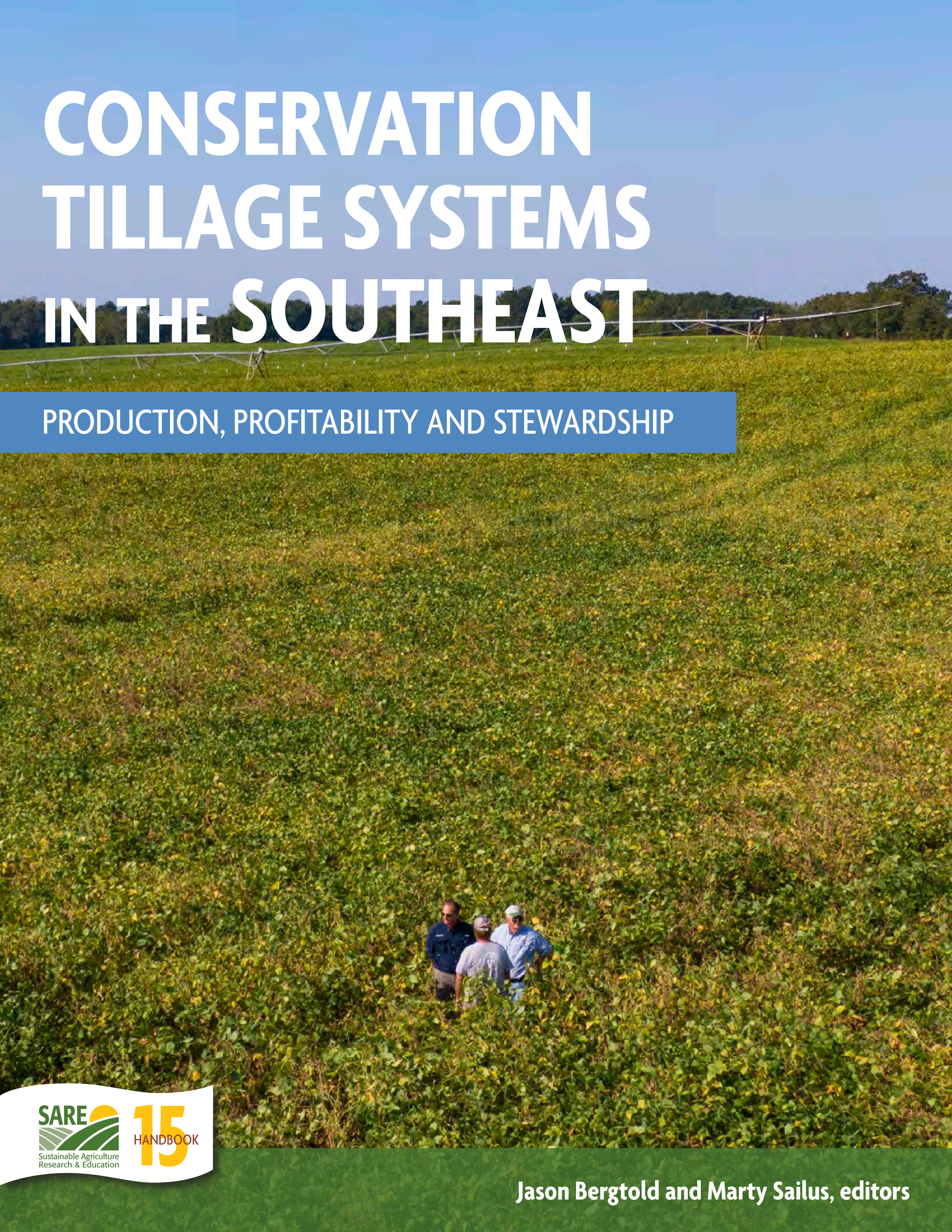


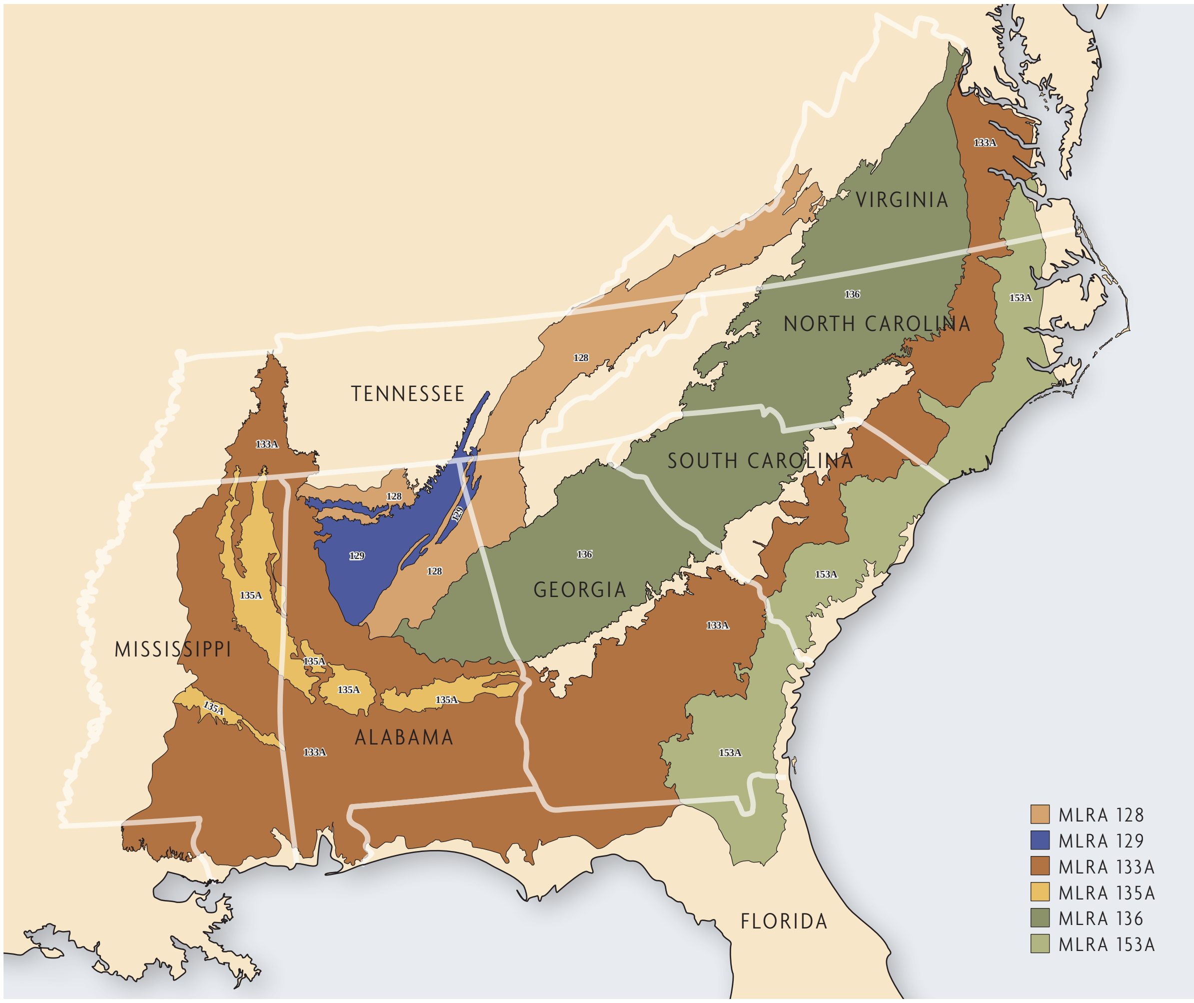
CONSERVATION TILLAGE SYSTEMS IN THE SOUTHEAST

PRODUCTION, PROFITABILITY AND STEWARDSHIP

SARE
Sustainable Agriculture Research & Education
15 HANDBOOK

Jason Bergtold and Marty Sailus, editors

Geographic Scope of this Book



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Foreword

The adoption of conservation tillage systems and practices has made conservation tillage the conventional tillage practice in use today in the United States. While much has been published on conservation tillage systems and practices over the past few decades, dedicated production manuals are still needed that provide updated information about practices and producers' experiences. The purpose of this book is to provide a comprehensive guide about conservation tillage systems for farms in the southeastern United States, providing information on the core components of conservation tillage systems as well as addressing regional considerations. The geographic coverage of the book examines these systems from southern Virginia to the panhandle of Florida and from the Atlantic Coast to eastern Mississippi (excluding the Mississippi Delta). This publication will build on existing books by the USDA Sustainable Agriculture Research and Education (SARE) program on conservation in crop production systems, including *Building Soils for Better Crops* and *Managing Cover Crops Profitably*.

This book provides an overview of conservation tillage systems, detailed chapters examining the different core components of conservation tillage systems, and specific recommendations for adopting and operating conservation tillage systems for crop production in different regions of the southeastern United States. The book takes an agricultural systems approach to understanding conservation tillage systems, recognizing that the different components of conservation tillage systems are interrelated. This systems approach is particularly evident in Section 3 of the book, which examines specific regional considerations. Chapters 1–3 (Section 1) provide an overview of what a conservation tillage system entails, the benefits and future of conservation tillage systems and the importance of conservation tillage systems for building healthy soils. Chapters 4–16 (Section 2) provide detailed information about the different core components of conservation tillage systems, including cover crop management, tillage practices, crop rotations, integration of livestock, planting practices, crop nutrient management, pest management and water management. A detailed chapter on assessing the economics of conservation tillage systems and cover crops is provided, as well as a chapter on bioenergy and conservation tillage systems. Finally, chapters 17–20 (Section 3) examine regional management considerations for different major land resource areas as defined by the USDA Natural Resources Conservation Service across the southeastern United States. At the end of the book a glossary of terms is provided.

The book was written with both producers and agricultural students in mind. While chapters provide much information from research studies and on the details of practices, the book was oriented and edited extensively so that it is accessible to farmers and agricultural students. In addition, the book should provide useful information for beginners, individuals interested in exploring the topic and the general public. The content in the book provides an overview of conservation tillage systems (Section 1), and the chapters on the core components provide much more detailed information about the different aspects of conservation tillage systems. While these chapters specifically relate to production systems in the southeastern United States, they include general information that is applicable to other regions of the country.

The book was the culmination of the hard work of 50 authors who have extensive experience with different aspects of conservation tillage systems in the southeastern United States. In addition, all chapters in the book went through a double-blind peer review, as well as detailed technical and editorial editing. My thanks and appreciation go out for all the hard work, effort and contributions made by the authors, peer reviewers and co-editors bringing this book to publication. The effort would not have been possible without all of their support. In addition, thanks needs to be given to financial support from multiple sources, including SARE, Cotton Incorporated (project No. 09-613), the Alabama Farmers Federation, the USDA Agricultural Research Service, the University of Georgia and the Georgia Soil and Water Conservation Society.

Sincerely,
Jason S. Bergtold
Editor

PART 1

Why Conservation Tillage Systems?

CHAPTER 1

Introduction to Conservation Tillage Systems

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The purpose of this book is to provide a comprehensive examination of conservation tillage systems used in select southeastern states. The book is targeted toward agricultural producers, producer advisors, researchers and students. The desired outcome is agronomic, economic and environmental sustainability on farms transferring to or seeking to improve their conservation tillage operations.

The book provides detailed information on a wide range of conservation tillage topics, including:

- soil management to improve soil health (Chapter 3)
- cover crop management (Chapter 5)
- soil compaction management (Chapter 6)
- cash crop management (chapters 7–10)
- pest management (chapter 11–13)
- water management (Chapter 14)
- economics (chapters 15 and 16)

Chapters 17 through 20 describe conservation tillage experiences from six major land resource areas (MLRA) in the southeastern United States. MLRAs are geographic areas, usually several thousand square miles, characterized by a particular pattern of soils, climate, water resources, land uses and types of farming. Figure 1.1 shows the six MLRAs discussed in these chapters overlying a map of select Southeast states. A wide range of farming conditions and conservation tillage practices occur over this area as described in the case study chapters.

The information in this book is presented using a systems approach to help the reader recognize the connections between different components of conservation tillage systems. This will help when integrating new conservation practices and technologies into farming operations.

The purpose of this chapter is to define *conservation tillage*, the beginning point for examining conservation tillage systems. The concept of a *conservation tillage system* will then be presented. The chapter ends by providing broad management guidelines that have been found to be significant in adopting conservation tillage systems. These guidelines serve as the foundation for recommendations in this book.

WHAT IS CONSERVATION TILLAGE?

The definition of *conservation tillage* adopted for this book is the definition given by the Conservation Technology Information Center [6]:

> "[Conservation tillage is] *any tillage and planting system that covers 30 percent or more of the soil surface with crop residue, after planting, to reduce soil erosion by water. Where soil erosion by wind is the primary concern, any system that maintains at least 1000 pounds per acre of flat, small grain residue equivalent on the surface*

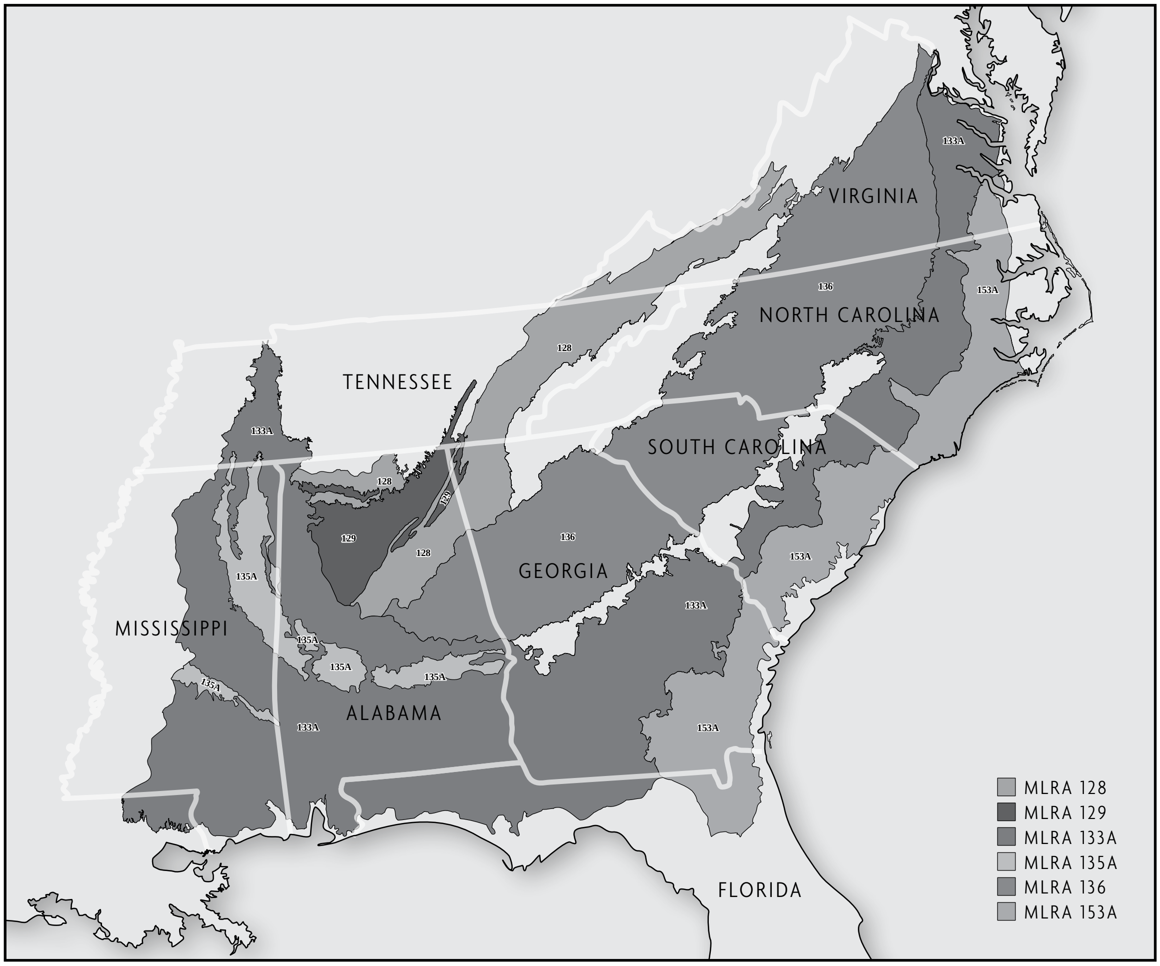

FIGURE 1.1. The six major land resource areas (MLRA) that comprise the geographic scope of this book are: MLRA 128 (Southern Appalachian Ridges and Valleys), MLRA 129 (Sand Mountain), MLRA 133A (Southern Coastal Plain), MLRA 135A (Mississippi and Alabama Blackland Prairie), MLRA 136 (Southern Piedmont) and MLRA 153A (Atlantic Coast Flatwoods).

> *throughout the critical wind erosion period.”*

By this definition, conservation tillage is any tillage practice that builds up crop residues on the soil surface to minimize the impact of water and wind erosion. The 30 percent residue benchmark for water erosion and the 1,000 pounds per acre benchmark for wind erosion are minimum requirements. There are a number of conservation tillage practices [6, 31]:

- **No-till**: The soil is undisturbed by tillage during the entire year. Crop residues left on the soil surface may be disturbed in strips up to one-third of the row width for planting or drilling seed. Other common terms for no-till include direct seeding, slot planting and zero-till.
- **In-row subsoiling**: The soil surface and residue are left undisturbed except for strips up to one-third of the row width. Within these strips, soil below the surface is disturbed or loosened using deep-tillage implements. In-row subsoiling is non-inversion tillage. Other names for in-row subsoiling include ripping, row-till and slot-till. Depending on the type of tillage shank used, names for this practice also include

paratill or terra-till.

- **Strip-till**: Strip-till, also called zone tillage, retains a number of the benefits of no-till, but disturbs the row or zone using tillage practices only where the next crop will be planted. The space between the rows is covered with residue. Strip-till improves the seedbed environment, disturbing the soil only in a narrow zone up to 6–8 inches wide and 6–8 inches deep. This tillage practice is commonly done concurrently with planting and can be combined with in-row subsoiling to break up compacted soil layers [18, 20].
- **Ridge-till**: Specialized planters and cultivators are used to form and retain permanent ridges on which cash crops are grown. Crops are planted on the top of the ridge after removing residue, which is left between ridges. Cultivation is used to form and maintain ridges, and to manage weeds.

The use of conservation tillage requires the management of crop residues on the soil surface. Crop residues, a renewable resource, play a key role in conservation tillage. When crop residues are properly managed they protect soil resources; enhance soil quality; restore degraded ecosystems; improve nutrient cycling; increase water conservation and availability; enhance pest suppression, for example weed and nematode suppression; reduce runoff and leaching of nutrients off-site; and sustain and enhance crop productivity and profitability [15].

The Natural Resources Conservation Service (NRCS) in the Southeast provides these additional considerations that deal primarily with management of crop residues or other residues [23]:

- Uniformly distribute loose residue in the field. Do not burn residue. A minimum of 30 percent coverage is needed to prevent erosion. Coverage of 50 percent or greater is recommended to conserve soil moisture and increase organic matter.
- Use planters and drills that can plant through untilled residues or into a tilled seedbed prepared using approved implements. Do not disturb more than one-third of the row width when planting or fertilizing.
- Equip combines and harvesting equipment with spreaders that are capable of spreading residue over 80 percent of the header width. The header is the part of the combine that harvests the crop. Limit removal of residue from baling or grazing to retain the recommended amount of residue on the soil surface.

Conservation tillage can be combined with other practices to enhance the soil benefits provided from reducing tillage and increasing soil-surface coverage. Complementary practices include cover crops; crop rotations that optimize biomass production; planting practices that adjust plant populations, such as alter-row spacing to manage residue; and integrated pest management and crop nutrient management that take account of the increased residue on the soil surface [23]. Many of these practices are already used on agricultural lands in the Southeast, as evidenced in Table 1.1. It is the bundling of these types of practices that form the basis of *conservation tillage systems*.

CONSERVATION TILLAGE SYSTEMS

The definition for a *conservation tillage system* is:

> *A bundle of complementary best management practices that are implemented in a crop production system, in conjunction with other conservation practices, to enhance environmental stewardship, farm profitability and agricultural sustainability.*

The best management practices used in conservation tillage systems achieve little to no soil disturbance; promote crop rotations; provide permanent soil coverage; increase residues on the soil surface; reduce use of inputs; improve

TABLE 1.1. Conservation practice adoption reported for select states in the Southeastern United States, 2012

State	Harvested Crop Land (000s acres)	Percent of Harvested Cropland under Conservation[1]		
		No-Till	Other Conservation Tillage Practices	Cover Crops
Alabama	2,158	33	14	9
Florida	2,184	9	5	6
Georgia	3,610	19	25	10
Mississippi	4,292	14	21	2
North Carolina	4,378	43	15	9
South Carolina	1,635	33	25	5
Tennessee	4,547	46	8	4
Virginia	2,618	36	8	12

Source: [22]

[1] Conservation practices are defined as follows: *No-till* refers to tillage practices where the soil is undisturbed by tillage during the entire year. Crop residues left on the soil surface may be disturbed in strips up to one-third of the row width for planting or drilling seed. *Other conservation tillage practices* refers to other tillage practices that leave at least 30 percent of the residue on the soil surface, but does not include no-till. *Cover crops* refers to crops planted between regular cash crops for conservation purposes to provide soil protection, water retention and improved nutrient cycling. Cover crops are terminated prior to cash crop planting and plant biomass remains on the soil surface.

soil quality; and control traffic [8]. Conservation tillage systems affect nearly every aspect of crop production, including crop rotations, planting, equipment performance, and fertilizer practices, as well as pest management and incidence through reductions in tillage and presence of crop residues [24]. Derpsch [8] recognizes that these types of systems can be developed from a "basket" of alternative conservation practices. The farmer chooses the practices that are best for the local conditions.

Conservation tillage systems are designed to enhance environmental stewardship, farm profitability and agricultural sustainability. Each of these concepts is addressed individually to emphasize their importance in the above definition.

Environmental Stewardship

Farmers who adopt conservation tillage systems are acting as environmental stewards by enhancing ecosystem services on and off agricultural lands. Ecosystem services are both direct and indirect. Direct services include the production of food, livestock feed, biofuel feedstocks and fiber for textiles. Indirect services include maintaining soil fertility and increasing the efficiency of nutrient cycling (cycling and filtration services); crop pollination (translocation services); carbon sequestration and water conservation (stabilizing services); and recreation or aesthetic values (life-fulfilling services) [5]. An important indirect ecosystem service provided by conservation tillage systems is the maintenance and protection of the land, and the services it provides for future generations.

Intensive agricultural practices such as inversion tillage can degrade indirect ecosystem services by reducing soil productivity, increasing soil erosion and degrading soil quality. This can contribute to eutrophication of water bodies, increased nutrient and pesticide runoff, higher rates of soil erosion, and a need for increased inputs such as fertilizer, water and energy as soil productivity declines [32]. In contrast, properly managed conservation tillage systems enhance ecosystem services, improving farm profitability and sustainability. These benefits are further highlighted in chapters 2 and 3 of this book. Other chapters highlight the benefits of alternative conservation practices.

Farm Profitability

Economics plays a significant role in the management of conservation tillage systems. Many factors contribute to farmers' conservation decision-making, including agricultural payment programs such as conservation programs; market conditions, for example crop prices, marketing options and the emerging biofuels market; market and production risk such as volatile commodity prices and weather; the cost of conservation practices; and management style. Economic factors are discussed in considerable detail in Chapter 15.

Conservation tillage systems tend to require a higher degree of management. The farmer needs to know how different conservation practices will interact to affect crop production and economics as well as soil and water conservation. Farmers also need to consider limiting factors such as low precipitation, high evapotranspiration and increased potential for soil erosion when making management decisions [10, 29]. Chapters 4–14 provide specific management guidelines for different conservation practices that make up conservation tillage systems. Chapters 17–20 provide management considerations for different areas of the Southeast. The management guidance provided is to help ensure the economic viability of these systems.

Agricultural Sustainability

Sustainability has many different connotations. A broad definition of sustainability for conservation tillage systems is production systems: *that meet current and future societal needs for food and fiber, ecosystem services, and healthy lives, and that do so by maximizing the net benefit to society when all costs and benefits of the practice [and system] are considered* [32]. Thus, agricultural sustainability pertains to the whole of society, not just the farmer.

What does this mean at the farm level? Sustainability on the farm encompasses (1) protection and long-term maintenance of soil and water resources, which includes using practices that reduce soil erosion, enhance soil quality and improve water use efficiency; and (2) enhancement of economic opportunities and growth by improving cash crop yields, lowering costs of production, reducing risk, improving crop profitability and improving overall economic management [24]. By being good stewards of the land, farmers are improving social welfare and are being socially responsible. Other actions farmers can take to improve sustainability include taking part in discussions concerning conservation and policy at the local, regional and national level; taking advantage of conservation-program benefits to improve on-farm conservation; and interacting with other farmers through conservation alliances, farm groups and conferences.

PRINCIPLES AND PRACTICES OF CONSERVATION TILLAGE SYSTEMS

While each conservation tillage system is designed based on local conditions, there are some general principles and practices born out of research and experience from around the world over the past few decades. All of these are applicable to crop production in the Southeast. They reflect the different agronomic, climatological, ecological, economic and social factors that affect the adoption and performance of conservation tillage systems.

Reduce Tillage

While no-till is preferred to reduce soil compaction, it is not always possible. Soil compaction occurs due to equipment traffic or through natural processes. In-row subsoiling may be required to loosen compacted zones below the planted row [25]. The management objective is to minimize surface disturbance in order to leave crop residues evenly distributed. Use of other conservation practices, such as deep-rooting cover crops, provides tillage benefits through "natural" means and reduces the need to disturb the surface residue with subsoiling [27]. Another method to control soil compaction and minimize the need for tillage is synchronizing operations and machinery to use the same paths through the field, referred to as traffic control [28]. A potential added benefit of controlling traffic using automatic guidance systems is improved crop yields and increased crop profitability [26].

Use Crop Rotations

Crop rotations are planned to enhance cash crop returns, improve soil conditions and fertility, minimize pest pressures and reduce risk. A diverse crop rotation can enhance conservation tillage systems, but diversification must be economical [8]. Bare soil is avoided in conservation tillage systems. Using cover crops or heavy-residue cash crops in crop rotations increases soil-surface coverage and provides significant soil and economic benefits [21, 30]. Sod-based rotations (see Chapter 8) allow for improved integration of livestock into cropping systems and provide another innovative way to enhance crop rotations [13]. Other considerations include the use of legume crops and crops that reduce pest pressures (see chapters 5 and 7).

Maintain Biomass on the Soil Surface

Lal [15] argues that the next step after getting conservation tillage working on a farm is to use cover crops to maximize residue coverage on the soil surface. Cover crops can also be utilized in cropping systems without conservation tillage, but conservation tillage further enhances benefits from retaining the biomass on the soil surface. Derpsch [8] states that "almost all advantages of the no-till system come from the permanent cover of the soil and only a few from not tilling the soil." Thirty percent residue cover is not the goal but the minimum to reduce erosion. Complete coverage of the soil across the field with as much biomass as can be managed is the best scenario. Selecting heavy-residue cover crops, for example cereal rye, when cash crops produce little to no crop residues is important to garner the maximum benefits from a cover crop and conservation tillage system. Maximizing cover-crop biomass, and therefore residue levels, improves the economic benefits of a conservation tillage system [21].

Manage Equipment

Equipment needs and modifications for use in conservation tillage systems will usually be site-specific and will depend on soil, climate, crop, size of the farm and other factors [28]. Equipment modifications may include (1) row cleaners, down pressure springs, spoke closing wheels, seed firmers and drag chains for planters; and (2) splitter points, polyshields and row cleaners for subsoilers [1]. Additional equipment needs may include the purchase of a no-till grain drill or planter, a subsoiler rig (for example a ripper, Paratill, or terra-till) or a roller/crimper [14]. Additional equipment costs may be offset by selling unused or under-utilized equipment. For example, intensive tillage implements such as a moldboard plow would no longer be used. As the number of trips across the field and the need for powerful equipment declines, under-utilized tractors can be sold.

Manage Carbon

Don Reicosky, an agricultural researcher, has said "true soil conservation is carbon management [29]." Soil organic matter is a key indicator of soil quality, and it is largely composed of organic carbon. Soil organic carbon is a significant determinant of soil biology, aggregation and structural stability. This in turn affects soil fauna and microorganisms, infiltration rates, available water-holding capacity, susceptibility to erosion and bioavailability of plant nutrients. Improving these characteristics improves farm productivity. Managing carbon through conservation tillage systems increases carbon sequestration, resulting in improved soil productivity and farm profitability. A significant step in carbon and soil organic matter management is soil testing. Proper soil testing is critical for transitioning to and properly managing conservation tillage systems [8].

Reduce Off-Site Impacts

Conservation tillage systems help minimize off-site environmental impacts. Conservation tillage systems improve soil quality, especially systems that maximize soil coverage with crop residues.

This reduces nutrient leaching, nutrient runoff and pesticide runoff into bodies of water off the farm. Additional complementary practices that further minimize off-site impact include integrated pest management and split applications of fertilizer [9].

Profitability and Sustainability

Farmers seek to maximize profits since profitability is critical to farm viability. For society, sustainability is critical for food, fiber, feed and fuel production needs. Achieving harmony between these two objectives is the goal [24].

Conservation tillage systems can reduce costs for machinery, fuel, labor, herbicides and fertilizer but increase other costs such as for planting and managing cover crops. Whether or not the cost reductions offset increased costs will affect farm profitability [2, 11]. Studies have shown conservation tillage systems with cover crops can reduce input costs for the cash crop, but this may not be enough to offset the increased expense for the cover crop [19]. Crop yields must be enhanced to provide a positive economic benefit. Management is the key! Successful outcomes from conservation tillage systems depend on proper and innovative management, which is addressed in this book.

Another consideration is that conservation tillage systems, especially heavy-residue systems, may stabilize crop yields over time from reduced soil erosion and improved soil productivity. Several studies show these systems can significantly reduce crop losses during drought [2, 11, 30]. Sustainability occurs in the long term, and farmers must have a long-term view. The benefits of conservation tillage systems will increase over time. Although farmers need to respond to short-term shocks, such as changes in crop prices, adhering to long-term conservation goals will maintain the benefits of conservation systems. A decision to implement intensive tillage for short-term gain can undo years of conservation-tillage improvements.

Manage Risks

Most farmers try to minimize risk. There is a certain amount of risk in investing in conservation, primarily due to the lack of certainty about the outcome. This lack of certainty is due to weather variability, time availability, market variability and uncertain profitability of different combinations of practices. Net returns might be less during the transition, though not all farms see a reduction in net returns. A farmer can reduce uncertainty through education, skills development and experience. Research shows that the use of conservation tillage practices may be less risky than conventional intensive-tillage practices [11]. In addition, conservation tillage systems with cover crops, especially legumes, can reduce production risks [12, 16, 17].

Lifelong Learning

It has been said, “No-tillage is not a farming practice; it is a concept of the mind. If you don’t believe in it you will fail [4].” A farmer’s mindset can be a significant obstacle to the adoption and success of conservation tillage systems. To overcome this, farmers and their technical support, such as Extension personnel, agricultural consultants and researchers, will have to become familiar with conservation tillage systems and not just individual conservation practices. They must be familiar with the different aspects of a conservation tillage system to be able to address the issues and problems that arise when transitioning to or managing a system [7].

The most significant hurdle when learning new skills and practices is on-farm implementation. An important strategy is trialing or experimenting with new practices on a small part of the farm. Rolph Derpsch, a well-known conservation tillage consultant in South America, suggests starting by adopting a particular practice or system on 10 percent or less of the farm’s cropped land [8]. Before implementation of a new practice or system, gather as much information as possible. You can find information on local practices from researchers, peers, no-till alliances, conservation agencies and organizations, federal agencies, local agricultural colleges and Cooperative Extension. Successful managers are lifelong learners and keep up with new developments, technologies and information. That is, farmers must get involved [7].

Conservation Programs and Resources

Federal and state governments have conservation programs to help farmers establish conservation practices. NRCS administers a number of conservation programs, including the Environmental Quality Incentives Program and the Conservation Stewardship Program (formerly, the Conservation Security Program; search for NRCS on the web for more information). These programs are voluntary with farmers entering into contracts with NRCS to meet conservation guidelines on their land. In turn, the farmer earns monetary incentives, usually in the form of cost-share assistance, to establish and maintain the practices. These incentives can make conservation practices affordable, for example heavy-residue cover crops, as the farmer transitions and builds experience. They allow the farmer to test particular practices to see if they are suitable to their operation. Taking advantage of these programs can increase the likelihood of farm-wide adoption and can act as a buffer for the farmer if they feel the practices are too risky [3].

SUMMARY

Conservation tillage has become the standard, but implementation of conservation tillage systems is still being developed. Farm policy is moving to more intensified conservation on-farm to further environmental stewardship while still promoting farm profitability and agricultural sustainability. Farmers can take the lead in pushing the envelope of conservation tillage systems and be involved in the dialogue that shapes adoption, policy and research. Farmers are the primary vehicle for change in agriculture. Their successful management of crop production using conservation tillage systems will benefit both the agricultural community and society.

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CHAPTER 2

Conservation Tillage Systems: History, the Future and Benefits

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Necessity is the mother of invention. A need or problem encourages creative efforts to meet the need or to solve the problem. Throughout time, mankind has strived to feed a growing population through improved farming practices. At times these efforts caused degradation of the agricultural landscape, diminishing productivity. In the southeastern United States, the climate, topography and soil morphology have resulted in a highly erodible landscape [43]. Once exposed to erosive forces, soil particles are easily dislodged and transported into streams, lakes and coastal waters resulting in less-fertile and less-productive farmlands. Severe degradation of soil from wind and water erosion during the late 1800s and early 1900s led to development of improved soil conservation practices. Conservation tillage systems are an effort to provide more food to more people while sustaining or improving a productive land base.

