it is hard when your fields look like they are full of trash, plus the neighbors want to know if you have quit farming or what is your problem. Strange thing though, is the ones that gave me fits are now beginning to do the same thing!

Dave Shultz, Altus, OK

The greatest obstacle seems to be the drastic changes in farming methods. Weeds are the largest challenge...learning chemicals to kill weeds, yet be able to plant your next crop without affecting the next crop. A no-till conference years ago posed the question, "What is the hardest part of change to a farmer?" Between the ears!

Ernest Trojan, Bison, OK



4. What would you do differently in beginning no-till?

Make sure you either own the equipment or have access to equipment when it is needed; especially spraying is very important to do when it is needed.

C. Trojan, Bison, OK

I would not be as conservative with chemicals. I tried to stretch chemicals at first and it is easier to go ahead and use recommended rates on first spraying, then you can cut back if conditions are right. Also, you need a good sprayer and planting equipment. Getting things at the right time really seems to matter.

D. Shultz, Altus, OK

Go all in at the start. Then you cannot be tempted to get the disc out.

J. Wuerflein, Kremlin, OK

Use cover crops to start a no-till rotation.

A. Mindemann, Apache, OK

Start with the right equipment, talk to experienced no-tillers, check your planter settings constantly, adapt, adapt, adapt!!

Larry Davis, Miami, OK

I would attend more no-till meetings and visit with farmers who have been using no-till for a while.

Clint Abernathy, Altus, OK

Spend a little more money and buy a better no-till drill that had better depth control and closing system.

Greg Leonard, Afton, OK

5. What would you consider to be your greatest success with no-till?

The first year of no-till we planted soybeans right after wheat and raised a great crop, the best we have raised to date.

C. Trojan, Bison, OK

The time and moisture savings, not to mention less labor and machinery needed has allowed me to double crop many more acres with less cost and stress.

Greg Leonard, Afton, OK

Water conservation.

Clint Abernathy, Altus, OK

Double cropping has been my bread and butter. Soybeans has been my big crop.

Larry Davis, Miami, OK

Successful summer crops in an area where traditionally they do not do well with conventional tillage.

A. Mindemann, Apache, OK

Seeing the neighbors start to adopt it into their farms.

James Wuerflein, Kremlin, OK

I think double-crop, no-till CONVENTIONAL soybeans is a great challenge and I am proud to say I have been very successful doing it.

Brent Rendel, Miami, OK

I am a total dryland farmer. I have had excellent yields on cotton, sorghum, and wheat—when the weather has cooperated...hard to make crops if you have no rain!

Dave Shultz, Altus, OK

The first time we planted beans after wheat yielded 35 bushels. Heck, seems like nothing to this no-till farming...filled a semi-truck each evening starting harvest after 5:00.

Ernest Trojan, Bison, OK

6. Will you continue/increase your no-till practices?

We continue to bring some of the ideas into some of the other farms, such as some years we may spray Roundup® instead of working the field. Also, we are looking at rotating crops in our fields.

C. Trojan, Bison, OK

I will continue my total no-till operation. I have one part-time employee and myself who work the operation. All harvesting is hired. I think as time goes on no-till land will be even better. My longest no-till fields feel like I am on a sponge when spraying.

Dave Shultz, Altus, OK

No-till will definitely remain in my arsenal of farming tools. As with anything else, I am always looking for ways to improve yields and reduce input expenses. In 10 to 20 years, I may not be using no-till, but for now, no-till practices provide my greatest profit per acre in many situations.

Brent Rendel, Miami, OK

I'm 100 percent no-till and would not go back.

James Wuerflein, Kremlin, OK

Yes, I am currently looking at several new ideas for cover crops and alternative cash crops.

A. Mindemann, Apache, OK

I plan to increase my no-till acres.

Clint Abernathy, Altus, OK

Plans are to continue to no-till 100 percent of my wheat into the corn stalks and the soybeans into the wheat straw, but at this time I am looking at strip-till for the corn.

Greg Leonard, Afton, OK





7. Do you have any advice to others who might be considering no-till?

Some years there will be a crop failure, other years there will be great success. Through our history the no-till has helped increase production while saving the moisture for the dry periods.

C. Trojan, Bison, OK

With fuel and machinery costs increasing at the rates they have in the past 10 years, I can't believe that there is anyone that has not tried no-till. You must be willing to commit to no-till and buy a drill made for no-tilling. You can add attachments and make a normal planter work in normal conditions. Most of all you should plan on spending some more time with your family as you will not be out there plowing and discing all night!

Greg Leonard, Afton, OK

I think that is a good farming practice and is worth trying, but don't expect miracles.

Clint Abernathy, Altus, OK

No-till requires constant attention. You have got to be on top of everything.

Larry Davis, Miami, OK

Find someone in the area who is being successful and do not listen to those who are not.

A. Mindemann, Apache, OK

Don't worry what the neighbors say because they too will eventually see the light. (Maybe they will have to wait for the blowing dust to settle first!) Rotate crops and do not think that there is only one right rotation. Your situation may be different.

J. Wuerflein, Kremlin, OK

I like the approach my father took 30 years ago and believe it is still the best approach...start slow and be ready to learn from your mistakes. No one farm is identical to another and the approach that works best for me may not work at all for you.

Brent Rendel, Miami, OK

Make sure the year before you start the hard pan is broken. Also make sure your ground is as smooth as possible. Remember it is hard not to go get a plow when things look like a wreck and your neighbors are talking about you, but if you plow you will mess up the soil structure and earthworm activity. Just remember the neighbors will be plowing while you are enjoying your family, lake, etc.