The purpose of this chapter is to examine why farmers adopt conservation tillage systems. It examines the history and future of conservation tillage systems as well as the benefits these systems provide. History allows us to learn from our failures and successes, and to capitalize on practices that will help agriculture thrive sustainably. Looking to the future provides a roadmap for the further development of conservation tillage systems. Understanding the benefits will allow farmers to assess the different options for their farm.

A HISTORICAL PERSPECTIVE

Agriculture in the Southeast was dominated by cotton in the late 19th century, with Georgia and Alabama as the leading cotton-producing states. In 1896, half of Alabama's population was employed on the state's approximately 3 million acres of cotton [36]. Although cotton is a profitable crop, growing it results in a greater risk of soil erosion due to the limited amount of crop residues produced [39]. Soil erosion in the Southern Piedmont major land resource area reduced cotton yields by as much as 4 percent for each centimeter of topsoil lost [9]. Erosion is a natural process by which land surfaces lose top soil gradually through the forces of wind, water and temperature. Crop residues covering the soil surface can significantly reduce or eliminate erosion.

Modern patterns of cultivation and mechanization have increased the rate of soil erosion [28]. Agriculture has historically relied on tillage to prepare the soil for planting and to control weeds. Plowing, or primary tillage, is used to invert the top layer of soil, break up compaction, turn under residues and bury weed seeds. Secondary tillage, including harrowing and/or disking of the soil, results in smooth, clod-free seedbeds. Although these tillage practices can increase cash crop yields, the soil surface is left prone to erosion that degrades cropland due to the loss of carbon and other nutrients. Eventually the soil becomes unproductive [38]. When soil and crop productivity decline, fertilizer and pesticide use increase. In many cases, these increased inputs result in pollution and health problems because they leach or run off into local water bodies [41].

Soil erosion has been recognized as a problem in the United States since the 1700s [4]. Leaving crop residues on the soil surface was one of the first strategies used to protect highly erodible soils planted to cotton. In 1896, J. F. Duggar, in Auburn, Ala., began testing his theory that crop rotations and winter legumes could protect southeastern soils from winter erosion [36].

In 1928, a USDA bulletin written by Hugh Hammond Bennett [5] and William Ridgely Chapline titled *Soil Erosion: A National Menace* roused national attention and focused the nation's interest on stopping soil erosion. One of the first federally funded initiatives focused on managing cool-season crop residues in the Southeast. In 1932, the first conservation tillage method, called the "middlebuster," was developed to manage cool-season crop residues at the Soil Erosion Experiment Station in Tyler, Texas [2]. The middlebuster was a non-inversion tillage method that plowed furrows into winter cover crops. It is similar to in-row subsoiling.

The Dust Bowl began in the early 1930s and resulted in a new era of soil conservation. In 1935, H.B. Hendrickson was transferred to the Southern Piedmont Soil Experiment Station in Watkinsville, Ga., where he further tested the middlebuster. Just north in Hall County, Ga., a farmer, Mr. J. Mack Gowder, developed a stubble-mulch implement [32]. This steel chisel was formed from a worn road grader and tilled the soil while leaving most crop residues on the soil surface. M.L. Nichols and the Peele-Beale team at Clemson, S.C., tested and developed conservation tillage practices under the umbrella of "Stubble-Mulch Tillage." In 1936, W. Kell and R. McKee published *Cover Crops for Soil Conservation*, which recommended the use of alternative cover crops as a "green manure," meaning a supplemental nitrogen source, as well as the use of a soil conservation practice [29].

In the 1930s, the Graham-Hoeme Chisel and the Noble Blade Cultivator were developed by farmers Fred Hoeme and C.S. Noble. Their goal was to reduce wind erosion. Edward Faulkner published *Plowman's Folly* in 1943. This controversial treatise generated one of the most significant agricultural debates in the last century [17]. Faulkner recognized the potentially destructive nature of intensive tillage practices and stated that plowing (1) interrupted the movement of water deep in the soil to the topsoil; (2) buried crop residues too deeply, resulting in slow decay using soil moisture that could be used by the growing crop; (3) accelerated the drying out of topsoil; and (4) increased the decomposition of soil organic matter. All of these contribute to decreased crop productivity [38]. Faulkner claimed that "there is nothing wrong with our soil, except our interference" [17]. Faulkner's work was central to the soil conservation movement, which led to the development of further conservation tillage practices and systems.

In the 1950s, Dudley and Wise [19] worked with John Deere to develop the "Grassland Drill" to plant directly into untilled soil or sod. Competition for soil moisture, soil fertility and sunlight from surviving vegetation plagued conservation tillage efforts and limited farmer adoption. Other major obstacles to adoption included weed pressures, inadequate equipment, soil fertility, insects, disease and economics.

During the 1960s, farmers were encouraged to adopt other conservation practices including crop rotations, contouring, strip cropping, terraces, conversion to grassland, and in extreme cases, conversion to woodlands. The southeastern landscape today reflects this conversion as we often see grass or trees rather than cropland. Eroded cropland was converted to grasslands, and if the land was highly eroded, it was converted to forestland. Major obstacles to conservation tillage began to be addressed by farmers and researchers in Virginia, Ohio, Texas, Kentucky and Illinois [16, 32, 50]. The emphasis was "non-inversion," with corn planted into a cool-season sod.

Also in the 1960s, herbicides were developed that diminished or controlled competition from weeds. The herbicides paraquat and atrazine were critical in the sustained development of conservation and no-till practices for corn [32, 50]. Development of 2,4-D, dicamba and glyphosate provided grass and broadleaf-weed control. Equipment innovations were taking place as well. Triplett et al. [49] modified a John Deere Grassland Drill by adding rolling coulters ahead of disc openers to cut surface residue and to allow proper seed placement into untilled soil. Jerrell Harden, an innovative farmer near Banks, Ala., developed an in-row chisel subsoil implement in the early 1970s. This implement is the forerunner of the in-row subsoiling implements used today.

Nationwide, conservation tillage increased from 2.3 percent of cropland in 1965 to just above 10 percent in 1979. Early conservation tillage research focused on small grains, corn and soybeans. For these crops, the time-saving and moisture-saving benefits of conservation tillage were especially advantageous [13]. Early adoption of conservation tillage in states along the Appalachian Mountains was encouraged because the soil, despite being insulated by crop residue, warmed early enough for timely spring planting of corn and wheat. Southeast states with farmland in the Appalachian Mountains include Alabama, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee and Virginia. By 1972, Appalachian state adoption rates were the highest in the nation. In contrast, adoption rates in the Mississippi Delta and Southeast regions lagged due to persistent weed problems in cotton, soybeans and tobacco [13]. New challenges began to arise with the increasing adoption of conservation tillage during the late 1970s into the 1990s. These challenges included shifts in the types of weeds, diseases and pests, as well as fertility problems. This fueled a new era of conservation research.

The Food Security Act of 1985 provided a boost to conservation tillage adoption; it aimed to reduce production on highly erodible lands and to increase the use of soil conservation practices by including them as a qualification for crop subsidy programs. Conservation tillage was one of the eligible conservation practices and had to be initiated by 1990. As a result, there was a sharp increase in the rate of adoption between 1989 and 1991 [53]. In 1996, the farm bill included a mandate for the Environmental Quality Incentives Program (EQIP), a voluntary conservation program. Approximately 30 percent of EQIP funds were used to combat soil erosion by giving farmers incentive payments to adopt conservation tillage and cover crops [11]. According to Claassen et al. [11], these programs have resulted in a significant reduction in soil erosion across the United States.

In the mid-1990s, the availability of glyphosate-resistant crops increased adoption of conservation tillage by effectively replacing tillage with herbicides for weed control. This greatly simplified weed management and dramatically reduced herbicide costs. The cost of glyphosate-based herbicides declined $40–$45 per gallon ($10.60–$11.90 per liter) in 1990 to $12–$16 per gallon ($3.20–$4.20 per liter) in 2005 [25]. Givens et al. [26] found that 33 percent of growers in the Southeast converted to no-till after adopting glyphosate-resistant crops. Most growers shifted to either continuous glyphosate-resistant cotton or continuous glyphosate-resistant soybeans. Culpepper [15] estimated that between 1997 and 2003 the number of acres planted in glyphosate-resistant cotton increased from 23 percent to 90 percent of total cotton planted. They reported similar patterns in soybeans but not for corn. The continued use of herbicide-resistant varieties has given rise to a new problem: weed species that are more tolerant or resistant to glyphosate [15].

As of 2004, over 50 percent of all corn and soybean acres in the Southeast were planted using conservation tillage practices, with cotton just surpassing the 40 percent mark. The use of conservation tillage in peanuts lagged because of harvesting methods [12]. Bergtold et al. [7] reported that 69 percent of crop producers in Alabama use conservation tillage and 66 percent use cover crops for soil protection, winter annual grazing or forage. While adoption rates continue to increase, increased weed resistance has resulted in some farmers reverting to intensive tillage to control weeds.

Conservation tillage has become more than just a tillage practice. Conservation tillage systems have evolved to include the use of cover crops that produce a considerable amount of residue, referred to as high-residue systems. These systems also emphasize the use of crop rotations to maintain the productivity of cash crops and to break pest cycles. New agricultural research has investigated production systems that dynamically integrate multiple crops, livestock and other agricultural enterprises.

A FUTURE FOR CONSERVATION TILLAGE SYSTEMS

To look into the future of conservation tillage systems, the authors interviewed members of the Conservation Agriculture Systems Alliance, a group of "voluntary producer organizations that work hard to promote no-till systems and other practices that provide economic benefits, as well as environmental benefits to their regions." We asked the members: (1) What do you see in the future for conservation tillage systems over the next 10–20 years? and (2) Do you expect conservation tillage to become the "norm"? Respondents answered an overwhelming "yes" to the second question.

A member of the group, responding to the first question, provided a response that sums up much of what was discussed:

> *I think conservation tillage systems will continue to grow in popularity. With increasing fuel prices, producers will eventually discover that they can successfully grow a crop without all of the tillage operations they currently use.*
>
> *I think the concept of 'conservation agriculture' as defined by the FAO will become more prevalent. The basic tenets of conservation agriculture are minimal soil disturbance; erosion is controlled; all crop residues are returned to the soil; something is growing all the time, whether it is an agronomic crop or a cover crop; and livestock are an integral part of the system.*
>
> *I think the interest in cover crops will continue to grow. The current level of use of cover crops will pale in comparison to what it will be in 10 years. We are just beginning to understand what cover crops can do for cropping systems in terms of soil-quality improvement, nitrogen fixation, nutrient cycling and carbon cycling.*
>
> *We will see equipment innovations, such as planters that can operate in standing corn, which will allow timelier establishment of cover crops.*
>
> *We will see the development of agronomic crop varieties and cover crop varieties that will enable timelier sequencing of these crops.*

Much of what is mentioned above constitutes a conservation tillage system as presented in Chapter 1. Other members emphasized the continued use of cover crops, continuous green ground cover and diverse cropping rotations. One member commented: "As fertilizer and oil get more expensive, farmers will turn to biological systems to provide fertility and focus on building their soil." Crop rotations may increasingly incorporate legume crops, also called green manures, to provide needed fertilization for cash crops in the rotation.

Some members mentioned that an intensification of conservation efforts is needed to further protect our degraded soils. These members came up with suggestions such as "maintaining at least 80 percent cover between crops; practicing invisible seeding of crops and cover crops (means using a no-till planter); including diverse rotations; and integrated pest and nutrient management plans." These members emphasized that continuous no-till, ridge-till or strip-till is needed to sustain vigorous and resilient agronomic systems. If conservation tillage is not continuous, it will not be sustainable and farmers will turn to continuous no-till.

One member suggested that environmental-credit markets, such as carbon markets, are a method to help unlock the value of conservation and may be a positive policy tool. The member suggests that "the value of the system beyond yield and environmental protection is just part of the overall value that must be unlocked." This additional value arises from the potential off-site benefits and societal benefits from conservation tillage systems. If these can be capitalized on, then farmers may have an additional incentive to intensify conservation efforts.

BENEFITS OF CONSERVATION TILLAGE SYSTEMS

There are both environmental and economic benefits to conservation tillage systems. Environmental benefits include improved water quality; reduced nutrient losses; increased water availability; improved air quality; and improved soil quality, meaning increased organic matter and improved soil structure, porosity and tilth. Economic and societal benefits include improved quality of life (reduced labor, greater flexibility in planting); improved profitability (reduces wear and tear on equipment, saves fuel and fertilizer, improved productivity, carbon credits); and improved wildlife habitat. The benefits are many, diverse and interwoven. More detail is provided on the benefits of conservation tillage in the sections below.

Environmental Benefits

Reduced Soil Erosion

When soil is tilled and loosened, and residue is buried or removed, the potential for erosion increases. The Southeast has highly erodible soils and experienced irreversible soil erosion prior to 1900 [31, 48]. Research has proven that conservation tillage, including crop-residue management, conserves soil and water on southeastern soils [31, 50] and improves soil productivity. On the loess silty-clay loams of northern Mississippi, soil losses declined about 86 percent when no-till equipment with fluted coulters was used rather than conventional tillage [37]. In the Southern Coastal Plain on highly weathered loamy sands planted in cotton, sediment losses were reduced significantly using conservation tillage rather than conventional tillage [52]. In the Southern Piedmont sandy-clay loams and sandy clays, conservation tillage has been shown to reduce erosion [30] when compared to conventional tillage. With the inclusion of winter cover crops, it will also restore soil productivity [31].

Improved Soil Health

In the humid Southeast, conservation tillage systems have positive effects on chemical, physical and biological soil properties when compared to conventional tillage. Reduced mechanical disturbance results in less destruction of soil organisms and their habitat. Biological activity is more robust. Organic matter in the soil and at the soil surface provides nourishment for soil organisms that are part of the foundation of the food web. Soils in conservation tillage systems generally have a greater abundance of earthworms, arthropods, microorganisms, fungi and bacteria. Disease is reduced due to the greater competition between disease microorganisms and beneficial microorganisms. Plants grown under conservation tillage experience less stress and are likely to be stronger and more resistant to disease.

Researchers have found higher values of organic matter, nitrogen, phosphorus, potassium, calcium and magnesium in cropping systems that utilize conservation tillage systems rather than conventional tillage systems. Results in Georgia have shown that the degree to which soil organic matter accumulates depends on the amount of organic carbon returned to the soil [27]. This suggests that the addition of cover crops in winter and limiting residue removal will increase organic-matter levels. Higher organic-matter levels have been shown to increase the soil's cation-exchange capacity, which helps keep nutrients in place and in a form easily exchangeable with plant roots.

Plant roots in conservation tillage systems have been shown to be more abundant and extensive, both laterally and vertically, than roots in conventional tillage systems. These extensive root networks provide more moisture and nutrients for plant growth. Edwards et al. [20] found that conservation tillage increased soil organic matter 56 percent in the Southeast, while no change in organic matter was measured for conventional tillage.

Improved Water Conservation

Crop residue protects soil from raindrop impact, which in turn reduces soil crusting that results in surface sealing [42]. Soil crusting reduces water infiltration and air exchange that can impair crop germination. In a rainfall simulation study on a Southeast silt loam, researchers found that runoff losses averaged 28.7 mm for conventional tillage and 16.7 mm for conservation tillage [44]. In Alabama, on Southern Coastal Plain loamy sand, researchers found that conservation tillage produced only half as much runoff as conventional tillage plots [47, 51, 52]. Conservation tillage systems increase soil porosity, resulting in increased rainfall infiltration and soil water-storage capacity [8, 21].

Improved Air Quality

In many regions, erosion by wind can be a serious problem both environmentally and agronomically. In the east, the Southern Coastal Plain soils are most vulnerable to wind erosion. Wind erosion factors influenced by soil management and sediment supply (or how loose and easily transportable the soil is) include vegetative cover and timing of farming operations. Conservation tillage does not loosen or invert the soil; it leaves vegetation in place to help prevent wind-erosion losses. Crop residues on the soil surface reduce wind velocity and the ability of wind to move soil particles.

Improved Wildlife Habitat

Management of agricultural land has vital implications for wildlife. Just as humans require nutritious food, clean water and adequate shelter (refuge from the environment and from predators), so does wildlife. Sedimentation is a critical water-quality problem, especially for aquatic fauna and other wildlife that feed directly on them. Conservation tillage systems reduce sedimentation in water bodies by reducing soil erosion. Conservation tillage also provides food opportunities and shelter for small mammals and birds [3] such as mice, rabbits, bobwhite or quail. This in turn provides nourishment for predators such as rattlesnakes, raccoons, great horned owls, red-tailed hawks, bobcats and coyotes. Researchers have reported higher nest densities and nest success in conservation tillage fields as compared to conventional tillage fields [14, 18, 34]. In the Southeast, cotton fields are abundant and provide little to no cover or food source if clean tilled. Cederbaum [10] reported higher densities of breeding birds in conservation-tillage cotton fields as compared to conventional tillage, especially with conservation tillage fields using strip cropping. Wildlife specialists recommend that areas within and around conservation tillage fields be managed to provide habitat, especially for birds and rabbits.

Economic Benefits

When farms convert from conventional tillage systems to conservation tillage systems, there is potential to lower production costs and improve farm profitability. The agronomic benefits associated with conservation tillage practices, such as improved soil productivity, may improve yields, thereby increasing net returns [6, 33]. While this potential exists, profitability of the cropping enterprise depends on a number of additional factors, including effective management, soil suitability, pest pressures and climate.

Lower Production Costs

Cost savings with conservation tillage systems over conventional systems primarily stem from reductions in the use of labor and machinery. This includes both short- and long-term cost savings in variable and fixed labor costs as well as fuel and machinery costs. The savings will likely differ from farm to farm due to differences in weather and farm characteristics, such as farm size, as well as management approaches [54]. Labor savings are a result of a decrease in pre-harvest activities. This includes reductions in operator labor for machinery as well as reductions in hand labor for other farming activities such as maintenance of equipment.

Reductions in fuel and machinery costs result from fewer passes over the field with less tillage and cultivation. Fewer pieces of equipment are needed, and smaller, less powerful tractors can do the work. A significant savings results from a decrease in diesel-fuel consumption. This savings increases as diesel-fuel prices go up. Labor savings and longer machinery life will allow farmers to increase the acres of land being farmed, further increasing farm profits and viability. Another factor that will lower production costs is the inclusion of high-residue winter cover crops. Winter cover crops reduce weed pressure and improve water conservation, resulting in reduced pesticide and irrigation costs [45].

Improved Crop Yields and Revenue Opportunities

Studies comparing conventional and conservation tillage systems have mixed results when analyzing crop yields. In a number of cases, conservation tillage systems resulted in reduced yields during transition to conservation tillage, but compensated with cost savings [46]. In a Georgia Piedmont Ultisol, conservation-tillage cotton fertilized with broiler litter produced more lint in four out of five years, compared to conventional-tillage cotton fertilized with mineral fertilizer [22, 23]. Averaged over the five years, conservation tillage, regardless of fertilizer, produced 32 percent more cotton lint than conventional tillage.

Addition of cover crops to conservation tillage systems often results in increased crop yield and net returns compared to conservation systems without cover crops. Past agronomic research has shown the potential yield benefits of using cover crops prior to cash crop planting [24, 35, 40]. For example, Bergtold et al. [6] examined the profitability of alternative mixtures of high-residue cover crops in conservation tillage systems. They found that net returns for cotton with a rye/black oat cover crop mixture increased 10–37 percent over the conventional tillage treatment.

Financial Incentives

To further enhance the profitability of conservation tillage systems, especially during initial periods of adoption, take advantage of financial incentives from programs such as EQIP and Conservation Stewardship Program (CSP) offered by the Natural Resource Conservation Service (NRCS). Other potential sources of revenue in conservation tillage systems may come from activities such as winter annual grazing [1], providing farm operations with additional sources of income and helping to reduce risk.

SUMMARY

Beginning in the 1700s, farmers came to recognize that intensive production practices led to increased soil erosion, which threatened the land's productivity. As a result, farmers and researchers gradually developed the practices that constitute today's conservation tillage systems. One of the earliest strategies was to add winter crops to rotations, which took advantage of residues to protect the soil. Extension researchers developed the first conservation tillage method in the 1930s, with more advanced techniques arriving in subsequent decades. The adoption of no-till increased with the development of the herbicides atrazine and paraquat in the 1960s, and again with the development of glyphosate-resistant crops three decades later. The federal government introduced conservation subsidy programs in the 1980s and 90s to further promote adoption. Although new challenges with herbicide-resistant weeds are emerging, advocates of conservation tillage think that such systems will remain popular as new advancements are made, in particular in the areas of technology, crop rotation and the use of cover crops. The agricultural community now recognizes a range of benefits associated with conservation tillage systems, including environmental benefits (e.g., improved improved air, water and soil quality), economic benefits (e.g., reduced labor, greater flexibility in planting) and quality of life benefits (e.g., reduced labor and greater flexibility in planting).

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CHAPTER 3

Benefits of Increasing Soil Organic Matter

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Soil organic matter is a complex mixture of plant debris, dead roots, soil microbe and insect bodies, animal manures and humus in various stages of decomposition and reformation. All the materials forming soil organic matter include carbon and are or were once living. Soil organic matter has an active fraction that decomposes over the course of days to years and a stable fraction that can persist for tens to hundreds of years [31]. As soil organisms decompose these fractions, the soil undergoes transformations that affect nearly every aspect of crop production, including compaction, water relationships, fertility and disease resistance.

Taking steps to increase soil organic matter is vital to ensuring agricultural productivity in the southeastern United States, where soils are usually acidic and do not have much natural fertility or organic matter. Southeastern soils are relatively old and have developed under warm and humid climatic conditions. Consequently, these soils are typically highly weathered. In forest soils of the Southeast, organic-matter concentrations are usually greater than 2 percent near the surface, and often less than 1 percent below 2 feet (Figure 3.1). The amount of soil organic matter varies with the amount of sand, silt and clay. Sandier soils have naturally lower soil organic-matter content. This can be seen in the Lakeland sand in Figure 3.1. Clayey soils, such as the Sharkey clay in Figure 3.1, tend to have higher soil organic-matter contents.

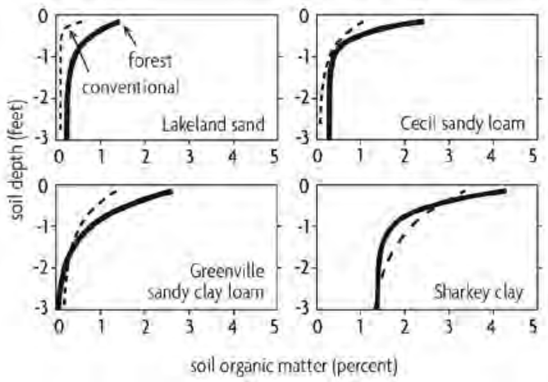

FIGURE 3.1. Soil organic matter distribution with depth in selected conventionally tilled soils and forest soils of the Southeast [22].

Organic matter is rapidly lost when the soil is disturbed. Over a 50-year period, 65 percent of the soil organic matter found under native forest was lost after the forest was converted to agriculture (Figure 3.2). Soil organic matter has been lost over the past 200 years in the Southeast because of excessive tillage and little use of crop rotation or cover crops. Tillage increases the oxygen content of the soil, stimulates soil microbes to decompose soil organic matter and breaks up soil structure that can protect organic matter from decomposition. When organic material is not added to the soil through manures, crop residues or cover crops, soil organic-matter levels rapidly decline in the Southeast. Relatively mild winter temperatures and moist soils in the region support soil microbial activity that decomposes organic matter over most of the year.

Soil organic matter was also lost in the Southeast due to the tremendous amount of erosion during the 19th and 20th centuries. Soil loss estimates where moldboard plowing was used range 8–13 tons-per-acre per year [11, 33]. Soil organic matter is concentrated in the surface soil and tends to be lighter than mineral soil, so it is preferentially removed as the soil surface is eroded [30].

As a result of past land-use practices in the Southeast, many agricultural soils have organic-matter contents less than 1 percent. Such low concentrations create management problems because organic matter has a profound influence on the physical, chemical and biological properties of soil. To reverse this deficiency, farmers have adopted conservation tillage systems with no-till or reduced tillage, cover crops, and crop rotations to increase soil organic matter and improve soil properties.

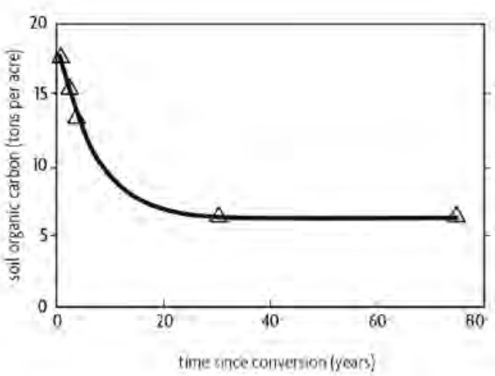

FIGURE 3.2. Organic matter decline in the plow layer (0 to 6 inches) of a Southern Piedmont soil following conversion from native forest to tilled row cropping [22].

For example, conservation tillage has improved a Cecil soil in the Piedmont of Georgia as shown in Figure 3.3. Conventional tillage resulted in the soil on the left that is crusted and has low permeability or infiltration capacity, low water-holding capacity, few aggregates and little biological activity. The soil on the right is the same soil type but has been in conservation tillage with winter cover crops and crop rotation for 18 years. Abundant aggregates and pore space indicate this soil absorbs and retains water, resists erosion, and supports a high level of biological activity.

SOIL ORGANIC MATTER AND SOIL PROPERTIES

As soil organic matter increases with conservation tillage systems, soil properties change for the better in many ways. Soil structure and soil-water relationships are improved, and the soil better resists compaction and erosion.

Soil Structure

Soil structure is formed from the interaction of mineral particles and organic matter. Soil organisms generate organic compounds, such as polysaccharides, that act as glues holding soil particles together to form water-stable micro-aggregates. Fungal hyphae and fine roots link micro-aggregates together to form macro-aggregates. Earthworms ingest and granulate soil. Root growth and burrowing activity of soil animals provide physical forces that create channels coated with organic materials, which further increase aggregation. Increasing soil organic matter increases soil aggregates, providing critical benefits related to improved soil-water relationships, reduced compaction and reduced erosion.

Soil-Water Relationships

Soil organic matter impacts soil-water characteristics including the infiltration, distribution and retention of water in soil. For water to infiltrate into soil, pores or channels have to be open at the soil surface. These are often referred to as macropores, meaning large pores. As soil organic matter increases, more water-stable aggregates are formed, which increases the number of macropores and improves water infiltration [6, 18, 54].

In addition to its beneficial effect on soil porosity, soil organic matter absorbs and holds water that has infiltrated into soil. So, as soil organic matter increases, the amount of water held in the soil for plant use also increases. Practices that keep the soil covered, such as cover crops or leaving crop residues in the field (Figure 3.4), help protect soil aggregates and keep macropores open by reducing crust formation. Tillage disrupts large pores in the short term and intermediate-sized pores in the long term. This reduction in porosity decreases infiltration and soil-water retention, and degrades soil quality and productivity [35].

A long-term study in central Alabama illustrates the relationship between conservation tillage and

FIGURE 3.3. Comparison of a Cecil soil crust that resulted from conventional tillage (left) with the same soil type in conservation tillage for 18 years (right). *Photo courtesy of Jimmy Dean.*

water storage. In the study, soil managed for 10 years with only in-row subsoiling to a 15-inch depth had twice as much soil organic matter and 21 percent more water-stable aggregates than soil managed with conventional disking and chisel plowing (Table 3.1). As a result, water infiltration was also greater. The use of winter cover crops further increased water infiltration. Figure 3.5 shows that 80 percent of a 2-inch simulated rainfall infiltrated when non-inversion tillage was used, and infiltration increased to 96 percent when winter cover crops were added.

Water that does not infiltrate into the soil first ponds on the surface and then moves across the soil surface. As water flows over the soil, soil erosion occurs. However, soil under conservation tillage is more resistant to erosion because large aggregates and the glue holding particles together protect the soil particles. Further, plant residues and cover crops protect the soil surface from raindrop impact, reducing soil particle detachment and overall erosion.

Erosion is a silent thief of productivity. It removes fertile surface-soil layers as well as organic matter needed to protect the soil. Conservation-management practices, such as reduced tillage or no-till and cover crops, reduce soil loss from fields. Figure 3.6 shows that non-inversion tillage reduces soil loss when compared to conventional tillage. Soil loss is the lowest when non-inversion tillage is combined with cover crops. These practices not only help to maintain or improve soil quality and productivity, but also improve water quality.

Soil organic matter also helps keep fertilizers, pesticides and other agro-chemicals from leaving the field through erosion. Agro-chemicals tend to bind with soil particles, and when erosion detaches and carries soil particles into streams, ponds or other surface water, the agro-chemicals are carried with them. As soil organic matter increases and erosion decreases, the amount of agro-chemicals reaching surface waters decreases [18]. Soil organic matter also interacts with agro-chemicals to reduce their leaching potential.

Compaction

Compaction is caused by excessive load or traffic on a soil and by natural processes. Soil conditions, including moisture, organic matter and the presence of living roots from crops or cover crops, affect a soil's resistance to compaction. Some soils are more prone to soil compaction than others. In parts of the Southeast with sandy soils, conventionally managed fields with little surface cover tend to have compaction problems due to low organic matter and high winter rainfall. These conditions cause sand particles to pack and a compaction layer to form. Soil organic matter improves soil structure and thus increases resistance to compaction.

Practices such as in-row, non-inversion subsoiling minimize soil-surface disruption and organic-matter losses through decomposition. These practices are preferred over those that invert the soil to alleviate compaction.

No-till fields can be more compacted, meaning more dense, than comparable soils under inversion-tillage practices. Although conventional inversion tillage loosens soil and initially reduces surface compaction, compaction quickly returns to a high level. This sets up a cycle of repeated tillage to loosen soil, which causes organic-matter decomposition, soil degradation and further compaction requiring more and deeper tillage. In no-till systems, vigorous crop and cover crop rooting helps avoid compaction by adding organic matter to improve aggregation and to keep soil pores more continuous. Consequently, despite greater soil density with some conservation tillage systems, continuous pores and better soil structure result in improved soil-water relationships and root growth.

SOIL ORGANIC MATTER AND SOIL FERTILITY

Soil fertility is one of the most important soil characteristics for crop growth. Crops require nitrogen, phosphorus, potassium and other nutrients at the right levels to grow properly and yield well. Fertile soils retain moderate to high levels of the nutrients needed for plant growth and good yield. Both soil organic matter and mineral composition influence inherent fertility. They affect the nutrients present, how they are stored in the soil, and, along with soil biology, how nutrients

FIGURE 3.4. Cereal rye cover-crop residue mat 17 weeks after termination with glyphosate and a roller/crimper. *Photo courtesy of Francisco Arriaga.*

TABLE 3.1. Increases in soil organic matter content and water-stable aggregates in a central Alabama soil after 10 years of in-row subsoiling to a 15-inch depth compared to disking and chisel plowing [54]

	Soil organic matter[1]		Water-stable aggregates
	Depth (inches)		
	0–½	0–1	
TILLAGE	**PERCENT**		
Conventional: disking and chisel plowing	0.9	0.9	37
Non-inversion: in-row subsoiling to a depth of 15 inches	1.9	1.5	58

[1] Soil organic matter estimated from total soil carbon content multiplied by a 1.724 factor.

are made available to plants.

The capacity of a soil to retain positively charged nutrients such as calcium, magnesium or ammonium is known as cation exchange capacity (CEC). The CEC is determined by the type of clay, organic matter content and pH. Kaolin, a type of clay typically found in Southeast soils, has a low CEC of 1–10 milliequivalents of charge per 100 grams of soil (meq per 100g). In contrast, soil organic matter can have 100–300 meq per 100g. Consequently, although soil organic matter is a small percentage of the soil, it can be a major contributor to CEC. The combination of low soil organic matter and clays with low CEC means most soils in the Southeast have a CEC in the range of 5–10 meq per 100g, whereas typical soils in the Midwest have CECs of 30 meq per 100g. The mineral fraction of a soil cannot be changed, but CEC can be increased by increasing soil organic matter and maintaining a near neutral pH of 6.0–6.5. In acidic soils, the CEC of both clay and organic matter increases as pH increases [53].

Soil organic matter also releases nutrients as it decomposes. Even when inorganic fertilizer is applied, nitrogen released from soil organic matter can be as much as 70 percent of the nitrogen used by a crop like corn [37]. The nutrients in organic matter cannot be used by plants until they are released through a process called mineralization. As soil organisms such as bacteria and fungi break down organic matter, some of the nutrients mineralized are used for their growth and some are left available for plant use.

Organic materials, such as cover crop residue and manures, play an important role in maintaining soil organic matter. For cover crops, in addition to moisture and temperature, residue quality determines how quickly these materials break down and release nutrients (Table 3.2). Residue quality is affected by the carbon-to-nitrogen ratio (C:N ratio), as well as by the amounts and kinds of organic compounds present. Nitrogen in residue is either released for plant uptake or immobilized in the microbial mass, depending on the residue quality. In general, residues with a C:N ratio less than 20 will break down within weeks or months depending on conditions, and will supply nitrogen to the following crop. An example is crimson clover with a C:N ratio of 17. Plants with lower C:N ratios also tend to have greater amounts of carbohydrates. Residues with a C:N ratio of 40 or greater break down slowly, so nitrogen is less available to the following crop. An example is a

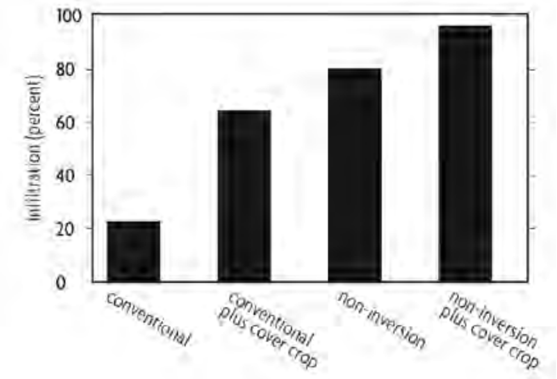

FIGURE 3.5. Water infiltration under different tillage and cover crop practices [54].

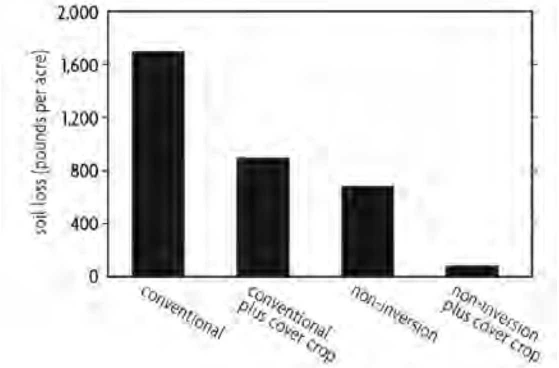

FIGURE 3.6. Soil loss under different tillage and cover crop practices [54].

mature cereal rye with a C:N ratio of 40. Residues with higher C:N ratios also tend to have greater amounts of complex organic compounds such as lignin and polyphenols, which decompose slowly. Between C:N ratios of 20 and 40, whether or not nitrogen from the residue becomes available to the following crop depends on a number of factors including the types of organic compounds in the residue.

Figure 3.7 shows this process over a growing season when a low-nitrogen, high C:N ratio plant residue is added to the soil. At first, microbial activity increases and nitrate concentration decreases as microorganisms decompose the residue, grow and incorporate nitrogen into their bodies. This process is referred to as immobilization. Microbial activity eventually declines and microorganisms die. Nitrogen is then released as the dead microorganisms decay. The advantage and disadvantage of nutrient release by organic matter is that it happens slowly over the growing season. This can mean that, with every rainfall, decomposition is encouraged and nutrients are released. It also means that nutrients, particularly nitrogen, may not be released fast enough when crop demand is high.

Soil organic matter has other effects on fertility such as making soil phosphorus more available to plants. These effects are intimately tied to soil biology. We often think of fertility simply in terms of adding fertilizer or lime. The chemical component of fertility is certainly important, but soil biology also plays an important role.

SOIL ORGANIC MATTER AND SOIL BIOLOGY

Soil is teeming with life, both macroscopic and microscopic. These life forms range in size from invisible microorganisms to easily visible insects, earthworms and plant roots (Figure 3.8). In a teaspoon of soil, there are millions of bacteria, hundreds of thousands of fungi, thousands of protozoa and many larger organisms. These soil organisms play essential roles in nutrient cycling and energy flow, both of which influence soil fertility and crop production.

Soil organic matter and soil organisms are inextricably connected. Microbial biomass is the living component of soil organic matter, and microorganisms are the catalysts for most nutrient-releasing processes. They make it possible for crops to grow and for soils to be productive. On the other hand, microbial growth and activities depend on available carbon and other mineral nutrients as well as a favorable physical and chemical environment. The way soil is managed through tillage and cropping systems has a profound impact on life below ground.

Soil Organic Matter as Food

Soil organisms form a complex food web, and soil organic matter is the base of the web. Most soil microorganisms use organic compounds in soil organic matter as carbon and energy sources. Some soil organisms feed directly on living roots, but most depend on dead plant matter [8]. Small insects such as the springtail, a micro-invertebrate, break up plant residue into small pieces, which accelerates further decomposition by microorganisms. Within the soil food web, there are also carnivores, parasites and predators. As in an aboveground ecosystem, these organisms are interdependent and help cycle nutrients from organic to inorganic forms that are available to crops.

Except for the area next to the root, called the rhizosphere, soil is a nutrient-poor environment for microbial growth. Nutrients and carbon, in the form of plant and animal residues, tend to enter the soil intermittently. Consequently, microorganisms are faced with a feast-or-famine existence. Soil microorganisms respond rapidly to the addition of plant and animal residues. They break down complex organic compounds, such as cellulose and lignin in plant residues, into simple organic compounds. Some of the carbon in these simple organic compounds becomes part of the microbial biomass and provides energy for microbial growth. Some becomes carbon dioxide.

The more stable fraction of soil organic matter, humus, is also a source of carbon for microorganisms. Organic compounds found in humus have complex chemical structures and are more resistant to decomposition than fresh plant or animal residues. Humus is also associated with mineral particles and forms materials called humate-clay complexes that protect the organic matter from decomposition by soil microorganisms. Therefore, humus serves as a slow-release source of carbon and energy.

In addition to carbon, soil organic matter contains substantial amounts of organic nitrogen, phosphorus, sulfur and many trace elements. Microorganisms perform an important function in cycling these nutrients. They convert organically bound elements to inorganic or mineral forms that are available for plant use. This process is called mineralization. Microorganisms, as well as plants, also immobilize nutrients in their biomass as they grow. These nutrients are unavailable to plants until the microorganisms and plants die and decompose. Mineralization and immobilization are key processes in nutrient cycling.

Nitrogen is the nutrient in highest demand by plants. Plants mainly use inorganic forms of nitrogen, such as ammonium and nitrate, which are products of microbial transformations. Plants and microbes use ammonium from nitrogen fixation and mineralization to form proteins, nucleic acids and cell walls. Nitrifying bacteria convert ammonium to nitrate in a process called nitrification. Microorganisms also convert nitrate to various gases, N_2, NO, N_2O, through a process called denitrification. This process occurs when soils are water saturated and oxygen is low. Denitrification causes nitrogen losses from the soil to the atmosphere.

Microorganisms compete with plants for nitrogen. During the decomposition of organic residues, microbial needs for nitrogen are met first. This is why with low-nitrogen residues, most nitrogen is immobilized and not available for plant use (Figure 3.7). Nitrogen not used by microbes is released to the soil and becomes available for plant use.

The increase in soil organic matter that occurs in conservation tillage systems results in greater soil biological activity and soil biodiversity. Generally speaking, microbial biomass increases along with soil organic matter and makes up 1–4 percent of the total organic matter. Reducing tillage increases the amount of microbial biomass in soil [45]. This improves soil quality and promotes a constant cycling of nutrients, some of which are available for crop growth.

Modification of Habitat

In addition to being a food source, soil organic matter modifies the habitat of soil organisms. Changes in water-holding capacity, porosity, infiltration, hydraulic conductivity and water-stable aggregation that occur with increased soil organic matter have a profound impact on microbial biomass development and its activity [21].

Changes related to soil water are particularly important. Soil organisms live in water films surrounding soil particles. Different types of organisms prefer different moisture conditions for growth. Consequently, changing moisture content alters the composition of soil microbial populations. For example, abundant soil moisture favors algae, protozoa and anaerobic bacteria, whereas low moisture favors fungi, actinobacteria and spore-forming bacteria [19]. The effects of soil-water content on microorganisms often result from changes in the amount of oxygen in the soil, because soil oxygen decreases as soil moisture increases. Generally speaking, total microbial activity is reduced when soil is either too dry or too wet.

Soil water also influences the movement of soil organisms. High water content makes movement easier for soil organisms. As water content increases, individual soil aggregates become con-

TABLE 3.2. Carbon to nitrogen (C:N) ratios of some commonly used cover crops and manures[1]

Cover crops	C:N ratio
Mature cereal rye (heading)	40 [41]
Young cereal rye (before boot stage)	14 [36]
Wheat straw	100 [7]
Crimson clover (mid-bloom)	17 [41]
Hairy vetch (early-bloom)	11 [41]
Cereal rye/crimson clover	28 [41]
Cereal rye/hairy vetch	21 [41]
Cowpeas	13 [16]
Manures	**C:N ratio**
Poultry litter	14 [46]
Dairy manure (solids)	13 [46]
Swine manure	14 [46]

[1] The superscript numbers in brackets refer to the reference list number for the C:N ratio.

nected by water and it is easier for bacteria to be eaten by predators such as protozoa [10]. In many cases, grazing by protozoa increases bacterial activity and increases the release of carbon and nitrogen bound in bacterial cells.

Soil aggregation increases with increasing organic matter and this modifies the microbial habitat. Large soil aggregates contain higher levels of nutrients than soil in general. Pores inside aggregates provide refuge for soil microorganisms, protecting them from predators and from drying. Soil aggregates vary in size as do the pores within them.

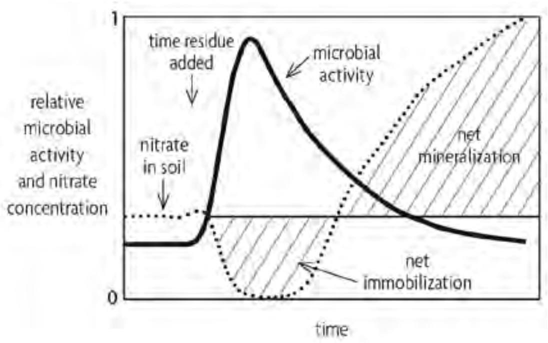

FIGURE 3.7. Changes in soil microbial activity and nitrate levels with the addition of plant residue with a low nitrogen content [12].

The size of pores determines the occupants, as illustrated by Figure 3.8. Bacteria usually live within micro-aggregates [20]. Fungi, nematodes and protozoa inhabit pores between micro-aggregates as well as pores within and between macro-aggregates. Most soil bacteria are physically separated from their predators, such as protozoa and nematodes. Soil mites are more abundant in macropores [9, 34]. Studies show that as protozoa, nematodes, fungi and mites feed on each other, nutrients are both released and incorporated into their bodies, affecting the fertility of soil.

Soil compaction crushes macropores and large micropores into smaller pores, reduces total pore space as well as air-pore space, and increases soil bulk density. Compaction limits the movement and abundance of larger soil organisms such as earthworms and soil insects. Microorganisms such as bacteria and fungi do not seem to be affected by soil compaction [49].

Disease Suppression

Most soils suppress soil-borne plant pathogens to some degree, including bacterial and fungal pathogens as well as parasitic nematodes. A soil's ability to suppress pathogens is directly related to its microbial biomass and microbial activities since microbial populations compete with pathogens for nutrients and energy. Disease suppression is often enhanced by adding organic matter such as compost and fresh organic materials [51].

BUILDING AND MAINTAINING SOIL ORGANIC MATTER

Agricultural production systems based on no-till or reduced tillage, cover crops, and crop rotation increase organic matter in soils of the southeastern United States. These systems leave more organic matter in the soil than conventional systems where organic matter is lost through erosion and decomposition. Soil organic matter can be thought of as a savings account where money can be deposited, withdrawn or left in the bank. Deposits are made to the savings account in the form of roots, crop residues, compost and animal manures. Soil organic matter is withdrawn from the account through decomposition, erosion and sometimes leaching. Some organic matter stays in the savings account as it transforms into humus.

Soil organic-matter content is dependent on soil type, climate, and current and past crop and soil management. Soils in cool, wet climates such as the Midwest tend to have higher amounts of organic matter than soils in hot and wet climates like the Southeast. When organic-matter deposits are made to a degraded soil, soil organic matter accumulates rapidly [25, 29, 44]. At a certain organic-matter level determined by soil type and climate, the deposits and withdrawals of soil organic-matter levels are equal [27].

Agricultural management practices have a profound effect on soil organic matter. Cotton production with no-till and cover crops results in an increase in organic matter of about a quarter of a ton-per-acre per year compared to no-till alone [5]. In South Carolina, organic matter increased by 76 percent after 25 years of a reduced-tillage system with crop rotations including winter cover crops [3]. In southern Alabama, soil organic matter increased 38 percent in the top 2 inches of soil after three years of a cotton>winter cover crop>peanut>winter cover crop>cotton>winter cover crop rotation in which livestock grazed the winter cover crop [50].

Reduced tillage is an important first step to rebuild soil organic matter because it reduces the amount of soil organic matter lost to decomposition. However, if reduced tillage is used with winter fallow, where only winter weeds are present as a cover, soil organic matter may not change much because only a small amount of residue is being left in the system.

Cover crops are a necessary second step to obtain the full benefit from a reduced-tillage system. On average, 430 pounds per acre per year of soil organic matter can be accumulated when conservation tillage is used [13], while 820 pounds per acre per year can be stored when conservation tillage is used with cover crops [5]. In the Southeast, cereal rye planted by November and grown to maturity can supply up to 10,000 pounds of dry-matter per acre in aboveground biomass, and the root system may provide nearly as much. The addition of this biomass boosts soil organic matter (Figure 3.9).

Crop rotations are also important to build and maintain soil organic matter. Greater amounts of soil organic matter are found in crop rotations with high-residue crops, such as corn and small grains, than in low-residue continuous cotton. A rotation can balance out differences in biomass inputs over a year. Some crops, such as corn, leave fairly heavy residues in the field. This helps compensate for the reduced biomass of a cover crop when it must be terminated early to allow for timely corn planting. In contrast, crops such as cotton leave little residue but can be planted into high-residue cover crops such as cereal rye. Crop rotation also helps break disease and pest cycles, and spreads risk to maximize profits over the rotation.

SOIL ORGANIC MATTER AND CARBON SEQUESTRATION

Along with the benefits to crop production, conservation systems that store more carbon in the soil are getting greater environmental attention. Carbon sequestration is simply defined as long-term storage of carbon [12] (Figure 3.10). It is important for reducing the amount of carbon dioxide in the atmosphere, which contributes to climate change. Trees, lumber, perennial roots, stable soil organic matter and deposits such as coal and limestone are examples of long-term carbon storage [26].

The storage of carbon from plant biomass in soil organic matter is a key sequestration pathway in agriculture. Stable soil organic matter can last for hundreds to thousands of years and is largely composed of carbon [52]. For carbon to be sequestered in soil, it has to be protected from microbial degradation. This tends to happen within stable micro-aggregates. Conservation systems are an effective way to increase soil organic matter and thus store soil carbon. If these systems were adopted on the 64 million acres of cropland in the southeastern United States, an estimated 47 million tons of carbon dioxide could be sequestered in soil each year [14].

Conservation systems can also reduce greenhouse gases by reducing fossil fuel use [38, 2]. Although the amount of carbon sequestered in conservation tillage systems is finite, the benefit of reduced fossil fuel use continues as long as reduced tillage is used [55]. Tillage and harvest represent the greatest proportion of fuel consumption in conventional tillage systems [17]. Consequently, converting from moldboard plowing to conservation systems could keep about 20 pounds of carbon per acre per year from entering the atmosphere through fossil-fuel emissions [26].

PREDICTING CHANGES IN SOIL ORGANIC MATTER

The amount of organic matter in soil depends on cropping history, current production methods, soil type, and variations in climate and microclimate. The Soil Conditioning Index (SCI) is used by the USDA Natural Resources Conservation Service to predict changes in soil organic matter as affected by cropping system, tillage management and soil texture [24]. When an SCI score is negative, organic matter is predicted to decline. When an SCI score is positive, organic matter is predicted to increase. The SCI is a useful way to look at the likelihood of a change in soil organic matter, but it does not predict an amount of change. In the following sections, the SCI was used to assess various cropping systems in these major land resource areas: Southern Piedmont, Southern Coastal Plain and the Southern Appalachian Ridges and Valleys [4].

Southern Piedmont

Soils in the Southern Piedmont have moderately high clay content, are mostly well drained, and are at least moderately permeable [40]. Historical tillage practices caused the loss of soil organic matter in these soils, resulting in organic-matter contents that are often less than 2 percent. The SCI predicts that continuous cotton production with no-till would increase soil organic matter marginally, but including a winter cover crop or grain in the rotation would do even better

TABLE 3.3. The Soil Conditioning Index (SCI) for several management scenarios in the Southern Piedmont region [4]

Location	Soil series	Soil texture	Slope (percent)	Scenario	SCI
Watkinsville, GA	Cecil	Sandy loam	4	Monoculture cotton, spring chisel tillage	-1.1
				Monoculture cotton, fall chisel tillage	-1.8
				Monoculture cotton, no-till	0.12
				Cotton>annual rye, no-till	0.36
				Cotton>corn>corn>tall fescue (pasture years)	0.61

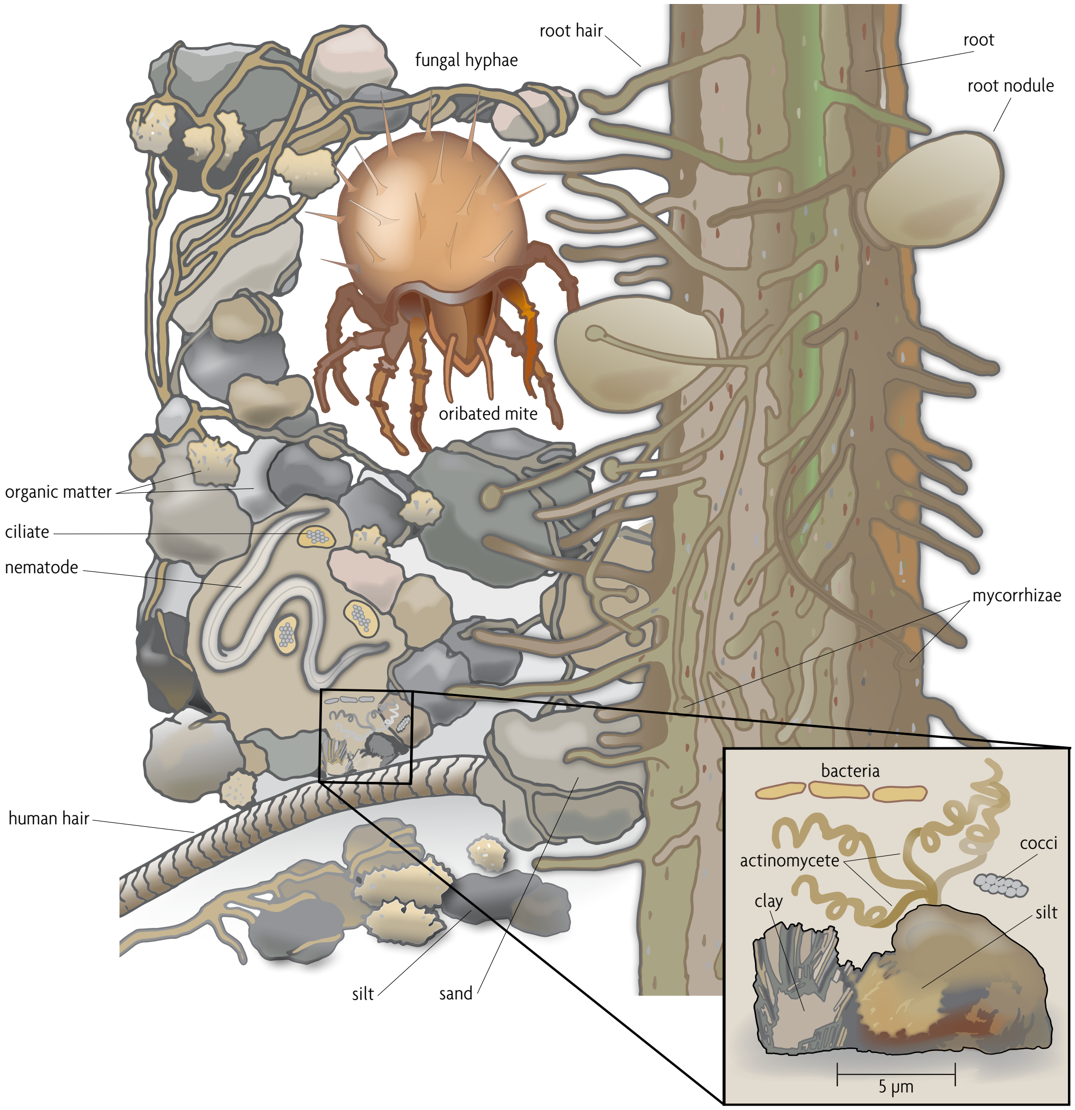

FIGURE 3.8. A soil habitat containing mineral particles, organic matter, water, plant roots with root hairs and soil organisms. The actual size of the soil in this drawing is slightly greater than 1 millimeter. *Illustration courtesy of Wendy E. Giminski.*

(Table 3.3). Increasing crop-rotation complexity with corn and short-term sod that could be used for livestock grazing would be the best way to increase soil organic matter. Surface-soil organic-matter contents of 4 percent are about as high as could be expected based on data from forest and pastures.

Cotton was the dominant crop for more than 150 years in the Southern Piedmont, causing great erosion scars in this sloping region [28]. Despite adequate rainfall, limited infiltration due to crusting resulted in high water runoff and low soil-water storage under conventional tillage. Maintaining good residue cover is particularly important for reducing surface sealing, water runoff, soil loss and agro-chemical runoff [11, 39]. Conservation tillage systems lead to more soil organic matter, improved soil quality and greater cotton yield [16, 47]. When converting to conservation tillage in this region, use deep tillage without inversion such as subsoiling to initially overcome a lack of soil structure resulting from decades of intensive tillage.

Southern Coastal Plain

Agricultural soils in the Southern Coastal Plain are located on floodplains, river terraces and gently sloping uplands [23]. These soils tend to have sandy textures and are moderately well drained to well drained. Conventional tillage in the Coastal Plain region causes loss of soil organic matter, as seen by the negative SCI in Table 3.4. Most agricultural soils in the region have organic matter contents less than 1 percent.

Management strategies to increase organic matter include reduced tillage or no-till, diversifying rotations with high-residue crops such as corn and cereal cover crops, applying animal manure, and including sod in rotations. For example, a Norfolk soil with continuous cotton using conventional tillage has an SCI score of -0.41. Changing management to no-till will increase the score to 0.44. Adding a cereal-rye winter cover crop and rotating cotton with corn increases the SCI score to 0.60. Because these sandy soils do not retain organic matter as well as the clayey soils of the Southern Piedmont, organic-matter contents

TABLE 3.4. The Soil Conditioning Index (SCI) for several management scenarios in the Southern Coastal Plain region [4]

Location	Soil series	Soil texture	Slope (percent)	Scenario	SCI
SC	Norfolk	Loamy sand	3	Conventional tillage, continuous cotton	-0.41
				No-till, continuous cotton	0.44
				No-till, cotton>annual rye>corn>annual rye	0.6
SC	Norfolk	Loamy sand	3	Conventional tillage, continuous cotton	-0.84
				No-till, continuous cotton	0.28
				No-till, cotton>annual rye>corn>annual rye	0.54
				Paratill, continuous cotton	-0.27
				Paratill, cotton>annual rye>corn>annual rye	0.45
				Paratill, corn>sunn hemp summer cover crop> wheat>cotton>white lupin/crimson clover	0.56

TABLE 3.5. Representative management scenarios and Soil Conditioning Index (SCI) for the Southern Appalachian Ridges and Valleys region [4]

Location	Soil series	Soil texture	Slope (percent)	Scenario	SCI [4]
AL	Decatur	Silty loam	3	Continuous cotton, fall chisel plow	-2.6
				Continuous cotton, no tillage	-0.36
				Cotton>annual rye>corn>annual rye	0.17
				Cotton>annual rye>corn>annual rye, five tons per acre of poultry litter prior to cotton	0.21
				Cotton>annual rye>corn>annual rye, paratill prior to cotton	0.09

FIGURE 3.9. Heavy residue left from an annual cereal rye cover crop six weeks after rolling/crimping with strip-tilled cotton. *Photo courtesy of Julia Gaskin.*

of 2–3 percent are probably as high as can be expected.

In Coastal Plain soils, non-inversion subsoiling is needed in the spring to alleviate compaction due to traffic and natural reconsolidation, which can constrain root growth. Paratilling disturbs the soil and results in a loss of organic matter. In Bama soils, paratilling continuous cotton would likely decrease soil organic matter, but paratilling cotton rotated with corn using cover crops would increase organic matter (Table 3.4). An even more intensive rotation, corn>sunn hemp summer cover crop>wheat>cotton>white lupin/crimson clover mixture, further increased organic matter. Increased plant growth, particularly in the root zone, adds organic matter. Several types of non-inversion subsoiling tools are used, including subsoil shanks and paratills. Methods that cause the least surface-soil disturbance are best.

Southern Appalachian Ridges and Valleys

Soils in the Southern Appalachian Ridges and Valleys region are fine-textured silts and clays derived from limestone, sandstone, siltstone, shale and dolomite [1]. Agricultural soils in this area typically have organic-matter contents of 2 percent under conventional tillage. The use of crop rotation and cover crops is particularly important. Continuous cotton production in the Tennessee Valley of northern Alabama is predicted to lose soil organic matter under both chisel plow and no-till (Table 3.5). By including a cover crop in a cotton>corn rotation, organic matter would likely increase, especially when applying poultry litter as a nutrient source. Even with soil disturbance with a paratill prior to cotton planting, including a cover crop in the rotation promotes increased organic matter. A soil organic matter content of 4 percent is probably as high as can be expected.

Soils in this region have a platy structure that leads to soil compaction and resistance to root growth, especially under no-till. In the early 1990s, the common practice was to plant without tillage directly into cotton stubble with no winter cover crop. Cotton yield reductions were common and jeopardized the adoption of no-till. It was later demonstrated that yields would increase with autumn non-inversion tillage under the row, coupled with an annual-rye cover crop to reduce compaction and to provide moisture-conserving surface residue [42, 43, 48].

SUMMARY

Conservation tillage systems can increase soil organic matter, which has many benefits to agriculture in the Southeast. Changing management by moving from inversion to non-inversion tillage or no-till is a good first step, but to maximize soil organic matter content, a crop rotation with heavy-residue crops and cover crops needs to be employed. These practices leave more carbon in the soil in the form of organic matter than is lost through erosion or decomposition. Soils with greater amounts of organic matter resist compaction and have improved infiltration, water-holding capacity, fertility and disease resistance. All of these factors ultimately affect productivity.

A farm's soil type, machinery, cash crops and other production factors will determine the best system for that farm. To achieve long-term sustainability and to enhance soil health for farms in the southeastern United States, focus on these principles:

- Reduce soil disturbance by using no-till or reduced tillage.
- Keep soil covered with cover crops and crop residues.
- Enhance biodiversity with crop rotations and integration of crop and livestock systems.

RESEARCH CASE STUDY

Demonstrating the Potential for Triticale and Annual Ryegrass as Both an Alternative Winter Crop and a Soil Organic-Matter-Building Practice

Project Information

Project type: Farmer/Rancher Grant
Project number: FS11-253
Project dates: 2011–2014
Principal investigator:
Jonny Harris, Greenview Farms
Screven, Ga.
Project reports: https://projects.sare.org/sare_project/FS11-253/

Problem Statement

Winter cover crops offer farmers a number of benefits: they increase soil organic matter, thereby protecting the soil from erosion during winter months; they provide an alternative, high-quality crop that can be used as forage in dairy and beef operations; and they can increase the sustainability and profitability of farms by decreasing environmental degradation and lowering input costs. Researchers at the University of Georgia conducted a two-year study on a farm in Screven, Ga., to identify and develop the management practices needed to produce a winter annual cover crop. In doing so they wanted to address problems specific to the farms of southeast Georgia, where the soil is low in organic matter and nitrogen, and has a limited capacity of holding water. The farmer, Jonny Harris, raises cattle and grows cotton, corn, soybeans and peanuts.

Not all producers in southeast Georgia are aware of a winter cover crop's ability to increase soil organic matter, organic nitrogen and water-holding capacity. For those farmers who are aware of the benefits, few fully perceive the economic advantages to be gained from cover crops. With the rise in the price of feedstuffs for forage-based livestock production systems and the recent technological innovations in forage conservation technology, cover crops have the potential to be used as a cash crop, with farmers storing and selling their cover crop to local livestock and dairy operations. This gives an additional economic incentive, beyond those that are motivated by environmental protection, for farmers to increase the production of cover crops.

For decades, Harris had been growing winter cover crops to build organic matter in his fields and provide forage for his cattle. He partnered with University of Georgia researchers on this SARE-funded project to begin quantifying the benefits to his operation. "I understood that it was good, but we needed documentation. I

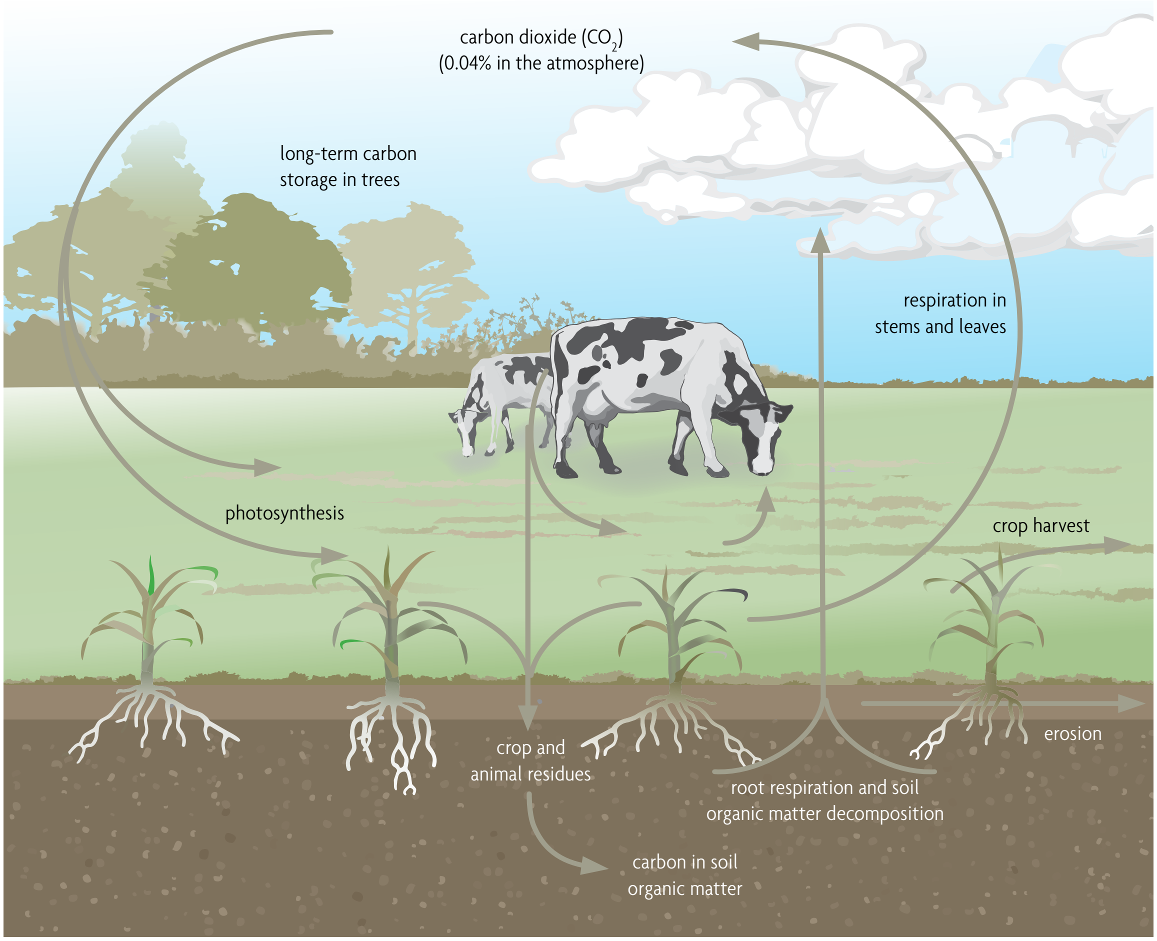

FIGURE 3.10. The carbon cycle showing major reservoirs of carbon and movement within the environment.

couldn't go to my neighbor and say if you use this as a forage cover crop, you can get this much production and market it for this much," Harris said.

Methods and Practices

Over three years, different winter cover crops (annual ryegrass, triticale, annual ryegrass and crimson clover, triticale and crimson clover) were planted on a 45-acre tract of land divided into seven plots. Changes in soil organic matter, organic nitrogen, bulk density and water-holding capacity across the different plots were monitored and compared to a control where no cover crop was planted. Differences in yield for the cotton cash crop were also noted, and results between years were identified.

Results

Following the first year's growing season, two varieties of ryegrass used for the cover crop were eliminated from the study and replaced with newer varieties. The study found that cover crop use increased soil organic matter by 1 percent in one year. The plots that used cover crops produced a cotton crop that yielded 150 pounds more of lint than the control plot. The results of the study were presented at a meeting the following year with more than 80 producers from the region present. The researchers placed emphasis on the need for further on-farm testing to add to information available for producers.

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PART 2

Conservation Tillage Systems: Core Components

CHAPTER 4

The Calendar: Management Tasks by Season

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Successful conservation tillage systems always have crops growing in the fields. Cover crops and cash crops follow each other and sometimes overlap. When summer crops are maturing or have just been harvested, it is time to plant winter cover crops. In the spring, the winter cover crop is terminated three to four weeks before the summer cash crops are planted. Soil and plant sampling, scouting, planning and equipment maintenance occur year-round. Seed, fertilizer and chemicals are ordered when the best selection and price are available. This chapter presents a generalized season-by-season task list for conservation tillage system management. It is a starting point for developing a farm calendar that considers local conditions.

JUNE THROUGH AUGUST

With cash crops in the ground, June through August is a time to look forward to summer crop harvest and winter crop planting. There are many tasks to accomplish during the fall so planning and preparation in the summer is essential.

Plan for Cover Crops

The best time to plant winter cover crops is often when summer crops are being harvested. Choose cover crops to accomplish specific farm goals:

- reduce compaction
- cover the soil surface year-round
- control erosion
- control weeds
- control nematodes
- attract beneficial insects
- fix nitrogen
- scavenge for nitrogen
- scavenge for phosphorus and potassium
- grow quality forage

See Chapter 5 for more information on cover crop selection and management.

Purchase Cover Crop Seed

Buy seed for fall-planted cover crops, seed patches and small-grain cash crops while supplies and selection are good. Seed can be hard to find at planting time. Search for the best price and quality, and have them delivered to the farm.

Service and Repair Equipment

Get equipment ready for harvesting summer cash crops and planting fall crops. This will help avoid downtime during planting.