Dave Shultz, Altus, OK

8. List three positive points to no-till.

Soil holds moisture for better crop yield, higher yields, less cost overall, less disease from crop rotation.

C. Trojan, Bison, OK

Time savings, lower fuel costs, labor savings.

Greg Leonard, Afton, OK

Soil and water conservation, less fuel used, less labor.

Clint Abernathy, Altus, OK

Less labor, time, get over the ground better.

Larry Davis, Miami, OK

Soil improvement, better infiltration rates, structure and organic matter, better long-term profitability, and most importantly passing on farm land in better shape than I received it!

A. Mindemann, Apache, OK

Water infiltration—saving more water in the soil allows you to withstand the dry spells longer than conventional ground. Less erosion—you do not worry when the wind comes up if your ground is going to blow; as more water soaks in you have less runoff erosion. More time—your workload is spread out with crop rotations, giving you time off at certain times of the year, you can use it with family or leisure activities or farm more acres.

James Wuerflein, Kremlin, OK

Conserves soil moisture, conserves fuel, and sequesters carbon dioxide.

Brent Rendel, Miami, OK

Conserves moisture, conserves fuel, less equipment, more free time.

David Shultz, Altus, OK

9. List three negative points to no-till.

Weed control, everything must be done very timely, may have some failures trying new things.

C. Trojan, Bison, OK

Must be much more attentive to details when planting. I have found that it is very difficult to make no-till work when planting corn on flat not well drained soils. More reliance on chemicals.

Greg Leonard, Afton, OK

Costly changes in equipment, weeds are becoming resistant to some herbicides, herbicide drift damage to nearby crops.

Clint Abernathy, Altus, OK

More attention, hard to get stands in adverse years, and personally, I have to plant 2,500 acres in two weeks regardless of how many rains I get.

Larry Davis, Miami, OK

Getting Dad or Grandpa to change as they typically hold the purse strings, higher level of management needed, and having to listen to your neighbors tell you "it won't work."

A. Mindemann, Apache, OK

Less runoff—if you rely on runoff to fill your ponds for livestock (or fishing) you had better pray for floods. Inexperience with new crops—it may be the first time you grow some crops but there are experienced growers out there to ask as well as Extension staff. Where do you market them? (Some elevators would rather sit empty than put anything but wheat in the bins.)

James Wuerflein, Kremlin, OK

Tougher to control weeds, requires specialized (or modified) equipment to plant, and requires more intensive management.

Brent Rendel, Miami, OK

It is hard to give up old ways, need special equipment and usually expensive if buying all new, and the chemical cost is expensive.

David Shultz, Altus, OK

10. Is there anything you would like to add concerning your no-till experiences?

It has proven to be a great choice for us and we plan on continuing the no-till and bringing more of the

experiences we have had into our other operations, even changing to more no-till in the future.

C. Trojan, Bison, OK

All growers should be ready for a shift in their weed species the longer they leave a field in a no-till system, but should also observe a great increase in their soils the longer it is no-tilled.

Greg Leonard, Afton, OK

I do not no-till corn. I cannot get the needed yield to justify it. I no-till an additional 500 acres of wheat into Bermuda sod each fall. I also bale and pasture, if harvested, I burn down then use Gromoxon® in late October.

Larry Davis, Miami, OK

Learning to manage no-till well has been one of the most exciting endeavors of my life, it's allowed me to be successful in a business that did not appear to have much future when I started.

A. Mindemann, Apache, OK

Long term no-till leads to improved: soil tilth and structure, soil health, water infiltration, raising organic matter percentage, less diesel fuel use, fewer hours on the tractor; crop rotations lead to more efficient use of combine, improved root health, crops harvested / marketed at different times of the year to take advantage of favorable weather patterns.

James Wuerflein, Kremlin, OK

It is a trial and error endeavor, just when you think you have it figured out something else happens, weather, weeds, insects, etc. Once you decide to do it, stick with it, be flexible and learn all you can from different sources. No-till conferences are very good, especially in your own area.

David Shultz, Altus, OK

***Editors note:** We wish to thank all of our contributing producers for their generous sharing of experiences and insights. It is our hope that you have benefitted from these discussions. If you have further questions or need more information, please contact your county Extension staff. They will be glad to hear from you. Good Luck!

The pesticide information presented in this publication was current with federal and state regulations at the time of printing. The user is responsible for determining that the intended use is consistent with the label of the product being used. Use pesticides safely. Read and follow label directions. The information given herein is for educational purposes only. Reference to commercial products or trade names is made with the understanding that no discrimination is intended and no endorsement by the Cooperative Extension Service is implied.

Oklahoma State University, in compliance with Title VI and VII of the Civil Rights Act of 1964, Executive Order 11246 as amended, Title IX of the Education Amendments of 1972, Americans with Disabilities Act of 1990, and other federal laws and regulations, does not discriminate on the basis of race, color, national origin, gender, age, religion, disability, or status as a veteran in any of its policies, practices or procedures. This includes but is not limited to admissions, employment, financial aid, and educational services.

Issued in furtherance of Cooperative Extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Robert E. Whitson, Director of Oklahoma Cooperative Extension Service, Oklahoma State University, Stillwater, Oklahoma. This publication is printed and issued by Oklahoma State University as authorized by the Vice President, Dean, and Director of the Division of Agricultural Sciences and Natural Resources and has been prepared and distributed at a cost of \$15,269.42 for 4,000 copies. This publication was printed at CareerTech Printing Services, Stillwater, Oklahoma. GH 0807.