SEPTEMBER THROUGH NOVEMBER

This is a busy time of year so planning ahead is important. The main goals are harvesting cash crops and planting cover crops. Along with these operations, soil testing, field repair, seed crop planting and small-grain cash crop planting are accomplished.

Harvest Cash Crop and Plant Cover Crops

Once harvest is underway, it is time to get cover crops planted. The best way to do this is to plant cover crops during or soon after harvest operations. The goal is to plant early to give the cover crop the best chance for maximum biomass production. On many farms, harvesting is done in the afternoon, after morning moisture evaporates. In these situations, cover crops can be planted in the morning. Some farmers broadcast cover crop seeds before harvest and use the harvest operations to improve seed-soil contact.

Take Nutrient Soil Samples

Now is the best time to pull soil samples for nutrient testing. Normally, soil nutrient levels are lowest in the fall. Pulling samples at this time provides the best results for planning applications of lime or other nutrients for fall and spring crops. Pull samples just before or soon after planting cover crops.

Take Nematode Samples

Nematode numbers are usually highest when fields are producing crops. When crops are taken off the land, levels begin to drop. So, the best time to pull nematode samples is when crops are in production, but this is difficult to do with crops such as cotton and corn. For these crops, sample problem areas during the growing season and pull the remaining samples as soon after harvest as possible. To save time, pull post-harvest nematode samples and nutrient samples at the same time, in the same bucket. Then prepare samples according to lab directions.

Fix Erosion Problems

Severe erosion problems may have occurred in fields that have been neglected. If fields need land leveling or washes need to be repaired, do it before implementing conservation tillage. Once conservation tillage is implemented, a good cover crop will prevent further erosion.

For fields already in conservation tillage systems, minor repairs will need to be made to pivot tracks and to places where equipment has bogged during the growing season. Take care of these problems in the fall before the cover crop is planted.

Plant Seed Patch

Growing a seed patch for cover crops saves the cost of buying seed and ensures a seed supply. Planting the seed patch with a grain drill is the best way to get a stand. Be sure to apply lime and fertilizer if soil tests suggest it is necessary.

Plant Small-Grain Cash Crop

Wheat and other small grains can be planted for double-cropping, meaning following one cash crop with another in the same year. Once the small grains are harvested in the spring, summer cash crops can be planted. In the Southeast, October is usually the best time to plant small grains for double-cropping. Fertilize these crops according to soil test results.

Do Not Stop

In spite of best efforts to get cover crops planted on time, weather and other factors may cause delays. If delays happen, plant the cover crop as soon as possible. Plantings delayed until the middle of December will still provide many benefits.

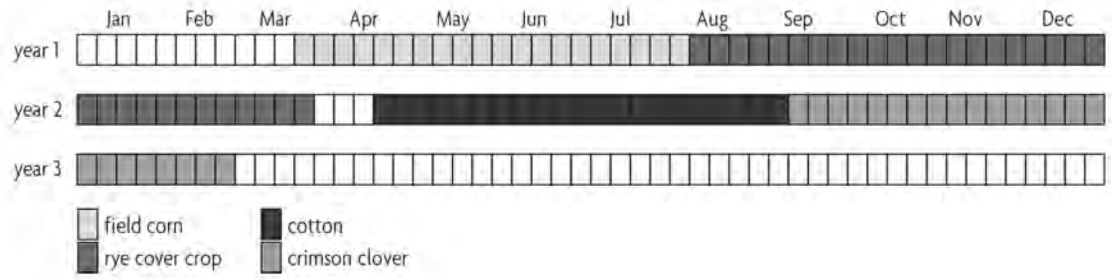

FIGURE 4.1. An example of a crop rotation plan.

Scout for Weeds

One advantage of planting cover crops early is winter-weed suppression. Still, it is a good idea to scout for winter weeds that may emerge during these months. Scout for chickweed and henbit, two common winter weeds found throughout the United States. For best results, it is important to control them while they are small. Herbicide choices for winter weeds are selective. Positive weed identification is important to making the best herbicide choice.

DECEMBER THROUGH FEBRUARY

The winter months before cash crop planting are not nearly as busy as the fall, but there are tasks to accomplish such as planning, scouting, maintaining equipment and purchasing supplies. It can also be a time to diversify the farm with livestock grazing.

Plan Crop Rotation

A good crop rotation spreads risk, breaks pest cycles and improves yields. Although cropping decisions are strongly driven by the market, planning ahead for a crop rotation can help maximize profits over the rotation cycle. Now is a good time to decide the cash crops and cover crops to be grown on each field and to look ahead to the next cover crop. For example, follow cereal cover crops with soybeans or other legumes. Grow clover or other legumes before cereal cash crops or corn.

Figure 4.1 shows a crop rotation planner for a two-year rotation of field corn>rye cover crop>cotton>crimson clover cover crop. This rotational sequence can be repeated for a four-year rotation. The horizontal rows of 52 boxes in Figure 4.1 represent one year and each box represents one week. Colored cells represent the time each crop is in the field from planting to harvest, or termination in the case of cover crops. Table 4.1 includes the days-to-maturity (DTM) data used to determine the number of weeks the crops will be in the field. Note the recommended three weeks between termination of the rye cover crop and planting cotton in year two.

Construct your own crop rotation planner using Figure 4.1 as a guide. This can be done with a spreadsheet, or your can make a template on paper and copy as needed. Compare alternative rotation scenarios using the days to maturity (DTM) data in Table 4.1 or local knowledge as a guide for planting and harvest or termination timelines. If winter grazing is being considered, block out sufficient weeks based on local practices or block out 15 weeks on the planner. You can use the crop rotation planner to define a rotation for the next

TABLE 4.1. Time to maturity for select crops grown in the Southeastern United States

Crop	Time to Maturity
Buckwheat	~4 weeks
Cotton	~21 weeks
Field corn	~20 weeks
Field peas	~8 weeks
Peanuts	~19 weeks
Soybeans	~20 weeks
Sweet corn	~10 weeks
Sweet potatoes	~17 weeks
Tomatoes	~10 weeks
Watermelons	~11 weeks
Winter wheat	~32 weeks

three to four years for each field. It can be updated as more information becomes available.

Graze Livestock

Diversity is often the key to a successful farm operation, and combining livestock and field crops is an example of a diversified operation. Rye or ryegrass as a winter cover crop is excellent for livestock grazing. Fields must be fenced. Grazing begins in late fall or early winter when plants are 6–8 inches high [1]. The forage variety and planting date influence when the field is ready for grazing. If the cover crop is planted from late September to early October, normally there will be enough growth by December to begin grazing. Grazing can continue until March. Once cattle are removed, the crop will recover and provide adequate cover for summer cash crops. See Chapter 8 for more detail on incorporating livestock into conservation tillage systems.

Manage Nitrogen

Decisions to topdress winter cover crops with nitrogen are based on the cover crop, the previous crop, the next crop, soil types, field experience and the weather. For example, if cover crops follow a legume such as peanuts, there is usually no need to apply nitrogen. Cereal cover crops are often given a sidedress of nitrogen in late winter to get maximum biomass production. Late-planted cover crops and those affected by cold temperatures sometimes need nitrogen to stimulate growth. The need for nitrogen applications will vary. Do not fertilize cover crops if they are intended to scavenge for nitrogen. Consider each factor and soil test results to determine rates and timing.

Control Winter Weeds

Scout for weeds in January. There may be weeds emerging that can affect winter growth of the cover crop and can compete with the following cash crop. In the Southeast, scout for these common weeds: horseweed, wild turnips, wild radish and cutleaf evening primrose. Even though these weeds are winter annuals, they will grow through spring planting and compete with cash crops. They are hard to control after crops are planted.

Scout for and Control Insects

There are not many insects to be concerned about in cover crops, although aphids can be an issue in small grains and legumes. Begin scouting for aphids a few weeks after cover crop planting.

Aphids do most of their damage in the early-growth stages of cover crops.

Prepare Equipment

Service equipment for terminating or harvesting winter crops and for planting spring crops. Before spring planting, use roller/crimpers for terminating cover crops and harvesting equipment for winter grains or seed patches. Service planters, strip-till rigs, sprayers and other needed equipment so they are ready for spring planting.

Purchase Spring Planting Supplies

Late winter is a good time to make plans for the cash crop. Get the best varieties by purchasing seed early. Make plans to buy fertilizer and pesticides, too.

MARCH THROUGH MAY

With spring planting, March through May is the busiest time of year on conventional farms, but this is not the case in conservation tillage systems. The elimination of most soil preparation tasks—harrowing, bottom plowing and bedding—saves a tremendous amount of time. Essentially, springtime comes down to just a few operations: terminating the cover crop or harvesting the small grain crop, fertilizing unless it was done in the fall, planting the cash crop, and pest management.

Cover Crop Termination

Cover crops are usually terminated with organic or conventional herbicides, by rolling/crimping, or by a combination of the two methods. Rolling/crimping is an excellent method to control weeds that may be less costly than herbicides alone. A roller/crimper flattens the cover crop and crimps (breaks) the plants to prevent regrowth. Maximizing biomass left on the surface from a terminated cover crop will help to block sunlight and to inhibit weed growth. Rolling/crimping a cover crop alone will kill it if the cover crop is mature. If the cover crop is immature, rolling/crimping may not kill it, so herbicides are often used as well, usually at a reduced rate (see Chapter 9).

Cover crops are normally terminated three to four weeks before cash crop planting. This allows time for them to die and dry out, making it easier for strip-till or planting equipment to cut through the residue. It also allows time for spring rains to replenish soil moisture and helps prevent pests such as cutworms from attacking the newly germinating cash crop. Terminating cover crops too early may allow weeds to emerge before cash crop planting. To avoid competition during cash crop emergence, kill all weeds before planting.

Fertilize Cash Crop

After cover crops are killed, it is time to fertilize for the cash crop if needed. Remember, fertilizer is surface applied, so there is no need to harrow it in. Fertilizers are spread with spreader trucks or broadcast spreaders. Base application rates on soil test results and any credits for nutrient release from decomposing cover crops or for nutrient fixation.

In-Row Subsoiling

Some Southeastern soils, notably in the Southern Coastal Plain, naturally compact and require in-row subsoiling. This is done after the cover crop has dried out and before or during planting. Use a soil penetrometer to identify soils that need in-row subsoiling and the depth of the compacted layer (see Chapter 6). Subsoil only if necessary and only as deep as necessary.

Plant Cash Crop

Planting the cash crop in a conservation tillage system is not much different from planting in a conventional tillage system. More time may be needed for the soil to warm up to the recommended planting temperature if the cash crop residue and/or cover crop residue blanket the soil. Use a soil thermometer to make sure conditions are right for cash crop planting. Delay strip-tilling if the residue is wet from morning dew or rain. This helps prevent problems with residue management. For example, wet residue may wrap around and get stuck in row cleaners. The row cleaners may need to be raised in these situations. Otherwise, follow normal planting procedures.

Conservation tillage equipment can be set up to strip-till and plant in the same operation or to strip-till and then plant in a separate pass. For small-scale farmers, the trend is to strip-till and plant in one pass to save labor and fuel (Chapter 9). Many large-scale farmers prefer to lay off or mark the rows in the field and then plant along those rows. In this situation, in-row subsoiling is done ahead of time, which helps with faster planting of large acreages.

Scout for Pests

Scout for weeds, diseases and insects during the spring. Manage them before they become a problem. A heavy cover crop residue will suppress weeds. This is especially important before the cash crop canopy is established.

CASE STUDY

A Vegetable and Fruit Calendar

Arnold Caylor is director of the North Alabama Horticulture Research Center in Cullman, Ala. (USDA Plant Hardiness Zone 7b). He uses conservation tillage systems to manage 30 acres of vegetables including tomatoes, peppers, cantaloupe, watermelons, sweet corn, sweet potatoes, pumpkins, brassicas, cowpeas and field peas, and perennial fruit including blueberries, bunch grapes and muscadines. Some of the center's acres are USDA-certified organic. Here is the to-do list for the farm.

June through August

Plant vegetable cash crops and summer cover crops. In June, plant sweet potatoes. From mid-

June onwards, harvest tomatoes and squash. From July onwards, harvest cantaloupes and watermelons. From June to July, harvest blueberries. From July to August, harvest bunch grapes. In August, tomatoes, watermelons and cantaloupes are finished: pull stakes, plastic and drip tape. Transplant brassicas. From August to September, harvest muscadines.

September through November

Plant winter cover crops as weather allows. The main winter cover crop is a mixture of cereal rye and crimson clover. Canola is used for insect and nematode pest control. Plant these cover crops into terraces to attract bees that will pollinate crops and improve crop productivity. Do equipment maintenance in September and throughout the fall and winter, if needed. From October to December, prepare compost windrows and turn them once or twice per week until windrow temperatures decline.

December through February

Order vegetable seeds and look for good deals on fertilizer and chemicals. Start tomatoes, peppers, cantaloupes, squash and watermelons in February. From late February to early March, prune blueberries, bunch grapes and muscadines.

March through May

Spread compost. From February through March, plant brassicas. In late March, shape beds and prepare them for plastic. Bed sweet potatoes and Irish potatoes. From March to April, terminate winter cover crops three weeks before cash crop planting. In early April, lay plastic, two to three weeks after bed preparation. In mid-April, transplant tomatoes, peppers, cantaloupes and watermelons. Plant sweet corn when soil temperatures are about 60°F. In May, plant summer cover crops. Plant an iron clay peas/sunflower mixture for nitrogen, biomass and cut flowers. Plant sorghum/sudangrass for biomass. Do not use herbicides. Instead, rely on cover crops for weed suppression. Continue planting summer vegetables and transplant sweet potatoes.

CASE STUDY

A Row Crop Calendar–Corn, Cotton, Peanuts and Soybeans

Barry Martin is a farmer from Hawkinsville, Ga. (USDA Hardiness Zone 8) in the upper Coastal Plains. He has been using conservation tillage since 1996 to grow 600 acres of row crops including corn, cotton, peanuts, soybeans and wheat. Here is the to-do list for the farm.

July through August

Scout summer crops for insects, diseases and weeds, and treat if needed. Monitor fields for nematodes. Use irrigation to finish out crops, meaning continue irrigation as needed until the crop is harvested. Once cash crops are harvested, use downtime to service and repair harvest and other equipment such as grain drills and broadcast spreaders used to plant cover crops. Purchase wheat cash crop seed and additional cover crop seed if needed. Harvest corn in August.

September through November

Harvest peanuts, cotton and soybeans. Take soil and nematode samples. If needed, apply dolomitic lime. Spread fertilizer for wheat and cover crop seed patches. Repair pivot tracks and areas where equipment bogged down during the growing season. Plant a rye cover crop and a rye seed patch during or soon after cash crop harvest. In November, plant winter wheat.

December through February

Scout the wheat crop, cover crop and seed patch for insect and weed problems, and treat if necessary. Monitor nitrogen and apply as needed. Service and repair equipment for spring planting. Purchase seed, chemicals and fertilizer for spring planting.

March through May

Terminate cover crops with glyphosate three to four weeks ahead of cash crop planting. Spread fertilizer once the cover crop is terminated. Plant corn in March, cotton in April and May, and peanuts in May. Use irrigation to activate herbicides and germinate seed. Scout the crops for insects, weeds and diseases, and treat if needed.

June

Plant soybeans in early June. Harvest the rye seed crop. Scout cash crops and treat as needed. Irrigate as needed.

SUMMARY

Successful conservation tillage systems require good management and planning. As with all farming operations, timely decisions and applications are important. Due to the use of cover crops and the presence of crop residue, timeliness may be more important with conservation tillage than with conventional tillage. The dates for planting and harvesting cash crops and cover crops are interrelated. The interrelationship is discussed in the following chapters. The impact of local conditions on decision-making is included in the discussion in chapters 17–20. With conservation tillage systems, it is never too early to make plans and get started.

REFERENCES

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TO-DO LIST:
A SEASON-BY-SEASON LIST OF CHORES FOR THE FARM

June through August

- Plan for cover crops
- Purchase seed
- Service/repair equipment

September through November

- Sample for nematodes
- Sample for soil nutrients
- Fix erosion problems
- Harvest cash crops
- Plant cover crops
- Plant seed patch
- Plant small grain cash crop
- Scout for weeds

December through February

- Plan crop rotation
- Graze livestock
- Topdress nitrogen
- Scout and control weeds
- Scout and control insects
- Prepare equipment
- Buy spring supplies

March through May

- Terminate cover crop
- Fertilize cash crop
- Subsoil
- Plant cash crop
- Manage pests

CHAPTER 5

Cover Crop Management

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Cover crops have long been recognized as an important component of conservation tillage systems due to the many benefits they provide. In addition to being a source of organic matter inputs to improve soil organic matter and bulk density, cover crop residues protect the soil surface from water and wind erosion. Due to mild winter temperatures in the Southeast, cover crops can be particularly beneficial as there is ample opportunity to produce significant amounts of biomass prior to planting a summer cash crop.

Finding the right plant or mix of plants that both fits into a "window" or "niche" within the crop rotation and accomplishes your objectives is a key component of cover crop management. Plant selection, planting date, fertilizing, termination date and termination method all affect the results achieved. In some cases, a mixture of plants may be the best approach to achieve the desired outcomes. Decisions concerning cover crop management are strongly influenced by the cash crop a producer plans to grow following the cover crop.

COVER CROP BENEFITS

Cover crop benefits result from the aboveground biomass and roots below the soil surface. Live or dead plant material above the soil surface protects soil from water and wind erosion. Surface material dissipates raindrop energy, which can reduce rainfall runoff, soil erosion, soil crusting and splash dispersal of pest organisms. It also slows wind speeds, thus reducing transport of soil particles.

The surface and subsurface changes that occur with cover crops improve soil moisture by increasing rainwater infiltration and water-holding capacity. In addition, cover crop residues provide an effective mulch that reduces soil-water loss via evapotranspiration. Together these three effects can increase water availability and help reduce the impact of short-term drought on cash crops common across the Southeast.

Cover crops increase soil organic matter and subsequent total soil carbon content, primarily near the soil surface. Increasing soil carbon promotes overall soil health by improving the physical and chemical properties of the soil. Soil aggregate stability is improved, which helps increase soil water infiltration, water-holding capacity and resistance to soil erosion. Soil crusting is reduced, enhancing crop emergence. Decreasing soil strength promotes root growth. Increased biological activity improves nutrient cycling and minimizes the negative effects from disease and pest cycles.

Legume cover crops increase nitrogen availability by fixing atmospheric nitrogen. Small grains "scavenge" residual nitrogen by using the nitrogen for growth, thus immobilizing it in their biomass. This improves nitrogen-fertilizer efficiency, reduces nitrate leaching and helps protect groundwater from nitrate contamination. Reducing erosion decreases the number of soil particles leaving the field with adsorbed plant nutrients, phosphorus in particular.

Cover crops provide early-season weed control via physical mulching and the production of compounds that leach from roots and aboveground residues during their decomposition. These compounds inhibit weed seed germination by providing a natural herbicidal effect against weeds (allelopathy). Cover crops may improve disease management by preventing splashing of pathogen-containing soil particles onto plants. Cover crops may also improve insect management by attracting beneficial insects, especially if allowed to flower.

COVER CROP SELECTION

The desired outcome is an important consideration when selecting a cover crop. Keeping the end result in mind during the cover crop selection process goes a long way in making the best choice. Be sure the plants chosen are not a host for pests of the following cash crop. In addition, consider the following characteristics when selecting a plant or a mixture of plants for a cover crop [10]:

- ease of establishment
- early growth rate
- rooting depth
- biomass yield
- pest resistance
- ease of termination
- cost
- nitrogen fixation

Cover Crop Considerations to Enhance Benefits

Identify your primary objectives when choosing a cover crop(s). Examples of objectives include reducing soil erosion, improving soil moisture, service as a nitrogen source, providing beneficial insect habitat and/or wildlife habitat, etc., or a combination of objectives. Table 5.1 summarizes the relative benefits of common cereal and legume cover crops, and brassicas. Once you have identified your objectives, determine the species that best fit your particular soil type, climate and cropping window. Fortunately, many cover crops provide multiple benefits and are useful for a range of purposes.

Soil Erosion

Grass cover crops are a good choice for reducing runoff and consequently soil erosion because they are fast to establish and have deep fibrous roots. Their rapid establishment and early season growth can provide better than 50 percent ground cover in as little as 30 days. Good ground cover protects the soil from the impact of raindrops and provides protection against erosion due to wind. Mixtures of grasses and legumes may provide even better soil cover. As soil physical properties improve with long-term cover crop use, additional benefits are often observed due to increased water infiltration and further reductions in runoff.

The key to reducing soil erosion is making sure the soil surface is covered with a growing crop or crop residues all of the time. The long growing season and mild winters in the Southeast are well suited to year-round soil coverage by growing plants. Winter cereals and many brassicas often put on significant growth in the fall, even when temperatures drop into the 40s and 50s. Their rapid fall and early-winter growth make them good choices for reducing soil erosion. By slowing erosion and runoff, cover crops reduce nonpoint source pollution caused by sediments, nutrients and agricultural chemicals.

Nutrient Management

Nitrogen and phosphorus are the two nutrients most likely to be lost from cropping systems through runoff, leaching and, in the case of nitrogen, volatilization. Cover crops help reduce these losses in a number of ways:

- increasing infiltration—thus reducing surface runoff and erosion of soil particles containing adsorbed nutrients
- taking up nutrients—acting as a “catch crop”
- using water for growth—reducing the water available to leach nutrients

Cover crop roots can even help unlock some nutrients in the soil and convert them to more available forms. Fast-growing grasses and brassicas reduce nutrient losses because they are good at scavenging excess nutrients, especially nitrogen, left in the soil after cash crop harvest. Scavenging excess nitrogen can also improve water quality by preventing nitrogen leaching to groundwater. In the Southeast, cereal rye is effective at reducing nitrogen leaching because it is cold tolerant, has rapid growth and produces a large quantity of biomass. Legume cover crops are not as effective

TABLE 5.1. Uses of Cover Crops

	Residue Persistence	Pest Control	Nitrogen Fixation	Weed Control	Erosion Control	Compaction Reduction	Nutrient Scavenger	Forage Quality	Attracts Beneficial Insects
Legumes									
Austrian Winter Pea	F	P	E	G	G	F	G	E	E
Cowpea	F	E	E	E	E	F	F	G	E
Crimson Clover	G	P	G	G	G	F	G	G	F
Hairy Vetch	F	P	E	G	G	F	G	G	F
Lupin	F	G	E	G	G	G	F	P	E
Medics	G	F	G	G	G	F	F	G	F
Sunn Hemp	G	E	E	G	G	G	F	P	F
Velvet Bean	F	G	E	G	G	F	F	G	F
White Clover	F	F	E	G	G	F	F	E	E
Cereals									
Barley	E	G	P	G	E	F	G	G	F
Black Oat	G	E	P	E	G	F	G	G	P
Buckwheat	P	P	P	E	F	G	F	P	E
Oat	G	G	P	E	G	F	G	G	P
Rye	E	G	P	E	E	E	E	G	G
Ryegrass	G	G	P	G	E	F	G	G	F
Sorghum-Sudangrass	G	G	P	G	E	E	G	G	F
Triticale	G	F	P	G	G	F	G	G	P
Winter Wheat	G	P	P	G	G	F	G	G	P
Other									
Brassicas	G	E	P	G	G	E	G	G	F

E=Excellent; G=Good; F=Fair; P=Poor/None

Adapted from *Managing Cover Crops Profitably, 3rd Edition*

[1] *Brassicas* commonly planted as cover crops include mustards, forage radish, canola and turnips.

at scavenging nitrogen before the winter leaching season, but they do take up some soil nitrogen and fix large amounts of atmospheric nitrogen. As a result, legume cover crops can provide 30–60 percent, and sometimes more, of the nitrogen needed by the following crop [10].

Winter annual weeds vary in their responsiveness to nitrogen: some species accumulate as much nitrogen as small grains while others take up relatively little residual soil nitrogen. However, winter weeds are not a good substitute for either a monoculture or mixed species cover crop because of the potential for increased weed seed density and management complexity. The amount and availability of nutrients from cover crops will vary widely depending on such factors as species, planting date, plant biomass and maturity at termination date, residual soil fertility, and temperature and rainfall conditions.

Soil Moisture

In addition to increased water infiltration from terminated cover crop residue, evaporation is also reduced, resulting in less moisture stress during short-term droughts. Winter cereal cover crops such as rye, oats and wheat, and late-summer/ early-fall grasses like a sorghum-sudangrass hybrid are especially effective at covering the soil surface.

Pest Management

Cover crops that produce high levels of biomass help manage weeds by competing with the weeds for water, light and nutrients. Cover crop residues or a growing plant canopy block light, alter the frequency of light waves and influence surface soil temperatures. All of these negatively impact weed seed germination. Many cover crops produce root exudates and organic compounds that provide natural herbicidal (allelopathic) effects against weeds.

In addition to suppressing weeds, some cover crops help reduce damage from diseases, insects and nematodes. A growing cover crop adds root exudates and organic compounds that encourage diverse populations of soil microorganisms. The increased diversity creates an inhospitable soil environment for many soilborne diseases and helps suppress certain disease organisms. Root compounds may also reduce harmful nematode populations and encourage beneficial nematode species. Brassicas release bio-toxic chemicals and metabolic byproducts that have shown some activity against bacteria, fungi, insects, nematodes and weeds. However, the level of activity is low compared to traditional soil fumigants.

Cover crops provide habitat for beneficial insects and wildlife. Beneficial insects and parasitoids that prey on pests can reduce insect damage below economic thresholds. Tillman et al. [11] showed that mixed cover crops increased the prevalence of insect predators, especially big-eyed bugs (Say, *Geocoris punctipes*) and red imported fire ants. This led to a reduction in the level of budworms and bollworms (Heliothine moths, *Lepidoptera: Heliothinae*) in conservation-tilled cotton compared to conventional-tilled cotton without cover crops. Cover crops provide both food and habitat that help reduce large fluctuations in insect populations and imbalances between pests and beneficial insects.

Cover crops also serve as sources of food and habitat for wildlife, and hunting leases can provide an additional source of income for growers. Cover crop benefits can be enhanced by increasing the diversity of cover crops grown through mixtures, the frequency of use between cash crops and the length of time that cover crops are growing in the field.

Improve Soil

Cover crops contribute indirectly to overall soil fertility and health by catching nutrients before they can leach out of the soil profile or, in the case of legumes, by serving as a nitrogen source. Soil organic carbon (SOC), a key indicator of soil quality, can be increased by using high-residue cover crops. Soil chemical and physical improvements associated with increased SOC contents are well documented. Recent interest in climate change highlights the potential that high-residue cover crops possess for carbon sequestration and potential government payments. The Soil Conditioning Index (SCI) is a tool used by USDA Natural Resources Conservation Service (NRCS) to predict how SOC levels are affected by cropping and tillage systems [7]. Positive SCI values predict SOC levels will increase, while negative SCI values predict SOC levels will decrease [6]. There is more information about the SCI in Chapter 3.

Table 5.2 summarizes SCI values for various scenarios and highlights the importance of crop rotations and maintaining residues. Government programs, such as the Environmental Quality Incentives Program and the Conservation Securities Program, do not currently use SCI values, but future payments related to carbon sequestration could potentially be based on SCI levels. Balkcom [1] examined the relationship between measured SOC values for various tillage and cover crop combinations after six years and predicted SCI values for one location in the Southeast. Although a reasonable relationship between the SCI and measured SOC values was observed, there were discrepancies that indicated opportunities to improve the SCI for the Southeast. In lieu of this information, growers should be aware of how their cropping and tillage practices may be evaluated in the future with regard to potential carbon sequestration.

Choosing a Cover Crop

As with any good crop rotation, it is more desirable for grass cover crops to precede legume cash crops and for legume or broadleaf cover crops to precede grass cash crops. This practice helps reduce insect and disease problems attributed to monoculture systems and helps ensure good nitrogen management. A legume cover crop following a legume cash crop has the potential for excess nitrogen accumulation, and a grass cover crop following a grass cash crop has the potential for significant nitrogen immobilization. In the Southeast, choose cover crops to maximize biomass because the warm, humid climate promotes crop residue decomposition, resulting in loss of organic matter needed to maintain soil productivity.

Cover crop mixtures enhance benefits associated with each plant type. For example, a legume/grass mixture provides the benefits of nitrogen fixation from the legume and greater biomass production associated with the grass. Combined residues may result in nitrogen release that more closely matches the nitrogen needs of the following crop. Another example is combining two legume species with different times to maturity to extend the flowering period. This provides an extended period of enhanced beneficial insect habitat. Cover crop mixtures can increase seed costs and do require greater management.

COVER CROP MANAGEMENT

Cover crop management begins with determining the objectives for the cover crop and then selecting a cover crop (see previous sections). When

TABLE 5.2. Management scenarios and Soil Conditioning Index (SCI) values for the Southern Piedmont region

Location	Soil series	Soil texture	Slope (percent)	Scenario	SCI
Watkinsville, Ga.	Cecil	Sandy loam	4	Monoculture cotton, spring chisel tillage	-1.1
				Monoculture cotton, fall chisel tillage	-1.8
				Monoculture cotton, no-till	0.12
				Cotton>annual rye, no-till	0.36
				Cotton>corn>corn>tall fescue (pasture years)	0.61
Auburn, Ala.	Marvyn	Loamy sand	3	Monoculture cotton, fall disk tillage	-0.82
				Monoculture cotton, no-till	0.27
				Cotton>grazed rye cover crop, no-till	0.42

Source: [6]

first using cover crops, consider the additional management needs. For example, wheat might be a better choice than cereal rye for a winter cover crop if growers are new to cover crops. Cereal rye is taller and produces more biomass, making it more challenging to manage late in the spring. To reap the most benefits from them, be prepared to manage cover crops to the same extent as cash crops.

Cover crop benefits are usually maximized by operations that maximize biomass production, for example by planting as early as possible and terminating as late as possible. The planting window of the following cash crop is a primary consideration in cover crop termination timing. Timely spring termination of a cover crop avoids potential negative impacts. Excess residue can retain moisture in wet years, resulting in cooler soil temperatures and delayed planting. Cover crops can deplete critical soil moisture in a dry spring. Decisions about termination need to be based on predicted weather patterns and labor availability. Table 5.3 summarizes characteristics of several

TABLE 5.3. Characteristics of several cover crops used throughout the Southeast

Cover Crop	Variety[1]	Seeding rate (pounds per acre of pure live seed)[2]	Seeding depth (inches)	Dry matter (pounds per acre per year)	Comments
Black oats	SoilSaver	50–90	½–1	3,000–7,000	Susceptible to winterkill, so plant in lower Coastal Plain. Excellent early-season weed control.
Oats	VNS[3]	D 80–110 B 110–140	½–1½	2,000–8,000	Provides adequate ground cover, but the cover does not persist for as long as other cereals. Select varieties based on university trials and tolerance to cold temperatures.
Rye	Elbon Wrens Abruzzi	D 60–120 B 90–160	¾–2	3,000–10,000	Typically produces the most biomass of the cereals and is well adapted to different soil types. Excellent early-season weed control.
Ryegrass	Gulf Marshall	D 10–20 B 20–30	0–½	2,000–9,000	Excellent soil builder, but can create problems for cash crop establishment. Excellent early-season weed control.
Wheat	VNS	D 60–120 B 60–150	½–1½	3,000–8,000	Typically the most inexpensive and plentiful seed. Concerns with Hessian fly if wheat for grain is also in the rotation.
Austrian winter peas	VNS	D 50–80 B 90–100	1½–3	3,000–5,000	Not tolerant of wet soil or drought and prefers well-drained heavy soils.
Crimson clover	AU Robin AU Sunrise Dixie	D 15–20 B 25	¼–½	3,500–5,500	Has reseeding potential due to early maturity. Can fix up to 150 pounds N per acre.
Hairy vetch	VNS	D 15–20 B 25–40	½–1½	4,000–7,000	More cold tolerant than clovers, but residue is less persistent. Can fix up to 200 pounds N per acre.

[1] Variety name is given when reported.
[2] "D" means drilled and "B" means broadcast.
[3] "VNS" means variety not stated.

popular grass and legume species grown in the Southeast. Biomass production is shown as dry matter in pounds per acre per year, and the seeding rate is based on pure live seed.

Planting Cover Crops

Establish cover crops with quality seed that has a high germination rate and a low weed-seed content. Plant using a no-till drill, conventional drill or by broadcasting onto the soil surface. Planting cover crops with a drill is more reliable because it ensures proper seeding depth and adequate seed-soil contact. Conventional drills may work, but no-till drills are generally heavier and are designed to operate in residues present in conservation tillage systems. Regardless of the type of drill used, monitor and control the seeding depth to ensure proper seed placement. Calibrate the drill to plant the desired plant population based on pure live seed.

Broadcasting is faster than drilling and can be performed with a variety of equipment that spreads seed onto the soil surface over a wide area. Aerial seeding (broadcast seeding by airplane) and broadcasting with fall-applied phosphorus and potassium fertilizers are common in some areas. Higher seeding rates are needed when broadcasting because seeds are left on the soil surface and are exposed to fluctuating moisture conditions. Broadcast seeding is dependent on timely rainfall for germination and early growth. The amount of seed should be increased 20–30 percent compared to drilling to ensure an adequate stand. For best results, roll fields with a cultipacker or similar piece of equipment after broadcasting. The need for this additional field operation can negate the time-saving advantage of a broadcast application.

Legumes should be inoculated with a species-specific rhizobium inoculant. This ensures good nodulation and enhanced nitrogen fixation. Even in fields where legumes have been grown before, the small expense of rhizobium inoculant provides “insurance” that good nodulation will take place. Fields where legumes have not been grown before may require two years for the legume cover crop to maximize nitrogen fixation, especially on sandy Southern Coastal Plain soils.

Planting date significantly impacts biomass production. Timely planting results in:

- more biomass production compared to later planting dates
- good root establishment and top growth before winter cover crops go dormant
- reduced chance of winter kill for winter cover crops
- greater uptake of residual soil nutrients

Table 5.4 summarizes planting dates for various cover crops in different Southeastern regions. Optimal planting dates vary geographically as well as across latitudes within a geographic region. If cover crops are planted later than optimum, increase seeding rates to the maximum recommended rate to compensate for the reduced biomass due to the shorter growing season. Regional experts, such as the Cooperative Extension Service or NRCS, can make recommendations on planting dates for specific regions.

Fertilizing Cover Crops

As with cash crops, ensuring soil fertility and pH are within recommended ranges is essential for

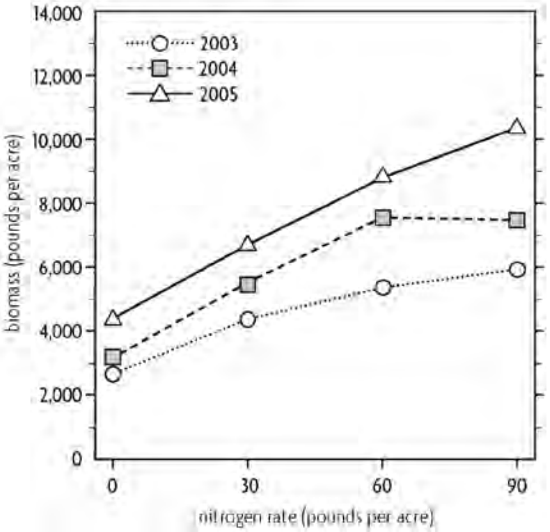

FIGURE 5.1. Rye biomass production following different nitrogen fertilization rates measured at the time of termination during the spring of three consecutive years at the Wiregrass Research and Extension Center in Headland, Ala.

optimizing cover crop biomass production and associated benefits. Nitrogen can be limiting for biomass production, particularly for grass cover crops. Most producers are reluctant to apply nitrogen fertilizer to cover crops due to the cost and the absence of a direct monetary return from the cover crop. Due to the inherent low fertility of many Southeastern soils, cover crops generally respond positively to 30–50 pounds of nitrogen per acre (Figure 5.1). Biomass increases of 50–100 percent with nitrogen fertilization are not uncommon, particularly on sandy soils (Figure 5.2). Growers who are new to cover crops may decide not to apply nitrogen fertilizer until they have more experience.

Cover crops should not be fertilized if your objective is nutrient scavenging. For soils with inherent fertility (i.e., soils with more than 2.5 percent organic matter or with a history of manure applications) or when following an extremely dry year with limited cash crop nitrogen uptake, additional nitrogen fertilizer is probably not needed and is not recommended. As cover crops decompose, their nutrients are released into the soil, but the availability of these nutrients does not always coincide with the following cash crop's needs.

Pests

Conservation tillage systems alter pest dynamics due in large part to residues left on the soil surface. Effects on the cash crop can be positive or negative. Cover crops impact disease and

TABLE 5.4. Recommended planting dates for several summer and winter cover crops across select states[1]

	ALABAMA [3]			GEORGIA [8]			TENNESSEE [4]	
Cover crop	North	Central	South	Limestone Valley	Piedmont	Coastal Plain	SPRING	FALL
SUMMER								
American jointvetch							Apr 15–July 1	
Buckwheat				Apr 15–June 15	Apr 15–June 15	Apr 15–June 15	May 15–Aug 1	
Chufa						May 15–June 30		
Clover alyce						May 15–June 15		
Cowpeas				May 1–June 15	May 1–June 15	May 1–June 15	April 15–July 1	
Lablab (hyacinth beans)							Apr 15–July 1	
Lespedeza (kobe), common				Feb 15–Mar 15	Feb 15–Mar 15		Feb 15–Apr 15	
Millet, browntop				May 15–Aug 1	Apr 15–Aug 1	Apr 15–Aug 15	May 15–June 15	
Millet, foxtail	May 1–Aug 1	Apr 1–Aug 15	Apr 1–Aug 15	May 15–Aug 1	Apr 15–Aug 1	Apr 15–Aug 15	May 15–June 15	
Millet, Japanese				May 15–Aug 1	Apr 15–Aug 1	Apr 15–Aug 15		

	ALABAMA [3]			GEORGIA [8]			TENNESSEE [4]	
Cover crop	North	Central	South	Limestone Valley	Piedmont	Coastal Plain	SPRING	FALL
SUMMER								
Millet, pearl	Apr 20–Jul 1	Apr 15–Jul 1	Apr 1–Jul 15			April 15–July 15	May 15–June 15	
Millet, proso	May 1–Aug 1	Apr 1–Aug 15	Apr 1–Aug 15	May 15–Aug 1	April 15–Aug 1	April 15–Aug 15		
Partridge peas					Mar 15–May 1	Mar 15–May 1		
Rhizoma peanuts						Dec–early March		
Sesame						May 15–June 15		
Sesbania						May 15–June 15		
Sorghum, forage	Apr 20–May 15	Apr 20–May 15	Apr 20–Jul 1				May 15–June 15	
Sorghum-sudangrass	May 1–Aug 1	Apr 15–Aug 1	Apr 1–Aug 15	May 15–Aug 1	April 15–Aug 1	April 15–Aug 15		
Soybeans							May 15–June 15	
Sudangrass	May 1–Aug 1	May 1–Aug 1	May 1–Aug 1	May 15–Aug 12	May 15–Aug 12		Apr 20–June 15	
Sunn hemp	Apr 1–Sept 1	Apr 1–Sept 1	Apr 1–Sept 15					
Teff grass							May 15–June 15	
WINTER								
Alfalfa				Aug 25–Sept 10	Sept 15–Oct 10	Sept 20–Oct 20	Mar 15–May 15	Aug 15–Sept 15
Barley	Sept 1–Nov 1	Sept 15–Nov 1	Sept 15–Nov 15	Sept 15–Oct 15	Sept 15–Oct 15			Sept 15–Nov 1
Black oats	n/a	n/a	Sep 15–Nov 1					
Caley peas (rough/winter)				Sept 15–Oct 30	Sept 15–Oct 30	Sept 15–Oct 30		
Canola	Aug 25–Oct 1	Sep 1–Oct 15	Sep 1–Oct 15					
Clover, arrowleaf				Aug 25–Sept 10	Sep 15–Sept 20	Sep 10–Oct 10		Aug 15–Oct 1

	ALABAMA [3]			GEORGIA [8]			TENNESSEE [4]	
Cover crop	North	Central	South	Limestone Valley	Piedmont	Coastal Plain	SPRING	FALL
WINTER								
Clover, ball	Sept 1–Oct 31	Sept 1–Oct 31	Sept 1–Oct 31					
Clover, berseem						Oct 15–Nov 1		
Clover, crimson	Aug 25–Oct 1	Sept 1–Oct 15	Sept 15–Nov 15	Aug 25–Sept 10	Sept 15–Sept 20	Sept 10–Oct 10		Aug 15–Oct 1
Clover, red	Sept 15–Nov 15 Feb 2–Apr 1	Sept 15–Nov 15 Feb 2–Apr 1	Sept 15–Nov 15	Sept 15–Oct 15	Sept 15–Oct 15		Feb 15–Apr 1	Aug 15–Oct 1
Clover, subterranean	Aug 25–Oct 1	Sept 1–Oct 31	Sept 1–Oct 31	Sept 15–Oct 10	Sept 15–Oct 10	Sept 15–Oct 10		
Clover, white (ladino)				Sept 15–Oct 15	Sept 15–Oct 15	Sept 15–Oct 15	Feb 15–Apr 1	Aug 15–Oct 1
Lupine (blue, white)	Aug 25–Oct 1 Apr 1–15	Sept 1–Oct 15 Apr 1–15	Sept 1–Oct 15 Apr 1–15	Sept 15–30	Sept 15–Oct 15	Oct 15–Nov 15		
Mustard	Aug 25–Oct 1	Sept 1–Oct 15	Sept 1–Oct 15					
Oats	Sept 1–Nov 1	Sept 15–Nov 1	Sept 15–Nov 15	Sept 15–Oct 15	Sept 15–Oct 15	Sept 15–Oct 15	Feb 20–Apr–1	Sept 15–Oct 1
Radish	Aug 25–Oct 1	Sept 1–Oct 15	Sept 1–Oct 15					
Rye	Sept 1–Nov 1	Sept 15–Nov 1	Sept 15–Nov 15	Sept 15–Oct 15	Sept 15–Oct 15	Sept 15–Oct 15		Aug 15–Oct 1
Ryegrass	Aug 25–Oct 1	Sept 1–Oct 15	Sept 15–Nov 1	Sept 15–Oct 15	Sept 15–Oct 15	Sept 15–Oct 15	Feb 20–Apr 1	Aug 15–Oct 15
Sweetclover				Sept 15–Oct 10	Sept 15–Oct 10		Feb 20–Apr 1	Aug 15–Oct 1
Triticale	Sept 1–Nov 1	Sept 15–Nov 1	Sept 15–Nov 15			Oct 15–Nov 15		
Turnips	Aug 25–Oct 1	Sept 1–Oct 15	Sept 1–Oct 15				Apr 15–June 1	Aug 15–Oct 1
Vetch, common					Sept 15–Oct 15	Sept 15–Nov 1		
Vetch, hairy	Sept 1–Oct 15	Sept 1–Oct 15	Sept 15–Nov 1	Sept 15–Oct 15 C	Sept 15–Oct 15	Sept 15–Nov 1		Aug 15–Oct 15
Wheat	Sept 1–Nov 1	Sept 15–Nov 1	Sept 15–Nov 15	Sept 15–Oct 15	Sept 15–Oct 15	Oct 15 –Nov 1		Aug 15–Nov 1
Winter peas	Sept 1–Oct 15	Sept 1–Oct 15	Sept 1–Oct 15	Sept 15–Oct 30	Sept 15–Oct 30	Sept 15–Oct 30		Aug 15–Oct 1

[3] Sources for each state are in bracketed numbers.

insect damage by releasing compounds that affect pests, but they can also serve as hosts to pests and beneficial insects. Conservation tillage systems with surface residues create a more diverse plant and soil ecosystem than the ecosystem created by conventional tillage systems.

Cover crops can be used to attract beneficial insects. One approach is to allow a live strip of cover crop to remain between crop rows to serve as an insect habitat and food source until the main crop is established. This approach resulted in one less insecticide application in conservation-tilled cotton compared to conventional cotton in south Georgia [11]. This approach may be limited in the Southeast because there may not be adequate soil moisture to fulfill the needs of both the cash crop and cover crop.

Cover crop residues have also been shown to reduce the incidence of several diseases by reducing the splash dispersal of organisms. Small-grain cover crops in a conservation tillage system have been shown to reduce peanut yield losses from tomato spotted-wilt virus (TSWV), with greater residue amounts resulting in lower incidence of TSWV. This benefit was directly related to a reduction in the population of thrips, the vector of TSWV [5].

Cover crops may harbor insects, diseases and nematodes harmful to the cover crop and future crops. Understanding the relationships and conditions that favor them helps minimize risks and improve management decisions. For example, cereal rye, orchardgrass and crimson clover attract armyworms. Clover root curculio, a pest common to red clover, attacks alfalfa. Chickweed attracts black cutworm or slugs, while Johnsongrass is a host to maize dwarf mosaic virus, which also infects corn.

Some cover crops serve as an overwintering host for nematodes and may increase nematode damage to the following crop. This problem can be worse when crops are grown continuously, such as cotton in some areas of the Southeast. However, crop rotation can alleviate these problems, while some cover crops, such as brassicas, can reduce nematode populations.

FIGURE 5.2. Rye biomass photographed in early March. Fertilizer was applied in fall to the rye on the left side, resulting in more biomass than the unfertilized rye on the right.

Cover crops may be adversely affected by carryover of herbicides applied to the previous crop. Read the herbicide label carefully or seek local expertise.

With the vast number of potential combinations of crops, cover crops and diseases, consult local experts and practitioners to ensure that selected cover crops will minimize the potential for pest problems.

TERMINATION OF COVER CROPS

Cover crop termination influences soil temperature, soil moisture, tillage, cash crop planting and weed suppression. It also affects the amount of nitrogen fixed by legumes or scavenged by grass as well as subsequent nitrogen release through cover crop decomposition and nitrogen uptake by the cash crop. In addition to the following information, Balkcom [2] published a management guideline to further assist growers in the Southeast in cover crop termination decisions to enhance crop productivity.

Timing of Cover Crop Termination

Due to complex interactions, the decision on termination timing must be site and situation specific, and should consider a number of factors [2]. A general rule is to terminate winter cover crops two to four weeks prior to the anticipated cash crop planting date. Table 5.5 summarizes the general effects expected following early termination or late termination.

The effects shown in Table 5.5 assume that the cover crop is suited to the climatic conditions and that the growing season is sufficient to produce adequate biomass. As a general rule, the minimum level of biomass needed to provide a good return on the investment of growing a cover crop is 4,000 pounds per acre, but lesser amounts can reduce erosion rates. Cover crop termination dates are often dictated by the target date for planting the subsequent cash crop. For example, early-planted corn (February through March) significantly shortens the cover crop growing season and eliminates the option of late termination. Consider planting the cash crop last on cover-cropped fields or using a shorter-season hybrid.

Terminating a cover crop two to four weeks before cash crop planting allows residues to dry out and become “brittle.” This enables planting equipment to easily cut through the residue. When cover crops are first terminated, the fresh, wet residue is harder to cut and can result in considerable dragging of residue by implements. In some cases, residue can become trapped in the seed furrow, a condition known as “hairpinning.” This reduces seed-soil contact, resulting in poor

TABLE 5.5. Effects of early and late cover crop termination timing

EARLY TERMINATION	LATE TERMINATION
Less biomass	More biomass
Increases time for replenishment of soil water	Higher soil moisture retention throughout the growing season
Early-season soil warming is enhanced	Cooler soils throughout the growing season
Reduces phytotoxic effects from decomposing residues	Weed control from shading and allelopathic compounds enhanced
Decreases survival of disease inoculum	Greater N contribution from legumes
Longer decomposition time for residue that improves some equipment operation	Cover crop reseeding enhanced, if applicable
Improves short-term N mineralization from low C:N ratio cover crops	Cover crop residue, particularly grasses, will persist for longer periods of time

seed germination. Allelopathic compounds are a bigger problem with hairpinning because they are much more concentrated in the seed-placement zone, especially for crops with small seeds like cotton. Allowing a two- to four-week period between terminating cover crops and planting cash crops enables the allelochemicals to dissipate before the cash crop is established.

A recent innovation by farmers in some parts of the United States includes "planting green," or seeding the cash crop into a living cover crop. A non-selective herbicide is used following planting but before the cash crop emerges to kill the cover crop. One advantage to planting green into a cereal rye cover crop is that the rye is still erect, which can reduce the potential for hairpinning. However, competition for soil moisture between the cover crop and emerging cash crop limits the feasibility of this practice across sandy soils of the Southeast.

Termination Method

Termination methods for cover crops can be chemical or mechanical, or a combination of the two. There are advantages to both approaches, and they are summarized here. In-depth information on terminating and planting into cover crops is in Chapter 9.

Chemical

Terminating cover crops with a non-selective herbicide is common because herbicides can be applied at any time or growth stage. In addition, most spray equipment allows coverage of a large number of acres in a short time to facilitate timely field operations. However, high-residue cover crops may lodge in many directions after chemical termination. This can negatively affect subsequent tillage or planter operations.

Mechanical

Mechanical roller/crimpers lay residues uniformly on the soil surface, parallel to the direction of planting. The residue forms a dense mat that aids in early-season weed control. Field operations (i.e., subsoiling and planting) are typically easier when residues are laid flat parallel to the direction of planting. Standing cover crop residue is more susceptible to wrapping around coulters, shanks or disks, which hinders field operations.

Roller/crimpers consist of a round drum with blunt blades mounted across the face of the drum. The traditional style consists of evenly spaced blades, but the spiral has become increasingly common because it produces less vibration. Several types of roller/crimpers have been developed, and many growers have modified existing designs to fit their situations. Roller/crimpers can be front mounted or rear mounted on tractors. Front-mounted roller/crimpers enable another implement such as the planter or sprayer to be mounted behind the tractor, which saves a trip across the field.

The roller/crimper kills the cover crop by breaking the stems, causing crop desiccation. The timing of the roller/crimper operation is critical if a grower is relying on it to terminate the cover crop. Delay using the roller/crimper until the cover crop is flowering or later, or it may not be successful. Consider this option especially if herbicides are not used in conjunction with a roller/crimper (e.g., organic growers).

Blunt blades are preferable to sharp blades because they crimp rather than cut the cover crop. Cutting or chopping results in the biomass being separated into two parts. The loose part can become oriented across the rolling direction and can cause hairpinning. If the material is crimped then it tends to lay flat in the direction of rolling, which reduces the tendency for plant material to wrap around the planter disks and shanks. When tall grasses are chopped, the lower portion of the plant may become erect in a short period of time and the benefits of rolling are lost.

Early roller/crimper designs had limitations primarily related to the speed and width of operation. Evenly spaced straight blades around the roller drum create vibration that is transferred to the tractor (and tractor operator), which dictates slower speeds. Curved or spiral blades on the roller/crimper drum enable the roller/crimper to stay in constant contact with the ground, thus allowing faster speeds and reduced vibration. Ideally, roller width should match planter width to avoid residues wrapping around coulters and disks on the planter. Due to design challenges with weight and transportation between fields, roller/crimpers are usually eight rows or smaller. Inventive growers have designed wider roller/crimpers that can be folded for transportation. Some pull-type rollers negate the need for a large tractor with a high-capacity, three-point hitch.

Integrating a roller/crimper with the planter allows producers to plant directly into a standing green cover crop. Charles Martin of Loysville, Penn., developed a roller attachment unit that is mounted directly in front of no-till planter units. The attachment is being manufactured and marketed by Dawn Biologic as the ZRX Electro-Hydraulic Roller-Crimper-Row Cleaner.[1] The design allows farmers to delay planting to get more growth out of a cover crop. The cover crop needs to be tall enough for the roller/crimper to be effective. Crimped and flattened cover crops can be chemically terminated a few days after planting, and farmers indicate they use less herbicide on the crimped and flattened cover crop. However, potential limitations previously mentioned for sandy soils should be noted. See tables 9.1 and 9.2 in Chapter 9 for a comparison of costs and effectiveness when terminating cover crops using a roller/crimper in combination with reduced herbicide application rates.

Another mechanical option for cover crop termination is mowing after the flowering stage. Flail mowers are preferred over rotary mowers because the residues are evenly distributed and are more uniform in length. Mowing terminates the crop quickly, but it is energy intensive and there is a possibility for regrowth depending on the species and time of termination. In the humid Southeast, mowed residues break down more rapidly, negating some of the benefits of keeping the soil surface covered. Chopping residue into small pieces adversely affects the performance of tillage and planting equipment. Coulters designed to cut through residue instead push small pieces of residue into the soil and then drag the residue through the soil.

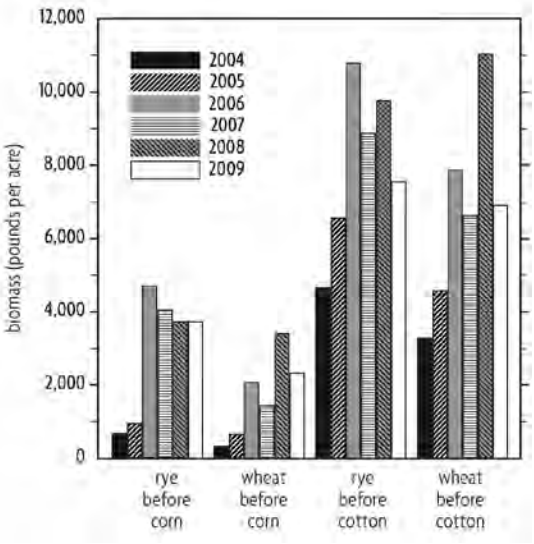

FIGURE 5.3. Biomass production for rye and wheat preceding corn and cotton over five growing seasons in Prattville, Ala.

Biomass Production

Time of termination significantly influences the amount of biomass produced. As expected, early termination reduces biomass production, while late termination promotes more biomass production. The planting date of the following cash crop dictates the termination time and also affects the biomass produced. Different cover crops produce different levels of biomass. See the dry matter information in Table 5.3.

Figure 5.3 shows differences in biomass production for rye and wheat preceding corn and cotton over five growing seasons in Prattville, Ala. Cover crops preceding corn need to be terminated about one month before those preceding cotton. The figure shows that biomass production preceding corn is always less than that preceding cotton and also shows that rye typically outperforms wheat.

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[1] The use of trade, firm, or corporation names, proprietary product, or specific equipment in this publication is made for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by USDA-SARE or by USDA-ARS (Agricultural Research Service), of any product or service to the exclusion of others that may be available.

The inherent variability in biomass production across growing seasons is also apparent and is similar to the variability in cash crop yields.

C:N Ratio—Persistence of Residue

The carbon-to-nitrogen ratio (C:N ratio) of the cover crop at termination influences whether nitrogen will be immobilized or released. In general, mineralization or release of nitrogen occurs when the C:N ratio is below 20:1, while immobilization or sequestering of nitrogen usually occurs when the C:N ratio is above 25:1. Cover crop residues with very high C:N ratios may also immobilize some soil or fertilizer nitrogen.

The C:N ratio of small-grain residues is dependent on its maturity. Early termination of grass cover crops results in a smaller amount of residue with a low C:N ratio typical of young plant tissue. This results in rapid decomposition and limited ground coverage. Killing small-grain cover crops after flowering results in significantly more biomass and a C:N ratio usually exceeding 30:1. Such residue will usually result in an initial, if not persistent, immobilization of nitrogen during the cash crop growing season. The nitrogen content of small-grain residues varies greatly but generally ranges 20–50 pounds per acre for the aboveground biomass and 8–20 pounds per acre for the root mass. Synchronizing the release of nitrogen from residues with the period of maximum cash crop uptake can be difficult. The nitrogen contribution to the following crop from small grains depends on nitrogen availability during cover crop growth, the total biomass produced, and the growth stage and C:N ratio at termination.

The C:N ratio of mature legume residues varies 9:1–25:l and is typically well below 20:1. The lower C:N ratio of legumes allows for rapid release of nitrogen but limits the persistence of their residues. Regardless of the C:N ratio of residues, surface residues decompose more slowly than incorporated residues.

COVER CROP INFLUENCE ON SUBSEQUENT CROP

Cover crops directly influence subsequent cash crops, such as when a legume provides nitrogen to the crop as it decomposes. They also indirectly influence subsequent cash crops by increasing soil organic matter, which affects water availability and nutrient cycling. In many cases, cover crops provide multiple benefits to cash crops that are enhanced as biomass production and years of cover crop use increase.

Effects on Soil Water

Cover crops use soil water while they are growing, which can negatively affect summer crop establishment if soil water is not replenished prior to planting. Short-term soil water depletion before cash crop planting may or may not be offset by soil water conservation later in the growing season. This is dependent on rainfall distribution in relation to cash crop development. Unger and Vigil [12] state that the “time of termination becomes more critical as the probability of precipitation decreases.” When soil moisture is depleted by a high-residue cover crop in the humid Southeast, a rainfall event can usually replenish soil water and can provide adequate water for cash crop establishment.

The most common practice to reduce the risk of early-season soil water depletion by cover crops is to desiccate the cover well ahead of planting the cash crop. For example, Munawar [9] and Wagger and Mengel [14] report that early-season soil water depletion can be reduced by killing the cover crop a minimum of two to three weeks before planting the cash crop. Once terminated, residues conserve soil moisture through reduced evaporation losses and increased infiltration. These factors increase the effectiveness of a rainfall or irrigation event by increasing efficiency of water use, thus reducing water requirements for the growing season. In irrigated systems, increased water-use efficiency can reduce the number of irrigation events and the total amount of water applied, resulting in reduced costs for diesel fuel or electrical power and preservation of water resources. These effects are most prevalent during short-term drought situations and would not be as effective under a prolonged drought situation.

Table 5.6 illustrates differences between three tillage systems following a simulated 2-inch rain. Conservation tillage combined with residue resulted in the highest infiltration amounts, which is equivalent to approximately one week of cotton water demand during the peak water use period. In contrast, because of runoff- and evaporation-related water losses in the conventional tillage system, the amount of water available only met approximately two days of cotton water demand under the same growing conditions.

Soil Temperature Fluctuations

In high-residue conservation systems, cover crop residues will reduce the amount of solar radiation reaching the soil surface. This results in cooler soils in the spring that are slower to warm up compared with conventionally tilled soils. Cover crop residues reduce daily fluctuations of soil temperature and reduce the difference between daily soil temperature maximums and minimums. The cooler soil temperatures benefit cash crops throughout the summer but can delay spring planting. Starter fertilizer applied at planting of a summer crop can sometimes offset the negative effects of cool, wet soil and delayed planting, but the cold and wet soils are the more critical factors affecting germination and early-season growth.

Delay Planting

The effect of reduced soil temperatures on crop growth is greater in northern areas of a crop's adapted zone. Residue removal from the zone of seed placement—by using row cleaners, for example, or in strip-till systems—will increase soil temperature in the seed zone and decrease the amount of residue that comes in contact with the seed. This results in better seed-soil contact and fewer allelopathic effects from residue on the developing seedling.

To optimize plant growth, summer crops should be planted according to soil temperature rather than calendar date. A delay in planting to let the soil warm up, especially with favorable growing degree days in the post-planting forecast, can eliminate associated stand establishment issues. For example, soil temperatures for cotton should be 65 degrees at seed-placement depth by 8 a.m., with the possibility of accumulating at least 50 growing degree days following planting to help ensure a good stand. A soil thermometer is easily obtained, practical and inexpensive. Use it in conjunction with local recommendations to guide planting dates for cash crops and to avoid cool, wet soil conditions that can persist with high-residue cover crops.

Starter Fertilizer

In nitrogen-limited soils, applying 25–50 pounds of nitrogen per acre as a starter fertilizer to cash crops following small-grain cover crops is a good management practice. Although yield increases from starter nitrogen applications are dependent on rainfall and crop, they occur frequently enough to justify the practice. Starter fertilizers can also benefit crops planted into high residue. Because soils beneath cover crop residue are typically cooler, nutrient availability is decreased. Early-season growth of the cash crop is almost always enhanced with starter fertilizers that contain nitrogen or a combination of nitrogen

TABLE 5.6. Tillage and residue effects on infiltration in a Southern Coastal Plain soil following a simulated 2-inch rainfall

Tillage treatment	Infiltration (percent)	Available water remaining (days)[1]
Conservation tillage with residue	95	5.4–7.6
Conservation tillage without residue	58	3.3–4.6
Conventional tillage; No deep tillage	28	1.6–2.2

[1] Based on a water use rate for a cotton crop during peak bloom (0.25 to 0.35 inches per day). Assumes no evaporative losses for illustrative purposes.

and phosphorus. Starter fertilizer promotes rapid canopy development, which reduces weed competition and may help offset the negative effects of cool, wet soils.

Starter fertilizers should be placed near the seeding row in a narrow band. Starters can be applied at the soil surface, but their effectiveness is increased if placed below the soil surface. The typical recommendation for placement of starter fertilizers is a two-by-two placement, meaning 2 inches to the side and 2 inches below the seed. Banding starters on the soil surface near the row is nearly as effective, especially if row cleaners are used when planting. Fertilizer materials may be liquid or solid. Take care not to over apply or place starter fertilizer too close to the seed as this could damage seedlings.

Cash Crop Fertilizer Management

Legume cover crops can add significant amounts of fixed nitrogen to a cropping system. The nitrogen content of legume cover crops and the amount of nitrogen available to subsequent crops is affected by:

- legume species and adaptation to specific soil and climatic conditions
- planting date
- residual soil nitrogen
- time of termination

Early establishment of legume cover crops (i.e., early planting, interseeding or natural reseeding) results in greater biomass production and nitrogen production. The nitrogen content of legume cover crops is optimal at the flowering stage, as much of the nitrogen in the plant is transferred to seed after this date. Typically, legume cover crops are terminated when about 50 percent of the legume cover is blooming. Legumes contribute 15–200 pounds of nitrogen per acre, with typical values of 50–90 pounds of nitrogen per acre. In North Carolina, delaying the kill date of crimson clover two weeks beyond 50 percent bloom, and hairy vetch two weeks beyond 25 percent bloom, increased the biomass of clover by 41 percent and vetch by 61 percent. Corresponding increases in nitrogen content were 23 percent for clover and 41 percent for vetch [13].

In almost all cases, legumes will begin releasing nitrogen as soon as they are terminated. Residue from young plants will have a low C:N ratio, which promotes quicker release of nitrogen. If there is not a cash crop actively growing soon afterward, that nitrogen could be lost and unavailable to the crop. Residue from mature legumes has a higher C:N ratio and is more resistant to decomposition, so the potential to synchronize nutrient release with cash crop uptake is greater.

Unless they are terminated when very young (before joint stage), grass cover crops typically have high C:N ratios, so they do not provide much nitrogen to the following crop and can actually consume nitrogen during the decomposition process. As a result, nitrogen rates for cash crops following a high-residue cereal cover crop should be increased 25–30 pounds of nitrogen per acre above the standard nitrogen fertilizer recommendations for the respective cash crop. The additional nitrogen should be applied early in the season, usually at planting. Over time, the use of high-residue cereal cover crops will increase organic matter content and may reduce nitrogen requirements in future growing seasons.

Mixtures or cocktails with both legume and grass components can help offset nitrogen immobilization by a mature grass cover crop or help reduce the likelihood of nitrogen loss following termination of a pure legume cover crop.

Disadvantages and Concerns

Despite the many positive attributes associated with cover crops, many growers are wary of high residue levels. They have concerns about field operations in the residue, soil moisture at planting and subsequent cash crop establishment. Cash crop establishment can be complicated if growers are unfamiliar with adjustments needed for planting equipment and how to manage high-residue systems. Possible causes of establishment problems:

- residue interference with planter operations, resulting in poor seed-soil contact
- soil water depletion
- wet soils due to residue cover

- reduction in soil temperature from residue cover
- allelopathic effects of residues
- increased levels of soil-borne pathogens
- increased predation by insects and other pests

One of the easiest ways to prevent potential problems is to desiccate the cover crop at least two to four weeks before planting the cash crop. However, terminating early will reduce the amount of biomass produced.

Cover crops may also reduce nitrogen-fertilizer efficiency in conservation systems, depending on the method of application. Surface applications of urea-containing fertilizers to soils with large amounts of residue can result in large losses of nitrogen. When applied on top of the cover crop residue, urea and urea-ammonium nitrate solutions volatilize more than ammonium nitrate and subsequently lose more nitrogen to the atmosphere. This is because urease, an enzyme present in soils and organic residues, reacts with urea and makes it unstable. This unstable form can quickly convert to ammonia and carbon dioxide and be lost to the atmosphere. Injecting urea-containing fertilizers into the soil eliminates volatilization losses. Banding urea-containing fertilizers reduces losses compared to broadcast applications because banding minimizes fertilizer and residue contact while increasing fertilizer and soil contact.

ECONOMICS OF COVER CROPS

Using cover crops increases production costs in both time and money. The cost of seed and planting along with the time associated with cover crop management can be a deterrent to using them. For example, growers need to adjust their schedule of operations to address both timely cover crop planting and termination. This adds to field operations when compared to conventional systems. However, costs associated with cover crop management may be offset by eliminating costs for certain inputs, such as nitrogen fertilizer or energy-intensive tillage operations. As a result, overall production costs could decrease by using cover crops, but costs versus benefits will vary across operations.

Depending on the system and the intended cover crop benefit, a return on investment may or may not be noticeable in the short term. For example, better water-use efficiency can reduce irrigation costs because residue on the soil surface improves water infiltration and reduces evaporation, and increased soil organic matter improves water-holding capacity, all of which increases plant available water. The increase in plant available water can sustain the crop during periods of short-term drought and can increase yield. This may eliminate a scheduled irrigation and thus save money. Many benefits associated with cover crop use, such as improved soil quality, are difficult to quantify in the short term, but ultimately improve the bottom line over the long term.

Factors affecting the economics of cover crops:

- cash crop grown
- cover crop selected
- time and method of establishment
- time and method of termination
- cash value applied to environmental protection, soil productivity and soil protection
- cost of nitrogen fertilizer and the nitrogen supplied by the cover crop
- fuel cost
- any increase or decrease in cash crop yield due to the cover crop

Input Costs

Cover crop seed costs vary considerably from year to year and from region to region. Legumes can cost up to twice as much to establish as small grains. The increased cost of legume seed can be offset by the value of nitrogen that legumes provide. Properly managed legume cover crops can be expected to supply at least 50 pounds of nitrogen per acre. On the other hand, a grass cover crop, such as cereal rye, terminated at a late stage of growth, may increase the cash crop's nitrogen fertilizer requirements by 25–30 pounds per acre. However, high-residue cereal cover crops can suppress weeds in the short term and can increase soil organic matter, and hence soil health, in the long term.

The Importance of Good Management

The benefits of cover crops are well known, but there are additional costs and time commitments required to ensure timely field operations that result in adequate biomass levels. The full benefits are realized only when you commit the time and attention that is required to manage a cover crop properly. If poor management results in no residue or minimal cover crop growth, the expense of planting a cover crop in the first place would be wasted. Poor management decisions can result in yield losses or cash crop failure. Therefore, when you assess the cost of using cover crops, you must account for the time you spend to manage them.

SUMMARY

Cover crops provide many benefits in conservation tillage systems. Many of the benefits are directly proportional to the biomass produced by the cover crops, which in turn is dependent on cover crop management. Management tips to enhance beneficial effects of cover crops:

- Maximize the cover crop's growing season by planting as early as possible in the fall and by terminating as late as possible in the spring.
- Use plants that are adapted to your local weather conditions.
- Consider using cover crop mixtures, which could include grasses, brassicas and legumes.
- Consider applying nitrogen fertilizer to small-grain cover crops to promote biomass production, or include legumes in a mixture.
- Terminate cover crops a minimum of two weeks ahead of the anticipated cash crop planting date to allow soil moisture to recharge and to reduce problems with allelopathy, pests, tillage and planting.
- Become familiar with cover crops by planting on a small area to learn how to manage both the cover crop and the subsequent cash crop.

RESEARCH CASE STUDY

Enhancing Sustainability in Cotton Production through Reduced Chemical Inputs, Cover Crops, and Conservation Tillage

Project Information

Project type: Research and Education Grant
Project number: LS01-121
Project dates: 2001–2004
Principal investigator:
Harry Schomberg
USDA-ARS (Georgia)
Project reports: https://projects.sare.org/sare_project/LS01-121/

Problem Statement

At the outset of this project, over 11.6 million acres in the Southeast United States was devoted to cotton production annually, of which only 13 percent was grown using conservation tillage. Prior research had demonstrated the beneficial role conservation tillage can play in reducing farm costs, which were achieved by improving the soil's productivity and capacity to store water. However, this research had a negligible impact on cotton producers' decision making, largely due to their perception that there were significant hurdles to overcome when implementing conservation tillage systems, including the cost of establishing such systems. Despite the best efforts of governmental conservation programs and local grower groups to respond to these concerns, national goals for conservation tillage adoption were not being met.

Hoping to encourage further adoption of conservation tillage practices, a team of USDA scientists investigated the effects of different cover crops on cotton production in a conservation tillage system. Their aim was to determine best production practices and to contribute to cotton producers' knowledge of sustainable agriculture methods.

Methods and Practices

The team began by using greenhouse experiments to identify cover crop mixes for cotton farming that would maximize biomass, increase biological diversity and minimize parasitic nematodes. On-farm studies were then held during the 2001 and 2002 growing seasons at farms near Louisville and Tifton, Ga. Scientists observed insect dynamics, soil microarthropods and plant parasitic nematodes under the different cover crop regimes.

The preliminary greenhouse experiments identified a legume blend of balansa clover, crimson clover and hairy vetch that best provided food for beneficial insects while increasing soil organic matter. The legume blend was one of the four cover crop treatments used in the on-farm study; other treatments were a legume blend plus rye, rye or crimson clover, and a no-cover-crop treatment. All four treatments were planted into mowed cotton stubble on 10-acre fields at each farm with a no-till grain drill. Weekly samples were collected for the cover crops and cotton in the spring and summer of each year. Insect population size and diversity were measured weekly, and microarthropods and nematodes were sampled at pre-plant, mid-season and after-harvest periods. This served as a measurement of biological diversity. Cotton biomass samples were collected from each of the four treatment fields periodically throughout the growing season. The effects of cover crops on soil carbon dynamics were found by measuring microbial biomass carbon and nitrogen, potential carbon and nitrogen mineralization, particulate organic carbon and nitrogen, and water-stable aggregates prior to cotton planting and after harvest.

Results

The results of this study indicated that the legume blend plus rye cover crop improved soil biological diversity and microbial diversity, while not clearly improving cotton biomass or yield. For both farms, cover crop biomass was found to be nearly two times greater in the legume blend plus rye treatment than in the legume blend or crimson clover treatments. The legume blend plus rye treatment also supported a more diverse above- and below-ground insect population. However, the effects of the legume blend plus rye cover crop on cotton yield were similar to the traditional (crimson clover) cover crop at the Tifton farm, while on the Louisville farm, no differences in yield were found between any of the cover crops. Similarly, differences in cotton biomass were statistically insignificant. The researchers also found no clear connection between cover crop treatment and declines in nematode populations, suggesting that farmers may be better off rotating a non-host crop (e.g., peanuts) to help in nematode reduction.

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CHAPTER 6

In-Row Subsoiling to Disrupt Soil Compaction

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Until the 1880s, agricultural vehicles were relatively light, horse-drawn and not particularly damaging to soils. Mass production of tractors began in 1902 [15] and these heavy vehicles caused excessive compaction, especially if operated across wet soils. In addition, integration of livestock grazing with crop management in conservation production systems showed that plant growth decreases as cattle traffic increases. Above-ground signs of compacted soils include ponding and erosion as well as decreased crop productivity. Below ground, compaction crushes soil pores, resulting in reduced rainfall infiltration, water-storage capacity and root growth.

At some distance below the soil surface, excessive forces from surface traffic combined with naturally occurring soil-profile formation can cause a layer of extreme compaction referred to as a hardpan. These dense layers restrict rooting within and below their depths. This limits root extraction of moisture and nutrients, resulting in reduced yields. Some hardpans occur naturally and are often caused by small silt and clay particles amassing in larger pore spaces between sand particles. The presence of all three particle sizes in problematic proportions can lead to reduced porosity and increased soil density.

Tillage is often used to disrupt compacted layers. Conventional deep tillage disrupts compacted soil layers but has negative effects because valuable crop residues are buried. In the 1960s, some considered residue a problem and felt burying it was desirable [14]. This is indicative of an era that valued a clean soil surface for unimpeded planting operations. At the time, most agriculturalists did not recognize that crop residue protects the soil from wind and water erosion. Excessive tillage was also responsible for decreasing soil organic matter over time throughout the soil profile, thus limiting water-storage and carbon-storage capacities. However, there are tillage strategies designed to disrupt soil compaction while minimally disturbing the soil surface and maintaining surface-residue cover.

This chapter reviews published research to illustrate that (1) soil compaction can be managed with deep tillage while conserving soil and water resources; and (2) even though deep tillage is an energy-intensive process, several steps can be taken to reduce fuel consumption. The conclusions drawn in the research reviews are applicable to the soil types, management strategies and other local conditions specific to the research project. Seek out local Extension professionals and others with knowledge of local practices when developing a farm plan.

SUBSOILING

Subsoiling is defined as non-inversion tillage below a depth of 14 inches [1]. Figure 6.1 shows an example of an agricultural implement that has been used for uniform disturbance of a soil profile to depths of 14–20 inches. Soils compacted from traffic, animals or natural processes benefit from subsoiling because the compacted zone is disrupted. Subsoiling creates larger pores that increase rooting and infiltration. The benefits of subsoiling depend upon many factors including soil type, soil management and vehicle management.

Much research has been conducted that provides evidence of the benefits of subsoiling. However, some research has shown no overall benefits to crop productivity. Reasons for the discrepancies include differences in equipment, climate, annual variations in weather, cropping systems, management practices and soil types.

The effect of subsoiling to a 15-inch depth was studied in sandy loams of South Carolina [12]. In this study, researchers found that subsoiling adequately disrupted the hardpan, reduced soil strength (see the sidebar, Determining the Depth of a Compacted Soil Layer), increased infiltration and increased rooting depth. Several other studies reported increased crop yields and reduced soil strength due to subsoiling [25]. However, most of these studies provided little crop management information, and it is assumed that conventional tillage practices were employed.

A four-year study on a sandy loam in Georgia evaluated the long-term effects of reducing soil strength by subsoiling to a depth of 14.2–15.0 inches [30]. It concluded that soil strength was reduced but that reductions were not detected after the second year. The use of a controlled-traffic system was recommended to increase the longevity of reduced soil strength. Another study showed that subsoiling down to 14.2 inches in a sandy loam in Georgia, along with irrigation, significantly increased grain yields [7].

IN-ROW SUBSOILING

In conservation systems, subsoiling is often conducted only in the row, instead of over the entire field. It is then referred to as in-row subsoiling (Figure 6.2). If adequate crop residue is left on the surface and if appropriate measures are taken to minimize residue disturbance, in-row subsoiling can be a valuable way to combat soil compaction. Large amounts of crop residues on the soil surface allow in-row subsoiling to be conducted without increasing runoff or soil erosion. To maximize the amount of crop residue on the soil surface, maximize cover crop growth and eliminate reduced and intensive tillage practices that

FIGURE 6.1. V-frame subsoiler used for soil disruption over the entire field. The shank spacing and depth are adjustable.

DETERMINING THE DEPTH OF A COMPACTED SOIL LAYER

Soil strength is a measure of a soil's resistance to penetration. As a soil becomes more compacted, soil strength and the soil's resistance to penetration increase. Soil strength is measured with a penetrometer, and the measurements are used to evaluate the depth and thickness of a compacted subsoil layer or hardpan. Penetrometer readings, referred to as cone index values, are shown in pounds per square inch (psi) on the penetrometer gauge (Figure 6.7). As compaction increases, cone index values increase and resistance to root growth increases. When cone index readings approach 290 psi, root growth is restricted [29].

A penetrometer consists of a circular, stainless steel cone with a driving shaft and a pressure gauge. The penetrometer usually comes with two cones: a three-quarter-inch cone for soft soils and a half-inch cone for hard soils. The driving shaft is usually graduated every 3 inches so the penetration depth can be easily determined.

To take penetrometer measurements, drive the shaft into soil at a rate of approximately 1 inch per second. Record the depth at which the 290 psi cone index is reached. This level is the top of the compacted zone. Continue pressing down the penetrometer. Record the depth at which the cone index value falls below 290 psi. This is the bottom of the compacted zone. If cone index values do not reach 290 psi, there is not a compacted layer. If cone index values increase above 290 psi but never fall below 290 psi, the compaction zone does not end within the depth of measurement, which is determined by the penetrometer design.

Take penetrometer readings when the whole profile is at field capacity, approximately 24 hours after a soaking rain for sandy soils and as much as four to five days for clayey soils. If the soil is too wet or muddy, compaction could be underestimated because the soil acts as a liquid. If the soil is too dry, compaction could be overestimated since penetration resistance increases as the soil dries out.

Consider tillage relief, wheel tracks, plant rows and other recognizable patterns in the field to determine where to take penetrometer readings. For example, if vehicle traffic is limited to certain areas, take transects in and out of the wheel tracks. If there are subsoiled zones in the field, measure penetration resistance in and out of the subsoiled zone. If there are planted rows, take measurements in and between the rows. Take separate readings for trafficked and non-trafficked areas. See figures 6.3 and 6.4 for examples of how cone index values can vary across a field under different conditions.

In the absence of vehicle traffic patterns or other patterns in the field, start with some preliminary readings at a few places to develop a sampling strategy. Take one reading every 100 to 150 feet, or three to four readings per acre. It is useful to compare the cone index values in the field with those in undisturbed areas.

After completing the sampling, a recommendation can be formulated using the table below. The measurement of the lower boundary of the compaction zone determines the depth of subsoiling. If in-row subsoiling is recommended, run the subsoiler 1 inch below the compacted zone.

INTERPRETATION OF PENETRATION RESISTANCE MEASUREMENTS

Percentage of measuring points having cone index >290 psi in top 15 inches	Compaction rating	Subsoiling recommended?
<30	Little to none	No
30–50	Slight	No
50–75	Moderate	Yes
>75	Severe	Yes

Adapted from: Lloyd Murdock, Tim Gray, Freddie Higgins, and Ken Wells, 1995. Soil Compaction in Kentucky. Cooperative Extension Service, University of Kentucky, AGR-161.

FIGURE 6.2. In-row subsoiling with heavy cover crop residue. Very little residue is buried or disrupted while in-row subsoiling.

bury crop residues.

The longevity of in-row subsoiling effects on a loamy sand in South Carolina was studied by tilling down to depths of 20 to 24 inches [10]. One year after subsoiling, signs of the previous year's tillage were evident, but the soil strength had increased to between 220–360 pounds per square inch (psi). This soil strength is considered limiting to root growth. Annual subsoiling of all agricultural soils in the southeastern Coastal Plain was and is still recommended.

In a two-year study in Alabama, in-row subsoiling gave different results on two soil types [31] when compared to no subsoiling. On a sandy loam, with a hardpan at an 8-inch depth, annual in-row subsoiling was conducted prior to planting by pulling a shank through the soil to a depth of 12 inches. On a silt loam with no hardpan, in-row subsoiling was conducted to an 8-inch depth prior to planting. For the sandy loam soil, in-row subsoiling produced the highest cotton yields for both years of the study. For the silt loam, significantly higher yields for in-row subsoiling only occurred in the first year of the study.

In-row subsoiling on a loamy sand in South Carolina was studied for two years [9]. Three subsoilers were used: Brown-Harden Super Seeder (Ozark, Ala.), Tye paratill (currently manufactured by Bigham Brothers Inc., Lubbock, Texas) and Kelly Manufacturing Company subsoiler (KMC, Tifton, Ga.). Soil strength was evaluated with and without conventional disking. All three implements effectively disrupted compacted subsoil. Corn stand establishment was less (67 percent) when disking was not used than for the disked treatment (92 percent), though the reduced stand did not significantly affect yield. Since the study, stand establishment problems with reduced tillage have been eliminated with improved no-till or reduced-till planters and drills.

The use of a paratill, a type of in-row subsoiling implement, was evaluated on a clay soil in Georgia [13]. Grain sorghum was no-till planted into wheat residue each year of a three-year study. Six shanks with equal spacing of 24 inches were pulled approximately 12 inches deep during the fall after harvesting sorghum. The tillage treatment was evaluated for its effect when completed every year, every other year, or once every three years. Soil strength increased significantly in the 5.5–8.3 inch depth range as the frequency of paratill use decreased. This indicates that in this soil subsoiling may need to be performed on an annual basis, though yields among treatments were not significantly different.

The effect of in-row subsoiling was evaluated on a silt loam in northern Alabama, as well as on a sandy loam and a sandy-clay loam in central Alabama [17]. In-row subsoiling to a depth of 15 inches was conducted with a deep-fertilizer applicator [33]. For the sandy loam, a 22 percent increase in cotton yield occurred over all three years of the study when compared to treatments without subsoiling on the same soil type. For the other soil types, no significant yield benefit was found with in-row subsoiling.

A controlled-traffic system was used to evaluate the effect of fall in-row subsoiling in a Mississippi clay soil [28]. In-row subsoiling was conducted after harvest with a parabolic subsoiler to a depth of 15.7 inches on 20-inch centers. Cotton row spacing was 40 inches. With no irrigation, yield increases averaged 15 percent with in-row subsoiling. With irrigation, yield increases averaged 8 percent. Yield was probably higher in non-irrigated plots because subsoiling increased water availability. When soybeans were grown instead of cotton in this same experiment, yields in non-irrigated treatments were 73–132 percent higher in three out of four years when compared to non-irrigated treatments using a disk harrow followed by a disk cultivator [34].

The relationship between soil strength and cotton yield was studied in a controlled-traffic system on a loamy sand in South Carolina [8]. In-row subsoiling to a depth of 16 inches with a KMC subsoiler was compared to no in-row subsoiling on plots with no surface tillage and with surface tillage using a disk to 15-centimeter depths. Soil strength was reduced by subsoiling and coincided with increased root growth. However, subsoiling did not influence cotton yield so it may not be necessary on an annual basis for cotton grown in traditional wide-row management, meaning row spacing of 36 inches or more. The positive effects of a rye cover crop were also noted, although they did not increase yields. The positive effects included increased soil water content, reduced soil erosion, reduced leaching of nutrients and increased organic matter.

A study on an Alabama sandy loam measured the effect of five years of in-row subsoiling and controlled traffic [21]. One of the initial tillage treatments used a Deere & Co. (Moline, Ill.) V-frame subsoiler (Figure 6.1), operating on 10-inch centers, to completely disrupt the soil profile down to a depth of 20 inches. Another tillage treatment used a KMC in-row subsoiler to a depth of 16 inches prior to planting. Traffic was eliminated on half of the plots using an experimental wide-frame tractive vehicle that can span a distance of 20 feet. Results from this study showed that when in-row subsoiling was used on an annual basis, re-compaction caused by traffic did not affect crop yields (Figure 6.3). Root growth is restricted when soil strength is in the range of 290 psi or greater. The advantages normally attributed to controlled traffic did not materialize due to the annual disruption provided by in-row subsoiling. Another study that used the same tillage treatments concluded that when traffic was not controlled, the plots that received the initial complete disruption treatment with the V-frame subsoiler re-compacted to levels similar to plots that had never been subsoiled (Figure 6.4) [20]. This may be due to vehicle traffic exposing loosened soil to extreme forces causing additional compaction.

An experiment on an Alabama silt loam was conducted to compare in-row subsoiling with a paratill [26] to a depth of 18 inches and with a KMC subsoiler to a depth of 17 inches. Results from this experiment indicated that both forms of in-row subsoiling in the fall resulted in the highest seed cotton yields: 16 percent greater on average than conventional tillage and 10 percent greater on average than strict no-till. Both subsoiling treatments significantly reduced compaction, which contributed to the increased seed cotton yields.

Rainfall infiltration and runoff were evaluated on the same plots used for the study in the previous paragraph [30]. Fall and summer rainfall simulation experiments measured infiltration and runoff at the end of one and two hours of simulated rain-

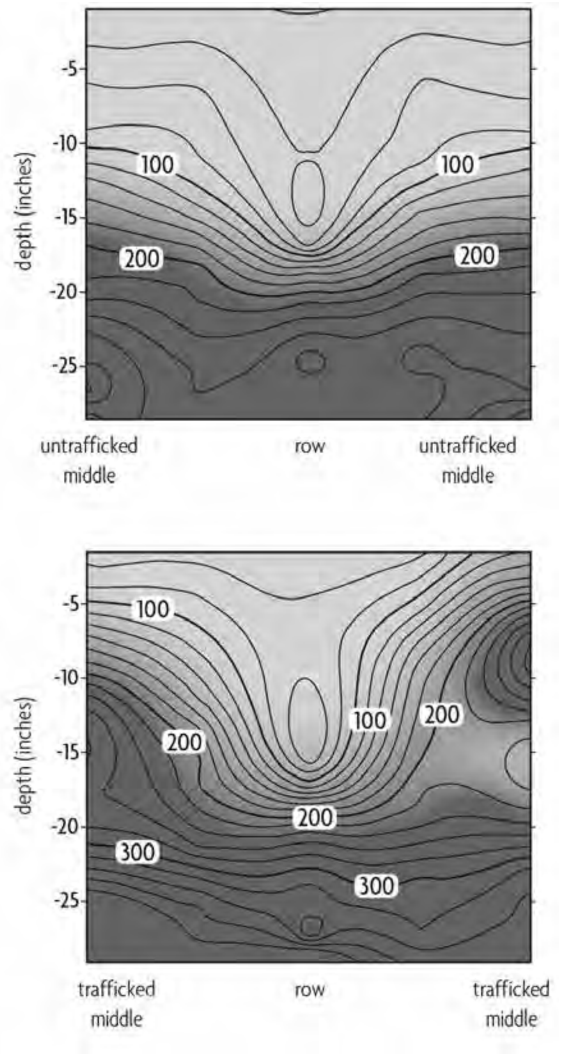

FIGURE 6.3. Cone index isoprofiles (pounds per square inch) showing the effect of annual in-row subsoiling without traffic (left) and with traffic (right). Soil strength values in the range of 290 pounds per square inch or greater restrict root growth [20].

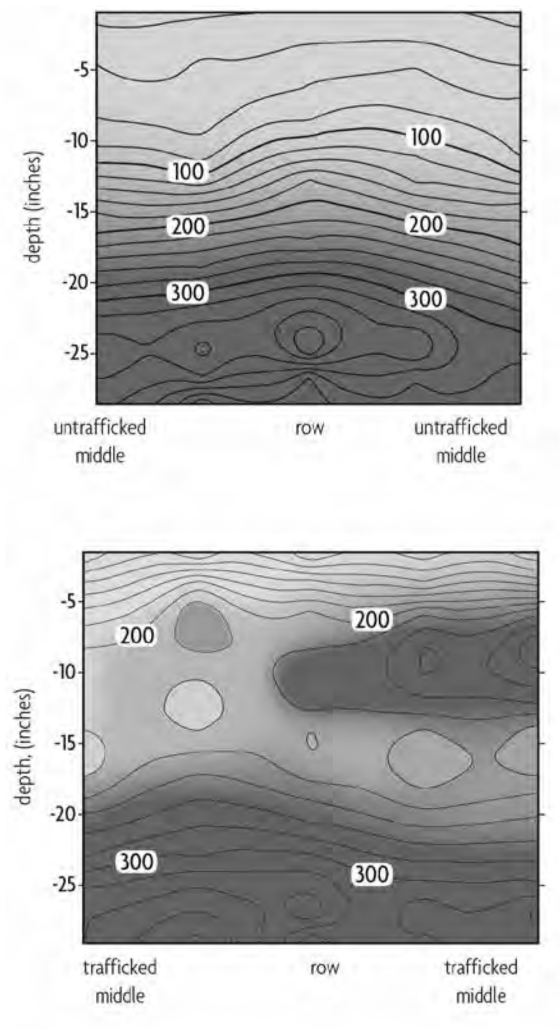

FIGURE 6.4. Cone index isoprofiles (pounds per square inch) showing the effect of the complete disruption conducted five years earlier without traffic (left) and with traffic (right). Soil strength values in the range of 290 pounds per square inch or greater restrict root growth [20].

fall. In-row subsoiling with the paratill influenced runoff and soil loss more than surface cover. The plots with no surface tillage, meaning no disking or chiseling, and an off-season rye cover crop had 3.4–10 times less runoff if they were paratilled (Figure 6.5). Similarly, conventional or clean-tilled plots had 1.5–5.4 times more soil loss than those that retained surface cover, even if they were subsoiled. A no-till system combined with the use of a paratill implement in the fall and a rye winter cover crop was recommended for the Tennessee Valley region as the best system to increase infiltration and plant-available water while reducing runoff and soil loss.

One of the few studies involving in-row subsoiling in pastures evaluated the use of a paratill and an Aerway (Wylie, Texas) pasture renovator in Alabama on a sandy loam [27]. These methods of renovation tillage effectively loosened the compacted soil and caused an increase in dry matter production. The effects of each in-row subsoiling method were still evident after one year.

One of the major reasons to in-row subsoil is to extend rooting depth into the soil profile where additional soil moisture is readily available. However, if moisture is made available to the plants by other means such as irrigation or frequent rainfall, it is possible that subsoiling will have little effect. This hypothesis was verified in a study examining a Coastal Plains sandy loam [11].

The four-year experiment examined three crop rotations, two tillage treatments and three water-management treatments. The rotations were corn>corn, corn>soybean, and soybean>corn. The two tillage treatments were in-row subsoiling and no in-row subsoiling. The three water-management treatments were rainfed, irrigation, and irrigation with nitrogen fertilization via fertigation. For the irrigated treatments, corn yields were 8–135 percent greater than rainfed treatments all four years, and soybean yields were greater three of four years by 26–31 percent. In-row subsoiling increased corn yields only two out of the four years by 4–6 percent.

REDUCING IN-ROW SUBSOILING EXPENSES

Planning budgets for 2011 estimated the total cost of using a four-row subsoiler to be $31.73 per hectare ($12.85 per acre) [16]. A third of this cost, $10.82 per hectare ($4.38 per acre), was for fuel. Wherever in-row subsoiling is needed, reducing the cost emerges as the most likely method of reducing the overall cost of crop management.

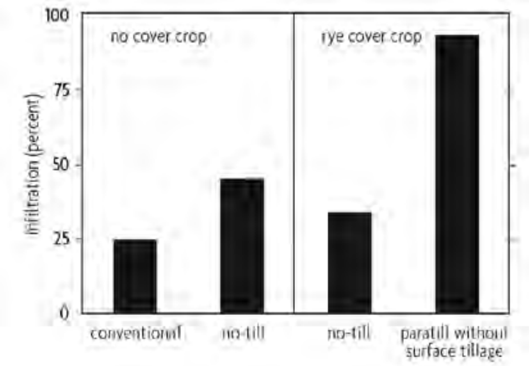

FIGURE 6.5. Percent infiltration measured during the second hour of simulated rainfall on an Alabama silt loam with and without cover crops [32].

Below, four strategies are described to reduce energy consumption during in-row subsoiling. Using all four of the strategies can reduce fuel consumption by more than 50 percent with the actual reduction dependent on your local conditions [19].

Adopt Controlled Traffic

Controlled-traffic systems limit vehicle traffic to certain areas of the field. When in-row subsoiling is used, controlled traffic keeps tractor wheels off the rows. This ensures that future in-row subsoiling events align with previous events and that the shanks will not be required to disturb excessively compacted soils such as occurs under wheel tracks. This minimizes the draft force needed for subsoiling since less energy is needed if the soil has been previously disrupted. When new rows in a controlled-traffic system are located close to rows from previous years, in-row subsoiling has longer-lasting effects. A study of a cotton cropping system evaluated the effect of annual, biennial and triennial in-row subsoiling on soil compaction in an Alabama silt loam over a four-year period. The study found that annual in-row subsoiling reduced bulk density compared to biennial and triennial in-row subsoiling, but there was no significant difference in cotton lint yields [23]. It was determined that a 9 percent reduction in draft force translated to a 6 percent reduction in fuel use [19]. Controlled traffic can reduce severe compaction, making it possible to in-row subsoil less frequently than once per year.

Subsoil When Soil Moisture is Optimum

Soil strength, and therefore the energy needed for subsoiling, varies considerably with moisture content. An extremely dry soil can increase the energy required for subsoiling and therefore increase fuel costs [19]. The effect of moisture content on subsoiling energy and soil disruption was evaluated on a sandy loam in a soil bin at the USDA-ARS National Soil Dynamics Laboratory

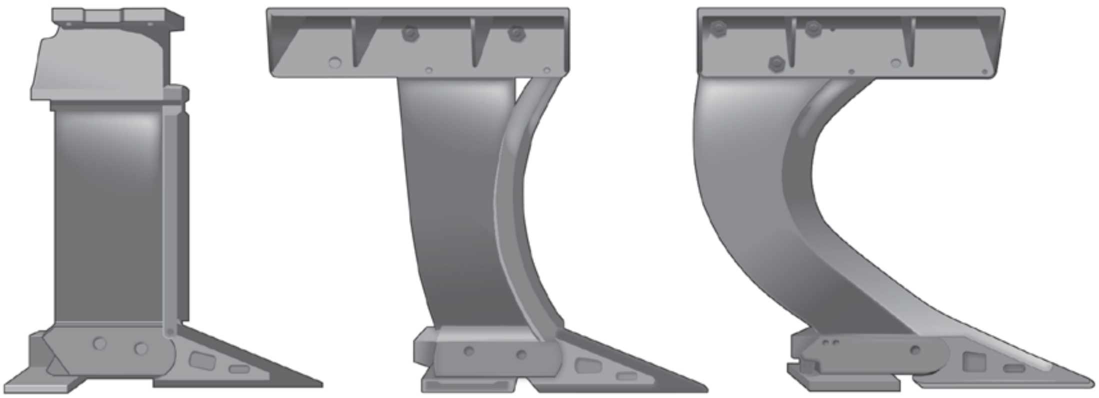

FIGURE 6.6. Subsoiler shanks used in studies to evaluate the effect of curvature on subsoiling forces. The shank with the most curvature had the lowest draft force and best fuel efficiency [18].

(NSDL) in Auburn, Ala. [24]. A 28 percent reduction in draft force was noted for a soil at field capacity compared to an extremely dry soil. This means that an estimated 19 percent reduction in fuel use could be obtained by avoiding operating in extremely dry soil [19]. On the other hand, vehicle traffic on extremely wet soils leads to compaction and the need for future deep tillage. Soil moisture conditions will depend upon soil type, weather and climate.

Choose the Right Shanks

The size and shape of shanks used for in-row subsoiling varies. As far back as 1958, the shape of subsoilers has been studied to determine their effectiveness (Figure 6.6) [18]. More recently, several experiments have been conducted in soil bins at the NSDL to determine the most efficient shank for both soil disruption and minimal surface-residue disturbance. Based on soil bin experiments, choosing the right shank can lead to an average reduction in draft force of 32 percent, which translates to a 15 percent fuel savings [19]. For example, a bent-leg shank gauged to disrupt only at the compacted soil depth is efficient at both disrupting the subsoil and minimizing surface residue disturbance.

Reduce Subsoiling Depth

Subsoiling at depths greater than necessary requires significant additional energy and may reduce crop yields while excessively disturbing crop residue on the soil surface. Additionally, loosening the soil deeper than necessary can allow vehicle traffic weight to penetrate deeper into the soil and cause additional compaction. Base the depth of in-row subsoiling on measurements of soil compaction (see the sidebar, Determining the Depth of a Compacted Soil Layer). Southeastern soils are especially variable, and knowledge about the field's variability allows for shallower or variable subsoiling depths, which will save fuel.

Soil cone penetrometer (Figure 6.7) readings of 290 psi or greater are used to locate the start and end depth of the hardpan (see the sidebar, Determining the Depth of a Compacted Soil Layer). The lower boundary of the hardpan determines the depth of subsoiling. An experiment in southern Alabama over four years evaluated whether tilling just deep enough to eliminate the hardpan layer would reduce tillage draft force requirements and reduce crop yields [22]. The depth of tillage varied from 10 to 18 inches. Corn and cotton crop yields were not reduced, but draft force was reduced by an average of 41 percent compared to deeper subsoiling. This translated into a fuel savings of 14 percent [19].

SUMMARY

Even though it is possible to subsoil a field to remove compaction, exercise care before performing this expensive operation. Use a soil penetrometer to determine when and where subsoiling is

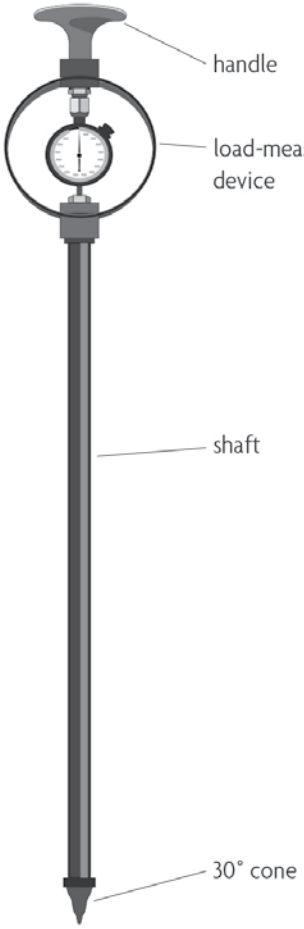

FIGURE 6.7. Soil penetrometer.

needed. Subsoiled soil easily re-compacts with vehicle traffic. Research indicates that two passes of a tractor in the subsoiled area will cause the soil to return to the level of compaction prior to subsoiling [6]. Use controlled traffic because traffic can compact soil and quickly undo the positive effects of subsoiling. When traffic was not controlled for five years, plots that had initially been completely disrupted were re-compacted as if they had never been subsoiled [20]. If traffic is controlled, however, the benefits of subsoiling to crops and soils can be long lasting.

This brief review proves that in-row subsoiling can loosen compacted soil profiles, increase infiltration, reduce runoff and, in many cases, increase crop yields throughout the Southeast. However, in-row subsoiling is an expensive field operation requiring large amounts of fuel. Following the energy conserving suggestions is this chapter can reduce the energy needed for in-row subsoiling by as much as 54 percent, based on cost information from 2011.

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CHAPTER 7

Cash Crop Selection and Rotation

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The crops commonly grown in the Southeast United States do well in the humid, temperate climate and low-organic-matter soils predominant in the region. Yields and soil quality are improved when these crops are part of a rotation. Production practices such as timing, tillage, pesticide application, irrigation and cover crops will vary based on cash crops in the rotation. Cover crops may include a single species or a mix of species. Common cover crops include grasses for nutrient scavenging and carbon addition, brassicas with deep taproots to break up hardpans, and legumes to add nitrogen.

This chapter discusses cash crop selection and crop rotations in the Southeast. Table 7.1 lists the crops grown in the Southeast from highest acreage to lowest. In this chapter, Southeast refers to the states represented in Table 7.1: Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Tennessee and Virginia.

TABLE 7.1. Common crops grown in the Southeastern[1] United States ranked by acreage planted in 2016

Rank	Crop	Acreage[2] (acres)	Value of Production ($1,000,000)
1	Soybeans	7,131,000	$2,783
2	Hay, all types	6,387,000	$1,713
3	Corn[3]	4,315,000	$2,110
4	Cotton	2,860,000	$1,807
5	Winter wheat	1,590,000	$321
6	Peanuts, all types	1,321,000	$794
7	Vegetables[4]	345,800	$1,978
8	Tobacco, all types	236,160	$943
9	Rye	200,000	$4
10	Oats	147,000	$10
11	Sweet potatoes	128,000	$464
12	Sorghum[3]	78,000	$11
13	Sweet corn	64,600	$242
14	Barley	33,000	$2

Source: [22]

[1] The Southeastern United States includes Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Tennessee and Virginia. Acreage and production value are the total for these states.
[2] Data is for acreage harvested.
[3] Value of production for corn and sorghum is for grain.
[4] This represents the sum of the 34 major vegetables grown in the Southeast, which varies by year.

When selecting crops and planning rotations, use strategies that mitigate the causes of yield reductions. The book *Farm Management*, published in 1918 [24], listed these main causes of reduced productivity:

- Fertile surface soil is carried away by wind or water erosion.
- Soil no longer has the water-holding capacity to supply plant needs.
- Soil ceases to provide a favorable environment for soil organisms.
- Nitrogen is carried away in drainage water.
- Monoculture cropping exhausts the available supply of plant nutrients.
- Organic matter is lossed: the most frequent cause of decreased yields.
- Alkali accumulates in the soil: a common reason for reduced yields in arid regions.

The same soil quality and crop production issues are at the forefront of agriculture today and need to be considered for optimal yield and environmental sustainability. Fortunately, problems in the Southeast, such as decreased crop yields and degraded soils, can be overcome with conservation agriculture systems, integrated nutrient and pest management, new technology and better crop selection.

CROP ROTATIONS VERSUS MONOCULTURE

Crop rotation systems are superior to the monoculture production systems that dominated the Southeast during the "cotton boom" from the mid-1800s to the 1920s. Monoculture systems grow the same crop in the same field year after year. Often, these systems dominate when one crop has greater profit potential than others that thrive in the same soils and climate. However, overtime, monoculture systems reduce yields and profit by aggravating existing problems with insects, weeds and disease, and by mining fertility.

Fungal diseases and nematodes are major causes of yield reduction in monoculture systems [6]. For instance, gray leaf spot (*Cercosport zeae-maydis*), a fungal disease, causes yield reductions in no-till corn because infested corn residue retains infection from year to year [20]. Similarly, insect-pest pressure increases because the same host plant is present each year. Weed resistance to pesticides increases because of the limited number of pesticides available for one crop [6].

Crop rotation has been practiced successfully for centuries. Rotations documented in ancient Roman literature included combinations of cereal crops, legumes and olive trees [25]. The Romans concluded that with proper crop rotations, a piece of land could be farmed productively year after year without ever going fallow.

In the late 1800s, long-term studies of crop rotation were started for research and education in the United States. An example is the "Old Rotation" located in Auburn, Ala. and established by the Alabama Agricultural and Mechanical College, now Auburn University. The Old Rotation studied and compared various crops and production practices common in the Southeast. The project generated more than a century of valuable research and experience that clearly demonstrates the benefits of rotations for a variety of crop sequences [14]. For example, soil quality and crop yield improvements were documented for alternating corn and cotton in a rotation and for adding a legume winter cover crop.

The benefits of crop rotation systems as compared to monoculture systems fall into four broad categories [14, 3]:

1. Insects and disease pathogens do not multiply because the host crop is not present each year in the crop rotation. Although the pathogen or insect might still be present, its reproduction is decreased or ceases when the host plant is not present.
2. Weed control is improved. The herbicides recommended for weed control vary based on the crop, so crop rotation results in more herbicide options that reduce the chance weeds will become resistant to a pesticide. Choosing pesticides

with different modes of action counters weed resistance. See Chapter 11 for more information on herbicide groups and weed resistance. As of August 2016 in the United States, 80 weed species have developed tolerance to at least one herbicide group. One common chemical group, acetolactate synthase (ALS) inhibitors, has 49 resistant weeds [11]. Many resistant weed species are prevalent in the Southeast, including Palmer amaranth (*Amaranthus palmeri*), Italian ryegrass (*Lolium multiflorumi*) and Common cocklebur (*Xanthium strumarium*).

3. The need for fertilizer is reduced or fertilizer-application timing changes. Within a rotation, one crop provides nutrients for other crops, reducing the total amount of fertilizer needed. For instance, when a legume is followed by a grass, the legume provides nitrogen for the grass. Likewise, a legume will not need phosphorus fertilizer if the phosphorus is added to the preceding grass crop and is readily available to the legume as the grass decomposes.

4. Soil organic carbon increases over time. Research from the Old Rotation compared monoculture cotton (*Gossypium hirsutum*) with no winter cover except cotton stubble to a crop rotation of cotton and a winter-annual-legume cover crop. The soil's organic carbon concentrations were doubled with the cotton>legume rotation [14].

The Old Rotation also compared a monoculture cotton system with a two-year cotton>winter-legume cover crop>corn rotation. Soil organic car-

TABLE 7.2. One-, two-, three- and four-year cash crop rotations common in the Southeast with winter cover crops[1]

YEAR 1		YEAR 2		YEAR 3		YEAR 4	
Summer	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
corn	wheat[2]	soybeans	cover crop	corn	wheat	soybeans	cover crop
corn	cover crop	soybeans	cover crop	corn	wheat	soybeans	cover crop
cotton	cover crop	cotton	cover crop	cotton	cover crop	cotton	cover crop
cotton	wheat	soybeans	cover crop	cotton	cover crop	cotton	wheat
cotton	cover crop	corn	cover crop	cotton	cover crop	cotton	cover crop
cotton	cover crop	corn	cover crop	peanuts	cover crop	cotton	cover crop
peanuts	wheat	soybeans	cover crop	corn	cover crop	peanuts	wheat
peanuts	cover crop	cotton	cover crop	peanuts	cover crop	cotton	cover crop
peanuts	cover crop	cotton	wheat	soybeans	cover crop	peanuts	cover crop
peanuts	cover crop	corn	cover crop	tobacco	cover crop	corn	cover crop
peanuts	cover crop	corn	wheat	soybeans	cover crop	corn	cover crop
rice	fallow	soybeans	cover crop	soybeans	fallow	rice	fallow
soybeans	cover crop	soybeans	cover crop	soybeans	cover crop	soybeans	fallow
soybeans	wheat	soybeans	wheat	soybeans	wheat	soybeans	wheat
tobacco	wheat	soybeans	cover crop	tobacco	wheat	soybeans	cover crop

[1] Traditional rotations leave the fields fallow instead of using cover crops.
[2] When wheat is included as a winter crop, it means wheat for grain.

bon was similar to the monoculture cotton system with cover crops: 1.0 percent versus 0.9 percent, respectively. However, when a third crop, soybeans, was added to develop a three-year rotation of cotton>winter-legume cover crop>corn>rye cover crop (*Secale cereal*)>soybeans, the highest concentration of organic carbon was measured: 1.2 percent. Of the rotations studied, this three-year rotation with legume and grass cover crops gave the most benefit for building soil organic matter. Soil organic matter provides the basis for improving soil structure and overall soil tilth.

Table 7.2 shows common cash crop rotations in the Southeast with cover crops incorporated over a four-year rotation. Traditional low-residue rotations leave fields fallow in the winter with only cash crop residue on the soil surface. Cover crops can be added into otherwise fallow areas of the rotation to offer additional biomass for sequestering carbon and protecting soil from erosion.

The first line of Table 7.2 shows one of the most common four-year rotations in the Southeast: corn>winter wheat>double-crop soybeans>-cover crop>corn>winter wheat>double-crop soybeans>cover crop. When wheat is listed in the table as a winter crop, it refers to wheat harvested for grain. Winter wheat provides excellent winter cover and adds valuable plant biomass for soil building if straw is left in place rather than harvested or burned. The cover crop selected will be influenced by the needs of other crops in the rotation, the farm's long-term goals for improving soil characteristics and reducing erosion, and the time available for cover crop growth. Table 5.3 includes information concerning the seeding rate, seeding depth, dry matter production and more for several cover crops common in the Southeast.

CROP SELECTION DECISIONS

The characteristics of the farm and region determine the cash crops and cover crops that can be successfully grown. Climate, soils, markets, government programs and producer preferences all influence the crops selected. Choosing the right crops and rotations will foster economic and environmental sustainability [4].

Climate

Climate is the long-term average rainfall, maximum and minimum temperatures, and temperature variations throughout the year. The United States is divided into four climate zones: a cold humid northern region, a warm humid southern region, a cold arid northern region, and a hot arid southern region [4]. Within these regions, the climate varies based on latitude, elevation and other site-specific factors.

Climate determines the crops that can be grown due to both growing-season factors and its long-term effect on soils. It influences crop yields through its effect on plant growth, pest and disease pressure, and water availability. Climate has long-range impacts on soil characteristics such as organic-matter content, nutrient cycling and movement, erosion, and ultimately the soil classification.

Plants naturally evolved over time to favor their regional climatic conditions. Figure 1 in the appendix shows a map of long-term rainfall averages in the United States. Figure 2 in the appendix shows a map of natural vegetative cover across the United States. Comparing the two maps shows how rainfall influences vegetative cover. Forests are more prevalent in the Eastern United States where there is more rainfall. The higher rainfall coupled with warm temperatures accounts for the well-leached, low organic-matter soils common in the Southeast as microbial processes can quickly degrade organic matter. Tall- and short-season grasses are predominant west of 100°W longitude where drier and desert conditions persist. The 100°W longitude line runs through the approximate centers of North Dakota and Texas.

Crops commonly grown in the humid, temperate Southeast are adapted to the region's climate. When evaluating crops and available varieties for a rotation, determine if a variety's preferred climate matches the farm's climate. Consider the farm's latitude, elevation and other site-specific factors that affect local climate.

Soils

Soil characteristics impact the types of crops that can be grown successfully, as well as crop production management. The cation exchange capacity (CEC), soil texture and organic-matter content are particularly important soil properties. Soils provide pores for water and air retention, anchor the plants and have ion exchange sites. These properties affect nutrient retention, water-holding capacity and the microbial population for nutrient cycling.

Soil CEC refers to the number of negatively charged sites on soil particles and is an indicator of soil fertility. These sites attract cations, positively charged nutrients, from fertilizer as well as cations released during organic-matter decomposition. The nutrients are held on the sites in the root zone, available for plant uptake. Soils with a higher CEC can have more available nutrients for plant growth since they can hold more nutrients in the root zone. The soil orders that formed in the United States were influenced by regional climate. Ultisols are prevalent throughout most of the Southeast, with Alfisols common in the western part of the region. The fertility of these well-leached, low organic-matter soils is much lower than the Mollisol soils of the fertile Midwest (Table 7.3).

Soil texture is defined by the percentages of sand, silt and clay in the soil (Figure 7.1). Sandy soils have a low water-holding capacity and a low CEC. Ions, negatively and positively charged, such as nitrate (an anion) and potassium (a cation) are more likely to be leached out of the root zone in sandy soils due to fast movement of water and lower CEC. Soils with higher silt or clay percentages have a higher CEC and a greater water-holding capacity. They are less likely to leach ions. This difference affects crop selection and production management including fertilizer-application timing.

The soil texture is an inherent field condition that cannot be cost-effectively changed using chemical fertilizers, additives or mechanical tillage. For example, it is difficult to change a highly leached Ultisol soil into a fertile Mollisol. However, over time, crop rotations that use the right crops increase soil organic-matter concentrations and improve the inherent physical and chemical properties of the soil.

Soil maps are available from local USDA Natural Resources Conservation Service (NRCS) offices. Or, search the web for "Web Soil Survey" to find NRCS soil maps online. Check these maps to determine an area's predominant soil type and its inherent soil characteristics. To determine the characteristics of a field's soil, collect soil sam-

TABLE 7.3. Average cation exchange capacities and average soil pH for different soils orders in the United States

Soil Order	Cation Exchange Capacity (cmol$_c$/kg)[1]	Soil pH
Ultisols	3.5	5.6
Alfisols	9	6
Spodosols	9.3	4.93
Mollisols	18.7	6.51
Vertisols	35.6	6.72
Aridisols	15.2	7.26
Inceptisols	14.6	6.08
Entisols	11.6	7.32
Histosols	128	5.5

Source: [12]

[1] Centimoles of charge per kilogram of soil (cmol$_c$/kg).

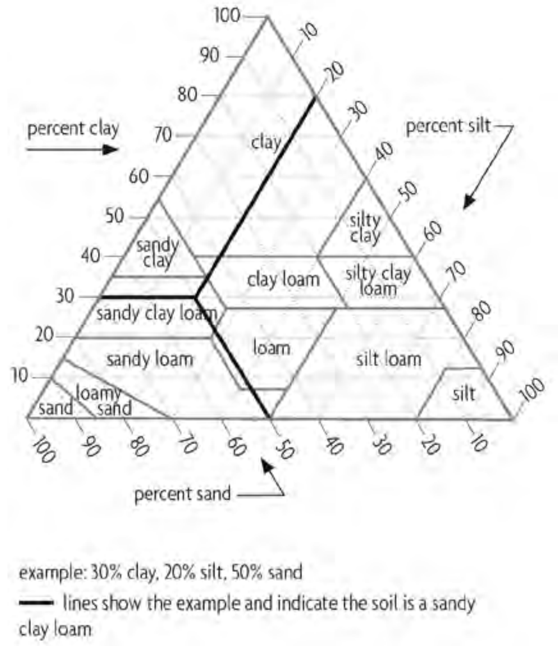

FIGURE 7.1. Soil triangle used to describe soil texture [23]. To determine a soil's classification, identify where its component percentages of clay, silt and sand intersect within the triangle. The arrow on each side indicates the direction to follow. For example, a soil that is 30 percent clay, 20 percent silt and 50 percent sand is classified as a sandy clay loam (i.e., the three components intersect within that section of the triangle).

ples from the top four inches for no-till fields and other undisturbed landscapes. For conventional and reduced-tillage fields, take samples from the top six inches. Testing at these depths assesses the root zone nutrient concentrations and assists in developing a fertility-management plan.

Crop Markets and Prices

Crop markets are well established throughout the country. Before including specialty crops in a rotation, identify the market for them. For instance, peanuts require special handling and belt-driven machinery for moving the pods from place to place without damage. Even though temperature, moisture and soils may be ideal for peanut production, if there is not a peanut-handling facility in the area, peanuts are not a viable crop option. Secure a market and buyer prior to introducing a new cash crop into the rotation.

Commodity price plays a major role in annual acreage shifts from one crop to another. World supply and demand principles directly affect the price. Prices change quickly due to new market demands, crop failures, bumper crops or other factors. When soybean prices are high, acreage is shifted to soybeans and less acreage is planted with other crops that have lower profit potential. Likewise, a corn-crop failure may prompt more corn acreage the following year since world supplies would be low and prices higher. Markets are also influenced by regional factors. For instance, a poultry or swine integrator may establish contracts for an alternative crop such as sorghum that has lower feed costs per unit than corn. Manage cash crop acreage for maximum profit potential, and adjust the rotation to meet the production characteristics of the cash crop.

Government Programs

Government programs continue to evolve with new programs being initiated while other programs are discontinued. There are many conservation-oriented programs that provide funding to defray the cost of implementing best management practices. Practices include certain conventional and conservation tillage practices, precision agriculture, and adding cover crops to rotations. The programs are managed through NRCS and local Soil and Water Conservation Districts. Additional programs managed by the USDA Farm Service Agency assist producers with operational loans, crop subsidy payments and energy programs. For more information, contact the local offices for these agencies.

Personal Preference

Fertility, disease, weed, insect and irrigation management vary by crop as do production techniques for establishing and harvesting plants. Adding a crop to the rotation may require different equipment, implements, fertilizer, pesticides and timing of field operations. Personal preference determines whether these changes will be made.

Take for example adding a high-residue cover crop to a rotation. These cover crops add organic matter, improve nutrient cycling, improve fertility and prevent erosion. The benefits are maximized when the cover crop is not terminated until late in the season when crop biomass is greatest, such as at heading for cereal crops. However, introducing a new crop or crop management plan requires a change in the traditional timing of field operations such as terminating the cover crop and planting the subsequent crop. Fertilization timing and rates may also change to achieve maximum cover crop biomass. Different equipment is needed for rolling/crimping the cover crop, strip tillage or planting into residue. Producer experience with the different equipment and tasks is a factor. Ultimately, producer preference determines if the cover crop will be added and the necessary changes made.

COMMON CROPS GROWN IN THE SOUTHEAST

Cash crops commonly grown in the Southeast work well in two-, three- and four-year rotations, and with cover crops (Table 7.2). They can be grown using conservation tillage but have historically been grown in monoculture systems.

The following sections discuss growth habits and Southeast production considerations for soybeans, hay, corn, wheat, cotton, rice, peanuts, sorghum, tobacco and rye. Planting and harvesting windows, and preferred soil types, are mentioned. Maps showing harvested-acreage density in the United States are included for each crop.

Soybeans

Soybeans are grown on virtually any soil type and are easily adapted to numerous rotations (Table 7.2). They are grown throughout the Southeast, with the densest production in the eastern parts of Virginia and the Carolinas (Figure 7.2). Soybeans are planted as full season or are double-cropped from March to July and harvested from September to December. Plant and harvest dates depend on the variety chosen and the crop rotation. Soybeans are commonly grown on marginal soils but are highest yielding on fertile, well-drained soils. Soybeans are legumes so nitrogen fertilizer is not needed.

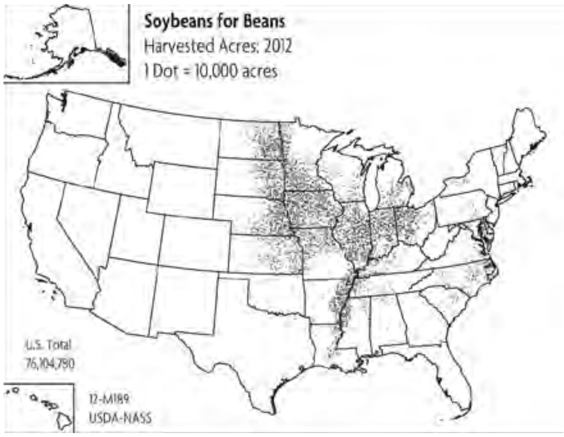

FIGURE 7.2. Soybean acreage harvested in the United States, according to the 2012 USDA National Agricultural Statistics Service Census of Agriculture [21].

High-yielding soybeans remove considerable amounts of potassium and phosphorus, as well as other macronutrients and micronutrients, from the soil. In many rotations, such as a rotation with winter wheat for grain>double-cropped soybeans>winter fallow>corn>winter wheat for grain, macronutrients such as potassium and phosphorus are often applied prior to planting winter wheat or corn. These applications usually meet soybean needs unless the whole plant is harvested, removing the nutrients [17]. Nitrogen mineralized from soybean residues is available for the following winter wheat crop and corn crop. Soil nutrient concentrations and pH are monitored with soil tests through university or private laboratories. Nutrient application rates are based on soil test results. Nutrients are added prior to soybean planting if needed.

Soybean varieties are divided into maturity groups (Group 00 to VIII) and are grown from southern Canada (Group 00, shortest season) to the southern United States (Group VIII, longest season). Most soybean varieties grown in the Southeast come from Group III to Group VIII [4]. Local day length and temperature control the length of the plant's vegetative stage and timing of flowering. Varieties with shorter seasons are used in double-crop rotations where a summer soybean crop follows a winter cereal crop such as barley (*Hordeum vulgare* L.), rye or soft-red-winter wheat. For maximum yields, production is managed to utilize the entire length of the

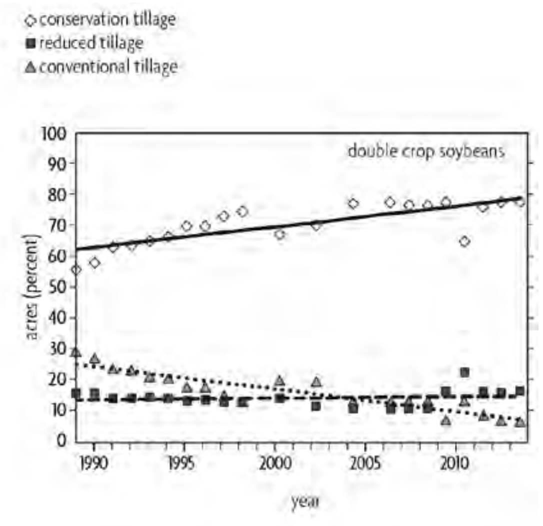

FIGURE 7.3. Tillage trends for double-cropped soybeans in the United States from 1989 to 2014 [7].

growing season.

Soybean farmers were early adopters of conservation tillage systems. Double-cropped soybean systems were successful because cereal-crop residues from barley, soft-red-winter wheat, or rye improved fertility, no-till planters were available, disease issues were minimal when compared to other crops, and herbicides were readily available. In the United States in 1989, approximately 55 percent of double-cropped soybeans were planted using conservation tillage techniques, and this number jumped to nearly 80 percent by 2014 (Figure 7.3). Producers in the Southeast adopted conservation tillage techniques even faster. Since 1989 in Virginia, over 95 percent of double-cropped soybeans were planted using conservation tillage techniques [7, 20].

Hay

Hay is grown across the Southeast, often in regions or soils less conducive to other cash crop production (Figure 7.4). "Hay" is comprised of several species that range from legumes to grasses, cool season to warm season, annual to perennial, and difficult-to-establish to invasive. The varieties selected depend on local conditions and farm goals. Hay is sometimes included in yearly rotations as a cover crop or as a winter cash crop, such as mixtures of oats and clovers.

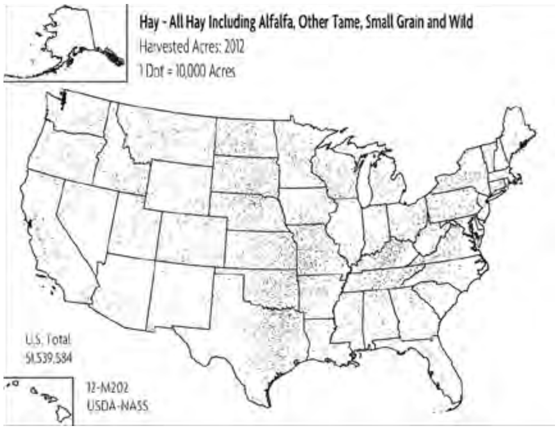

FIGURE 7.4. Hay acreage harvested in the United States, according to the 2012 USDA National Agricultural Statistics Service Census of Agriculture [21].

Hay reduces erosion, builds soil structure and adds organic matter. Deep-rooting hay species take up nutrients deep in the soil profile and incorporate them into its plant biomass. In areas where livestock production dominates, hay is used to recycle nutrients from manure back into plant biomass for livestock feed. Recent research is utilizing the hay production system to improve overall soil quality and nutrient cycling. Depending on farm needs, the hay cropping system now has many uses that range from cover crops for grazing or baling for feed, to projects that are taking an entire field out of production for a three-year period. These perennial hay cover crops utilize routine hay mixtures with complementary characteristics, such as alfalfa, orchardgrass and clover, with the overall biomass returning to the soil for carbon sequestration and nitrogen additions. Nitrogen-fixing alfalfa and clover provide fertility for the nitrogen-scavenging orchardgrass. The orchardgrass provides significant residue for soil protection and addition of organic matter. A benefit of the hay mixture is that the seeds can be mixed and planted at the same time. Although the mixture generally performs better if planted in the fall, it can also be planted in early spring.

Corn

Corn was first cultured in Mexico and was initially grown in the Southeast by Native Americans. Production has been revolutionized over time through extensive research. Corn is grown

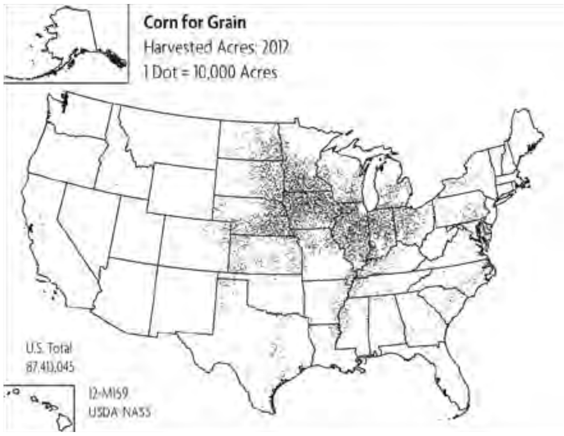

FIGURE 7.5. Corn harvested for grain acreage in the United States, according to the 2012 USDA National Agricultural Statistics Service Census of Agriculture [21].

throughout the Southeast on a wide range of soils (Figure 7.5). It is planted from March to May and harvested from August to October. The most productive soils are loam and silt-loam soils, which provide excellent nutrient-holding potential as well as water-holding capacity.

For successful field corn production, meaning corn for grain, follow these recommendations adapted from Boone, 1991 [4]:

- Use a hybrid adapted to the local climate with a high disease tolerance.
- Use fertilization techniques recommended for conservation tillage systems including proper nitrogen placement and application timing to reduce losses from immobilization and volatilization.
- Use a plant population appropriate for the hybrid and soil.
- Time field operations so that seed germination, fertilizer application, and pest and disease scouting occur when recommended for local conditions.
- Control weeds, insects and diseases common with the cool, wet and undisturbed soils found in conservation tillage systems.

Corn takes considerable management on sandy soils because it has a high water requirement during June and July, which are traditionally hot, dry months in the Southeast. Sandy soils in the Southeast Coastal Plain have low water-holding capacities [10]. Corn is not drought tolerant and even short dry spells can cause significant yield reductions. Without irrigation, a droughty situation may result in low yields and financial loss. Crops such as grain sorghum (*Sorghum bicolor*), cotton and soybeans have lower water requirements and are preferred for rotations on sandy soils.

Nitrogen management is an important consideration for corn crops grown in conservation tillage rotations. Sandy soils in the Southeast have inherently low fertility. A legume cash crop or cover crop is included in rotations to assist with nitrogen fixation as part of overall nitrogen fertility management. Split application of nitrogen, first at planting and then when the corn is knee high, significantly reduces nitrogen losses via leaching, runoff, immobilization and volatilization. With split application, nitrogen is available for crop establishment with the at-planting application and later in the season with the knee-high application when rapid nitrogen assimilation occurs.

Wheat

The types of wheat grown in the United States include hard-red-winter wheat, soft-red-winter wheat, white wheat, hard-red-spring wheat and durum wheat (*Triticum durum*). Wheat prefers well-drained soils and is commonly grown in arid regions west of 95°W longitude. However, soft-

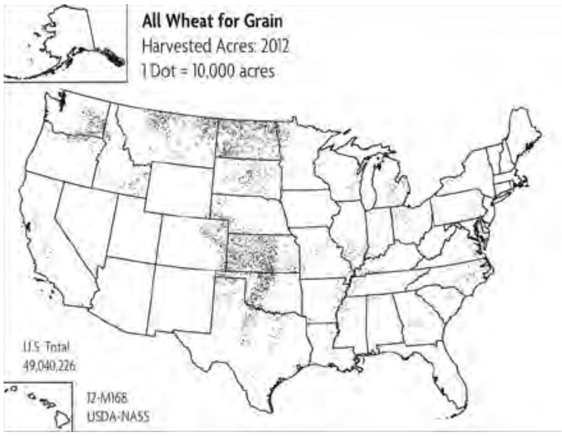

FIGURE 7.6. Wheat acreage harvested in the United States, according to the 2012 USDA National Agricultural Statistics Service Census of Agriculture [21].

red-winter wheat is predominantly grown in the northern stretch of the Southeast that includes Virginia, North Carolina, South Carolina and Tennessee (Figure 7.6).

Soft-red-winter wheat is commonly seeded from October to December and harvested from May to July. Successful production focuses on yield-building factors such as variety selection, plant nutrition and precision planting, as well as yield-protecting factors including weed control, insect control, disease control and harvest management [1]. Yield is determined by the number of kernels per head, weight per kernel and heads per acre.

Wheat grown in conservation tillage systems has increased dramatically in recent years with the advent of equipment such as grain drills that can penetrate thick crop residue from the previous crop, such as corn stover, and allow good plant establishment. By 2012, over 85 percent of wheat acreage in the Eastern United States was grown using conservation tillage techniques [7, 21].

When growing soft-red-winter wheat in conservation tillage systems, avoid yield reductions by addressing system-management challenges. High-disease pressure, especially following corn or in rotations that incorporate cereal cover crops, can be problematic and is now a common occurrence. Immobilization and volatilization of spring-applied nitrogen can be an issue due to significant corn stover remaining on the soil surface. This adds carbon, which increases the system's C:N ratio. A higher C:N ratio along with urease enzymes from the fertilizer may cause volatilization. Seed germination, plant growth and root growth may be delayed because soil warming under residue is delayed.

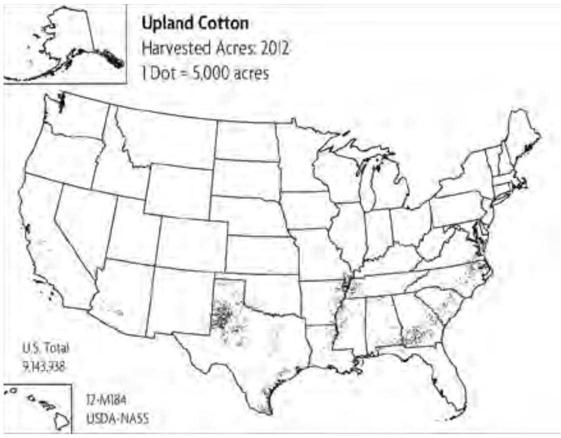

FIGURE 7.7. Cotton acreage harvested in the United States, according to the 2012 USDA National Agricultural Statistics Service Census of Agriculture [21].

Wheat is also grown as a winter cover crop in conservation tillage systems; it produces ample biomass, protects the soil surface and takes up inorganic nitrogen from the soil profile. However, research has demonstrated that continuous wheat/cereal grain rotations can aggravate wheat disease problems, such as take-all (*Gaeumannomyces graminis* var. *tritici*). When wheat, or any crop, is being evaluated for a rotation, assess its impact on the timing of field operations and the scouting for pests and diseases.

Cotton

Cotton is a warm-season perennial fiber crop grown as an annual in the Southeast. In the Southeast, production is densest in the Coastal Plain region (Figure 7.7). American-upland cotton varieties require approximately 180 frost-free days, warm climatic conditions, ample moisture and well-drained soils [4]. Similar to corn and full-season soybeans, cotton is planted from April to May and harvested from September to November. Local seed dealers can help identify cotton varieties suitable for local conditions and the crop rotation.

Due to the warm, moist growing conditions, disease pressure is significant in cotton rotations. When cover crop residues are left on the soil surface, disease pressure increases further because the soils take longer to heat in the spring and ground cover holds moisture next to the seedlings. To reduce the disease pressure that occurs in no-till systems, cotton is planted using strip-tillage. The narrow tilled area provides a warm, clean and consistent seedbed for seed placement 0.5–1 inch deep.

Cotton has long been king in the Southeast and is known to be hard on soils, meaning that cotton-monoculture fields were apt to erode, lose nutrients and lose productivity. This occurs because minimal residue is left on the soil surface following cotton harvest. Adding a high-residue winter cover crop such as rye protects the soil, adds organic matter and recycles nitrogen applied to the previous cotton crop. If cover crops are allowed to grow until early heading, biomass production increases. To increase biomass further, nitrogen fertilizer is applied. The nitrogen added becomes available to the following cotton crop through mineralization of organic matter during the growing season [18, 19].

Peanuts

Peanuts (*Arachis hypogaea*), a legume, are grown in the Coastal Plain region of the Southeast in sandy-textured, well-drained soils (Figure 7.8). Peanuts are planted from April to May and harvested prior to frost, from September to October. When grown using conventional tillage, the soil is tilled to loosen the soil surface. This allows the peanut pegs to penetrate the ground where they grow into the actual peanut pod and seed. A moldboard plow is used to incorporate residue for disease reduction and to reduce the amount of foreign material in harvested peanut pods.

In recent years, research has found that peanuts can be raised using conservation tillage techniques including rotation with high-residue cover crops (Table 7.2). Peanuts are planted using strip-tillage to allow peanut pegs to be planted in a clean and loosened soil. When peanuts follow corn in rotation, with or without a cover crop, corn stover and other residues are typically incorporated to reduce problems with foreign material at the point of sale, to assist with disease management and to loosen soil around the plant to facilitate pegging.

Peanut rotations work well with double-cropped wheat and soybeans. However, research in North Carolina demonstrated that adding soybeans to peanut rotations may negatively impact peanut yields [13]. The research also found that four-year rotations, even with soybeans, had yields superior to long-term monoculture production. Peanuts are grown in rotation with small grains, cotton and corn to help with disease, insect and weed problems.

Sorghum

Sorghum (*Sorghum bicolor*) is a grass species commonly grown in the Midwest, and acreage is increasing in areas of the Southeast (Figure 7.9). In the Southeast, sorghum is typically planted from April to May and harvested August through November. Well-drained soils are preferred. Sorghum, like corn, is used as livestock feed and is an alternative to corn in drought-prone areas, such as areas with sandy-loam, loamy-sand, and sand soils. Production practices for sorghum are comparable to corn with similar pests and fertility needs. Sorghum is treated similar to corn in conservation tillage systems. However, harvest

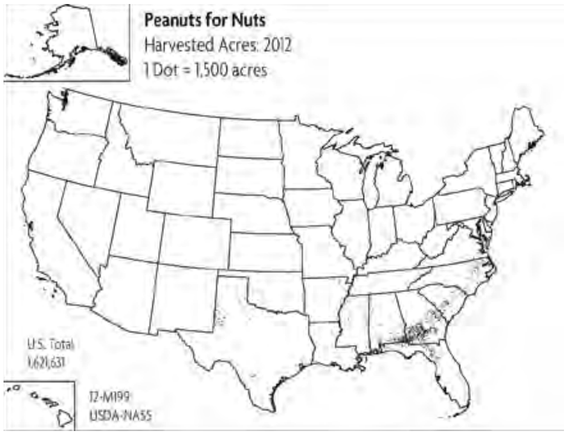

FIGURE 7.8. Peanut acreage harvested in the United States, according to the 2012 USDA National Agricultural Statistics Service Census of Agriculture [21].

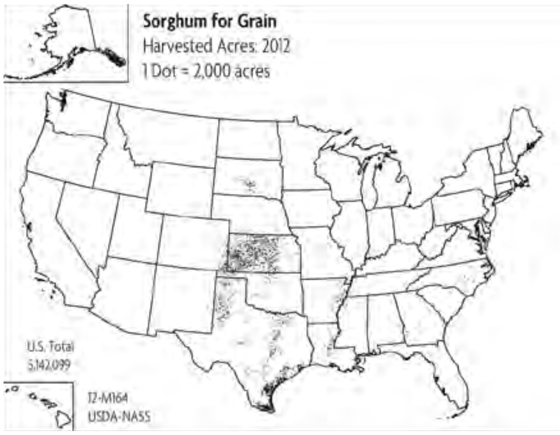

FIGURE 7.9. Sorghum acreage harvested in the United States, according to the 2012 USDA National Agricultural Statistics Service Census of Agriculture [21].

and storage for grain sorghum are more difficult because the grain heads do not dry uniformly in the field and it is difficult to pass air through stored sorghum grain.

Tobacco

Tobacco (*Nicotiana tabacum*) is a high-value crop with a long history in conventional tillage production systems. It grows well in various soil types and is typically planted from April to May and harvested July through August. Due to high labor costs and maintenance levels, tobacco is commonly grown on less acreage per farm when compared to other cash crops. Most tobacco production in the Southeast occurs in southern Virginia and North Carolina (Figure 7.10). Similar to other high-value crops, rotations are generally less important for pest control, but a proper rotation can significantly reduce disease pressure. Crop income covers the costs of the herbicides, insecticides, fungicides and fertilizers needed for high yields and quality tobacco leaves.

Historically, tobacco was grown using conventional tillage because the soft, bare soil was conducive to transplanting tobacco plants, reducing weed and disease pressure, and warming soil early in the spring. In recent years, strip-till has become more commonplace. The row is strip-tilled to assist with plant establishment, but row middles are left undisturbed. This reduces runoff and erosion, and increases soil organic matter.

Strip-till requires only minor modifications to transplanting equipment, and soil fumigants can be applied simultaneously with the strip-till machinery. No-till tobacco systems have not been successful because available transplanting equipment does not work in heavy residue.

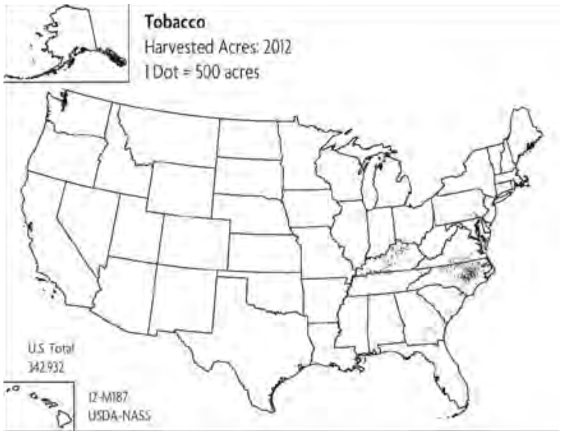

FIGURE 7.10. Tobacco acreage harvested in the United States, according to the 2012 USDA National Agricultural Statistics Service Census of Agriculture [21].

Rye

Rye is a cereal grain grown extensively as a winter cover crop as well as for grain. In the Southeast, most production occurs in the Coastal Plain region (Figure 7.11). Rye is a winter annual and an excellent substitute for wheat on marginal soils. When compared to wheat, its yield is greater on poor soils and it is more cold and drought tolerant. When grown for grain, rye is typically planted from September through November and harvested May through June. Earlier harvest than winter wheat allows the producer to begin planting double-cropped soybeans sooner. This is often cited as a reason for increased soybean yields.

Rye is a superior winter cover crop; it has excellent winter hardiness and produces relatively large amounts of persistent mulch. It is fairly easy to kill with herbicides, has allelopathic properties on weeds and "catches" more nitrogen from the soil profile than other cereal crops. These attributes reduce pollution, increase fertilizer efficiency, improve soil structure and increase cash crop yield [5, 8, 9, 15, 18, 19].

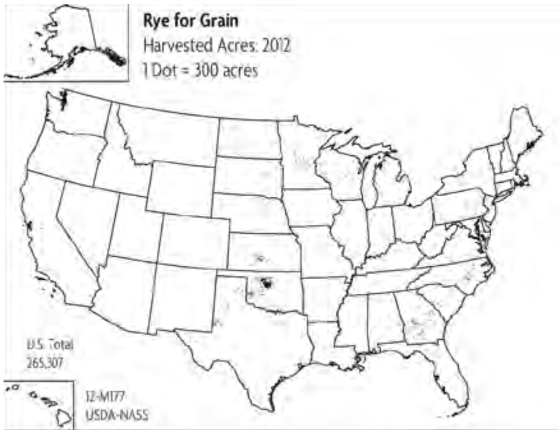

FIGURE 7.11. Rye acreage harvested for grain in the United States, according to the 2012 USDA National Agricultural Statistics Service Census of Agriculture [21].

Research in Alabama investigated the impact of tillage timing, tillage depth and winter cover crops on cotton yields. A rye cover crop was the most critical factor in increasing yields of conservation-tillage cotton in the Tennessee Valley [16]. Waiting until early heading before termination of the rye cover crop is ideal for maximum biomass production. At this late growth stage, mechanical termination with a roller/crimper is an option instead of termination with chemicals such as glyphosate [2]. If maximum biomass production is desired, rye is a better choice than other cover crops or fallow. Rye increases soil tilth and rotation productivity while reducing nutrient and sediment losses that occur on fallow winter fields.

SUMMARY

Many of the cash crops common to the Southeast can be incorporated into a crop rotation that improves yields, reduces pest and disease pressure, and improves soil health. Depending on the desired crops and local conditions, they can be grown using reduced tillage in two-, three- or four-year rotations that include cover crops. When selecting crops for a rotation, consider local climate and soil conditions, markets, each crop's growth characteristics, and producer preference and expertise. Develop a crop production system that is sustainable and profitable, and that maintains the soil for future generations.

RESEARCH CASE STUDY

A Farmer-Researcher Collaborative Effort to Design No-Till Systems Appropriate for Small-Scale Organic Producers in Alabama and the Deep South

Project Information

Project type: Research and Education Grant
Project number: LS09-218
Project dates: 2009–2013
Principal investigator:
Joseph Kloepper
Auburn University
Project reports: https://projects.sare.org/sare_project/ls09-218/

Problem Statement

No-till has been implemented successfully on large-scale conventional farms that rely on herbicides, chemical fertilizers and no-till seeders and transplanters in production. Adoption of no-till on small-scale organic farms, however, presents several challenges. Without the use of herbicides, cover crops must be terminated by crimping or mowing at the exact time at which they are the most vulnerable. Without the use of fast-release chemical fertilizers, nitrogen and nutrients must be applied through either a cover crop mix that includes legumes or through large amounts of compost. The lack of herbicides and tillage also means that farmers rely heavily on cover crop residue to prevent the growth of weeds during the cash crop growing season.

Five farmers from Alabama and researchers at Auburn University and the USDA Agricultural Research Service (ARS) partnered in a study investigating the implementation of no-till methods in small-scale organic vegetable production over a four-year period (2009–2012).

Methods and Practices

For the study, a variety of cover crop monocultures and mixes were evaluated in trials at Auburn research stations and by farmers at the farm level. The farmers adopted no-till, choosing the cash crops and cover crops they would grow in consultation with researchers who provided equipment and field demonstrations of no-till techniques. Farmers were responsible for maintaining no-till methods for the length of the study, with researchers visiting periodically during the growing season to evaluate the effectiveness and profitability of no-till in small-scale vegetable production. Cash crops included tomatoes, squash, okra and corn. Site-specific and cropping-system-specific tillage treatment evaluations were conducted annually. Participants were provided with no-till equipment (seed drills, rollers, crimpers and transplanters) by the Alabama

Sustainable Agriculture Network and shown how to use the equipment during educational field days. USDA-ARS researchers advised participants on optimal weed management techniques.

Results

Four of the five participating farmers produced a healthy cover crop and were able to use the residue for the planting of cash crops. Farmers' cash crops were less successful. One of the findings of this study was that no-till vegetable production is difficult in the South due to the high rate of cover crop residue decomposition and the amount of space left between crop rows. This allowed for increased weed invasion but also interfered with weed management strategies, such as mowing. No-till was also shown to be poorly suited to the traditional method of vegetable row-crop production, with aisles left between crop rows. While fall crops were not heavily impacted, summer crops faced intense competition with weeds. Though the on-farm trials indicate that no-till is an unviable method for organic vegetable farming, crop studies continue at research stations across Alabama, with the potential for more insight into the better implementation of no-till.

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CHAPTER 8

Sod, Grazing and Row-Crop Rotation: Enhancing Conservation Tillage

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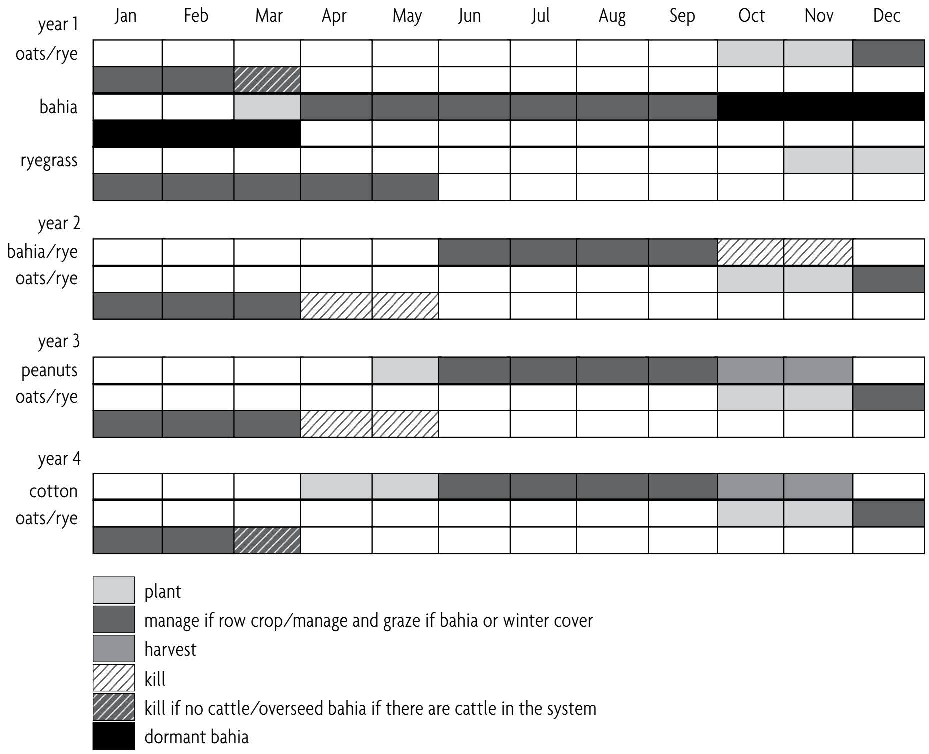
Agriculture in the United States followed the European model of integrating livestock and row crops until the mid-20th century when mechanization and specialization caused farmers to separate these enterprises. Reintegrating livestock and sod into row-crop rotations is being evaluated now because perennial grass (sod) in a rotation has beneficial effects on soil, water availability, crop productivity, pest control and risk management. Because profit margins for most crops are slim, it is difficult for growers to consider farming practices that do not maximize yields and economic returns. A diversified system with a rotation of perennial grass, livestock grazing, row crops and winter cover crops can improve farm profitability and reduce the risks associated with climatic extremes and crop price fluctuations [40, 48].

Although there are many advantages to a sod-based rotation, currently there is not widespread adoption. On rented land, producers have little incentive to put fields into perennial grass for two to three years because of the loss of income. Additionally, the lease may be lost when another farmer sees the "layout" of the sod-based rotation and offers a higher rent. On row-crop farms, opportunities for grazing are limited since much of the land is not fenced. Higher crop yields and lower pest pressure are expected on land in a sod-based rotation, but there is little information showing the economic benefit of keeping perennial grass in the rotation after the land is put into row crops.

This chapter analyzes a rotation with bahiagrass, livestock grazing, cotton, peanuts and winter cover crops as depicted in Figure 8.1. The economics and risk management of the rotation are compared to a short-term rotation and a standard rotation used in a conservation tillage system. Short-term rotations alternate peanuts and cotton with winter covers: peanuts>winter cover>cotton>winter cover. A standard conservation tillage rotation in this analysis refers to one year of peanuts followed by two years of cotton with winter covers: peanuts>winter cover>cotton>winter cover >cotton>winter cover. The sequence of events in a short-term rotation is the same as the last two years of the sod-based rotation in Figure 8.1. The sequence of events in a standard conservation rotation is the same as the last two years of the sod-based rotation plus another year of cotton. Research results concerning variations of these rotations are also described in the chapter.

All the rotations discussed in this chapter use conservation tillage practices. The soil is covered throughout the year with perennial grass and/or an oat or rye winter cover crop. Winter cover crops always follow row crops. When bahiagrass is grown, the winter cover crop is overseeded into the dormant bahiagrass. Bahiagrass is dormant from October through March.

Row crops are strip-tilled into terminated sod or winter cover crop residue. Sod and cover crops are planted using a grain drill. If cattle are in the



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
year 1												
oats/rye										░	░	▓
	▓	▓	▩									
bahia			░	▓	▓	▓	▓	▓	▓	■	■	■
	■	■	■									
ryegrass											░	░
	▓	▓	▓	▓	▓							
year 2												
bahia/rye						▓	▓	▓	▓	▨	▨	
oats/rye										░	░	▓
	▓	▓	▓	▨	▨							
year 3												
peanuts					░	▓	▓	▓	▓	▒	▒	
oats/rye										░	░	▓
	▓	▓	▓	▨	▨							
year 4												
cotton				░	░	▓	▓	▓	▓	▒	▒	
oats/rye										░	░	▓
	▓	▓	▩									

░ plant
▓ manage if row crop/manage and graze if bahia or winter cover
▒ harvest
▨ kill
▩ kill if no cattle/overseed bahia if there are cattle in the system
■ dormant bahia

FIGURE 8.1. The sequence of events in a four-year, sod-based rotation.

system, the winter cover crop is killed only three to four weeks before planting peanuts or cotton.

THE SOD-BASED ROTATION

The sod-based rotation shown in Figure 8.1 starts with two years of bahiagrass, followed by one year of peanuts, then one year of cotton: bahiagrass>winter cover>bahiagrass>winter cover >peanuts>winter cover>cotton>winter cover. When the rotation begins, there is a winter cover crop in the field; if it is being grazed, bahiagrass is overseeded into the cover crop. If it is not being grazed, the cover crop is terminated in March and bahiagrass is overseeded into residue.

This analysis used a Great Plains drill with a drill spacing of 7 inches, a seeding rate of 30 pounds per acre and a maximum seeding depth of one-half inch. Nitrogen is applied at a rate of 50 pounds per acre to bahiagrass and 100 pounds per acre to oats and rye. The grass is in place through the fall of the following year for two years of continuous bahiagrass. Winter covers are overseeded into bahiagrass when it goes dormant in October of the first year. When bahiagrass is grown it displaces a row crop in the rotation.

If fencing is installed, grazing can begin when the bahiagrass is established, 10–12 weeks after planting. In the fall, when the oat or rye cover crop is overseeded into the dormant bahiagrass, livestock are kept off the field for six to eight weeks until the cover crop is established.

In the second year, grazing on the cover crop continues until May. Then the bahiagrass comes back for summer grazing starting in June. In October and November, the bahiagrass is terminated with an herbicide, and oats or rye is planted.

In the third year, the winter cover is grazed until it is terminated three to four weeks before planting peanuts in May. Peanuts are harvested in October and November, and the winter cover crop is planted.

In the fourth year, the winter cover is grazed until it is terminated in March. Cotton is planted in April and May. The cotton is harvested in October and November, and the winter cover crop is planted. After the fourth year, the rotation begins again.

An economic model of the sod-based rotation is reviewed later in the chapter for a 200-acre farm. The farm is divided into four 50-acre fields. Each year, one field is in peanuts, one field is in cotton and two fields are in bahiagrass, with one field being grazed.

THE BENEFITS OF A SOD-BASED ROTATION

Growing bahiagrass for two years prior to growing row crops in a conservation tillage system has numerous economic and environmental advantages over standard conservation practices. The chemical and physical properties of the soil are improved. Crop yields increase, pest pressure decreases, and the need for fertilizer, pesticides and irrigation decreases. This section reviews the benefits of a sod-based rotation to the soil, peanut production and cotton production [16, 21, 24, 25, 47].

Soil Benefits

The biggest benefit of adding sod to a standard conservation rotation is improved soil quality [35]. Adding bahiagrass and livestock grazing to the standard rotation helps sequester carbon, which increases soil organic matter. In the Southeast, it is estimated that pasture-based rotations with row crops and conservation practices could sequester 13–29 percent of the carbon potential in the United States (132–298 million metric tons of carbon or 145–328 million tons) [13].

Perennial grasses sequester more carbon and increase soil organic matter more than annual winter cover crops. Roots have a greater influence on soil organic matter than the aboveground plant biomass [31, 34, 43]. For example, corn roots contribute 1.6 times more carbon to soil organic matter than stover [2]. When the carbon from root exudates, mucilages, sloughed cells and roots are considered, corn root biomass contributed between 1.7–3.5 times more carbon to the soil than stover [1]. A perennial grass like bahiagrass provides about 8.5 tons of biomass per acre [5] compared to 1.3–1.8 tons per acre from a small-grain cover crop. Adding sod to a standard conservation rotation can increase soil organic-matter content up to 0.8 percent over a nine-year period.

Figure 8.2a shows the seedbed prepared in a perennial grass system, and Figure 8.2b shows the seedbed prepared in a system using annual


a

b

FIGURE 8.2. Seedbed prepared in perennial grass (a) as compared to the seedbed prepared in winter-annual cover crop residue (b).

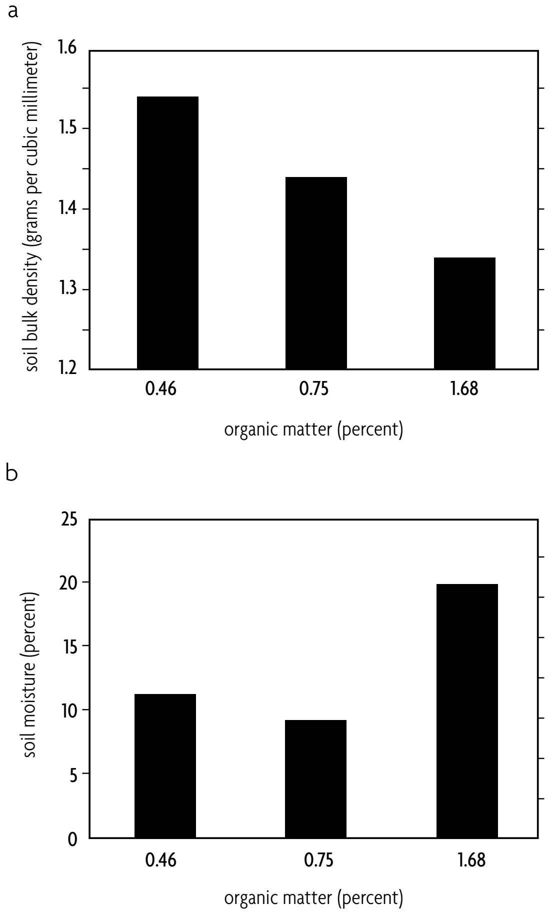


FIGURE 8.3. Bulk density (a) and soil moisture (b) in soils in a bahiagrass rotation with different levels of soil organic matter. Measurements were made in a non-grazed area.

winter cover crops. In each case the seedbed was prepared using a ripper, a type of in-row subsoiling. The root mass in the perennial system is about 20,000 pounds per acre while the root mass in the annual winter cover crop system is 3,000–4,000 pounds per acre. With the greater root mass, ripping results in a narrower tilled area compared to the tilled area in the annual winter cover crop system. The narrow-tilled area is preferred because more of the soil surface is covered with residue.

Perennial grass in a row-crop rotation also has a positive impact on earthworm populations. Earthworms aid in rooting of subsequent crops, reduce nutrient losses to the environment by 40–60 percent [27, 28, 29] and reduce soil erosion. At a research site in Quincy, Fla., the number of earthworms per acre was 7.5 times greater after a sod-based rotation as compared to a short-term rotation.

Soils with higher organic matter hold more moisture and experience less compaction from livestock grazing and planting and harvesting equipment (Figure 8.3). Compaction results in an increased bulk density and is a function of soil texture, soil moisture, grazing intensity, equipment traffic, vegetation and climate [39]. The risk of compaction is greatest as the soil begins to drain after being totally saturated. To minimize compaction, remove livestock from the field if there is standing water or saturated soil. Keep the livestock out of the field until excess moisture drains away and the soil can be worked (drier than field capacity). For sandy soils, this might be only one-half to one day. For clayey soils, this could take four to five days.

Studies of grazing in row-crop systems in Alabama observed compaction to a depth of 4–6 inches, but strip tillage eliminated the problem [37]. In general, livestock grazing affects soil compaction mostly in the top 6 inches of soil [45]. Systems with bahiagrass can limit that compaction to the top 2 inches due to the greater root mass and general improvements in soil structure that result from a sod-based rotation.

Perennial grasses grow under conditions that are less than ideal for many agronomic crops and are often planted in fields degraded by poor cropping practices. The grasses prevent erosion and rejuvenate “worn out,” low-fertility soils even under droughty or excess moisture conditions. Several perennial grasses are used in the Southeast for forage and grazing as well as for reclamation. In the Southeast, fescue is the dominant cool-season grass for pasture, while bahiagrass is the dominant warm-season grass [46]. Bahiagrass is a good choice for a sod-based rotation because it grows on all soil types found in the Southeast and is drought tolerant [18].

Coastal Plain soils have a natural compaction layer 6–8 inches deep [11, 22]. Bahiagrass roots will penetrate this layer, leaving root channels for crop roots to follow [16, 25, 47]. The porosity in the dense soil layer below the plow depth

TABLE 8.1. Days without plant water stress following rainfall for different rooting depths

Rooting depth (inches)	Days without water stress following rainfall[1]
6	3
9	5
12	6
24	12
35	18
48	24
60	30

[1] The available water was 1 inch per 6 inches of soil, and the evapotranspiration was 0.33 inch per day. *Source: [16]*

was evaluated for cotton following three years of continuous bahiagrass and for continuous cotton with winter cover crops. With the bahiagrass, there were seven times more pores greater than 0.04 inch [30]. This allows the cash crop to exploit a larger volume of soil for moisture and nutrients. Corn, soybeans, peanuts and cotton produce the most root growth in the first 50–60 days after planting. Any conditions that limit root development during this time, including compacted soil, slow plant growth.

The increased rooting depth following bahiagrass decreases irrigation needs. For the average Coastal Plain soil, a crop with a rooting depth of 12 inches will experience 60 drought days from May through August in five out of 10 years [16]. However, if the rooting depth were 60 inches, the crop would experience only 11 drought days. If the plant rooting depth is only 6 inches, which is the soil above the normal dense layer that occurs in Coastal Plain soils, plants will experience water stress after only three days without rainfall. By increasing rooting depth to 60 inches, the plant would not experience water stress until 30 days without rainfall [16] (Table 8.1).

Other perennial grasses have similar effects. Figure 8.4 compares infiltration after peanuts on four fields with four different rotations. The pictures were taken at the same time. Field A used a short-term rotation. Field B used a soybean>cotton>cotton>peanut rotation with winter cover crops. Field C had two years of continuous fescue prior to cotton and peanuts for a fescue>fescue>cotton>winter cover>peanut >winter cover rotation. Field D had two years of continuous orchard grass prior to cotton and peanuts for an orchard grass>orchard grass>cotton>winter cover>peanut>winter cover rotation. There is less standing water on the two fields that included two years of perennial grass in the rotation (fields C and D).

Increased water demand and droughts in the Southeast have increased the need for water conservation. Capturing more water through improved infiltration and increased rooting depth will reduce irrigation water demand by the agricultural community.

Peanut Production Benefits

Sod-based rotations typically increase peanut yields by 15–30 percent, resulting in more profit than could be expected in a standard conservation rotation. Typical peanut yields in the region using standard conservation or short-term rotations are 3,000–4,000 pounds per acre. Growers have experienced yield gains of 1,500–2,000 pounds per acre as well as significant disease reduction when growing peanuts following two years of bahiagrass. Research has shown that even one year of bahiagrass could increase peanut yield significantly [15, 32, 44]. More years in bahiagrass had a positive impact on peanut yield [21]. This yield benefit lasted only two years after bahiagrass. Then, yields were similar to continuous peanuts with winter cover crops [8]. Overall, the big selling point for having peanuts in the sod-based rotation is increased yield and profit potential for peanuts, along with income from livestock grazing and cotton.

The increase in peanut yield after bahiagrass may be the result of nematode reduction and increased rooting depth [8, 16]. One study showed reduced population densities of the root-knot nematode (*M. arenaria*) in peanuts early in the growing season following one year of bahiagrass. However, the nematode population increased to high levels at the end of the season [15].

As compared to the standard conservation rota-

Field A

Field B

Field C

Field D

FIGURE 8.4. Water infiltration differences between four rotations. There is less standing water on the fields that included two years of perennial grass in the rotation (fields C and D). The rotations are: field A is cotton>winter cover>peanuts>winter cover; field B is soybeans>winter cover>cotton>winter cover>cotton>winter cover>peanuts; field C is fescue>fescue>cotton>winter cover>peanuts>winter cover; and field D is orchardgrass>orchardgrass>cotton>winter cover>peanuts>winter cover.

tion, peanuts had more extensive root systems and less plant stress following two years of bahiagrass in 2007, one of the driest years on record. After 80 days of peanuts following bahiagrass without irrigation, plant stress measured as leaf water potential was not significantly different from that of irrigated, standard conservation rotation peanuts (Figure 8.5). As leaf water potential becomes more negative, it is harder for plants to get water from soil. No aflatoxin was observed on either irrigated or non-irrigated peanuts following bahiagrass, while high levels of aflatoxin were found in the standard rotation non-irrigated peanuts planted into oat cover crops. Aflatoxins are naturally occurring fungal toxins produced by *Aspergillus flavus* and *Aspergillus parasiticus*. These toxins cause serious liver dysfunction in humans and animals. Peanuts are extremely susceptible to infection by these species, and aflatoxin control is critical since contaminated peanuts have no market value.

Perennial grasses are more effective in controlling soil-borne diseases in peanuts than in cotton [36, 41]. Tomato spotted wilt incidence was 50 percent less when peanuts were strip-tilled into bahiagrass as opposed to a winter cover crop [42] (Figure 8.6). The sod rotation in this study was cotton>bahiagrass>bahiagrass>peanuts with winter covers. Likewise, diseases such as leaf spot are delayed and have lower severity in a bahiagrass rotation as compared to standard conservation rotations [7, 42].

Peanuts planted into terminated bahiagrass that has been grazed tend to have slightly lower yields in some years than peanuts planted into bahiagrass that was not grazed. There was more surface compaction in the top 6 inches of the soil due to livestock traffic. This may result in yield losses due to more peanuts falling from the vines during the digging operation.

Cotton Production Benefits

Rotations of cotton with perennial grasses have not been studied as much as peanut and grass rotations, though several studies indicate that cotton yields will increase. Increased cotton yields following bahiagrass have been attributed to a more extensive cotton rooting system [16]. Virginia scientists observed as much as a 50 percent yield increase when cotton is strip-tilled into fescue or orchardgrass as compared to winter small-grain cover crops [17]. This may be due to increased infiltration, access to soil moisture deeper in the soil profile and less compaction.

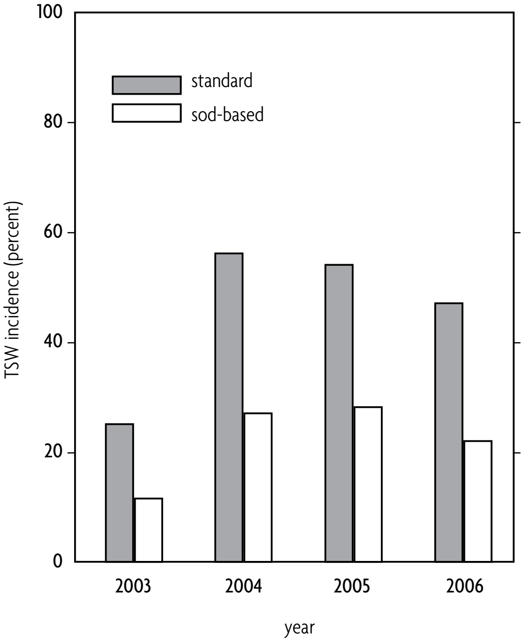


FIGURE 8.6. Incidence of tomato spotted wilt (TSW) on peanuts in two rotations. The sod-based rotation in this study was cotton>bahiagrass> bahiagrass>peanuts with winter cover crops. The standard conservation rotation was cotton>cotton>peanuts with winter cover crops.

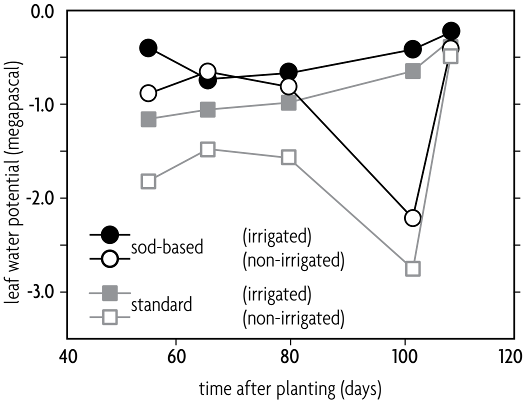


FIGURE 8.5. Plant stress in peanuts through the growing season in a sod-based rotation compared to a standard conservation rotation.

As with peanuts during a dry year, cotton grown after two years of bahiagrass had less plant stress as noted by leaf water potential readings from 2007 (Figure 8.7). Even though 2007 was one of the driest years on record, non-irrigated cotton had very low stress levels for the first 90 days in the bahiagrass rotation as compared to cotton in a standard conservation rotation. Cotton growth and development was greater in the bahiagrass rotation. The plants were taller and the leaf area index was higher. The leaf area index characterizes plant canopies; it is defined as the one-sided green leaf area divided by ground surface area.

After eight years (two cycles) in the sod-based rotation, total nitrogen applied in cotton was reduced because more nitrogen is tied up in the soil organic matter and released slowly over the growing season. Lint yields for cotton in a bahiagrass rotation without nitrogen were similar to yields in a standard conservation rotation with 60 pounds of nitrogen per acre applied (Figure 8.8). Close to three-bale cotton (1,500 pounds lint yield per acre) has been produced in recent years with no nitrogen applied using the sod-based rotation.

Winter grazing of bahiagrass compacts only the top 2 inches of soil instead of the 6 inches that is common without bahiagrass. The effect is due in part to the greater root mass and general improvements in soil structure that result from a sod-based rotation. The benefit of grazing is greater nutrient cycling, which can be seen in

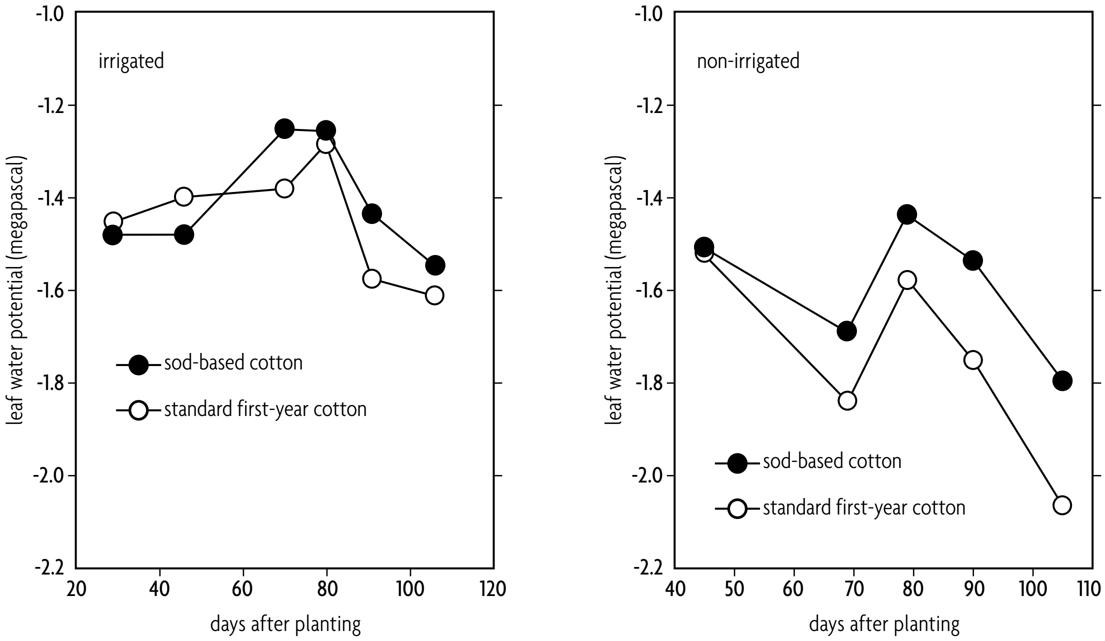


FIGURE 8.7. Plant stress through the growing season for cotton in a sod-based rotation and for first-year cotton in a standard conservation rotation.

the nitrate-nitrogen values of cotton petioles in the grazed bahiagrass system (Figure 8.9). Plant growth was more vigorous throughout the growing season in the grazed field although surface soils were more compacted. Lint yields in the grazed system increased over the non-grazed system by 228 pounds per acre in irrigated plots and by as much as 392 pounds per acre in non-irrigated plots (Figure 8.10).

INTEGRATING SOD AND LIVESTOCK GRAZING INTO ROW-CROP FARMING

About 50 percent of the row-crop farms in Alabama and about 25–30 percent of row-crop farms in Florida and Georgia have livestock [33]. This is an opportunity for sod-based rotations. Livestock provide many advantages to row-crop farming. They are an inexpensive method for harvesting low-value crops or forage and turning them into meat or milk products. If grain does not meet market standards, it can be used in a livestock ration. If grain prices are low, it may be more profitable to feed grain to livestock. Note the flexibility the sod-based system provides to maximize profits and reduce risk.

Land not suitable for crop production can still generate income if a perennial grass is planted and grazed. Weeds and briars are controlled to some extent with grazing, and nutrients are recycled so less commercial fertilizer is needed. Ground-nesting birds, small mammals and deer are found in well-managed pastures. Perennial grasses also provide feed and habitat for wild turkey and rabbits [3, 12].

Integrating livestock into row-crop production has synergistic effects. Livestock can graze efficiently on winter small grains planted after row crops. Winter small grains do not compete with summer cash crops and are grown at a time when there is seldom drought and pest pressure is low. Livestock are the most cost-effective method to harvest forage [3]. In most cases, soil remains covered during the winter and a profit is made from the livestock. Livestock manure increases soil organic matter content [20]. Manure and urine also raise the soil pH and accelerate the decomposition of organic matter that releases nutrients [9, 10].

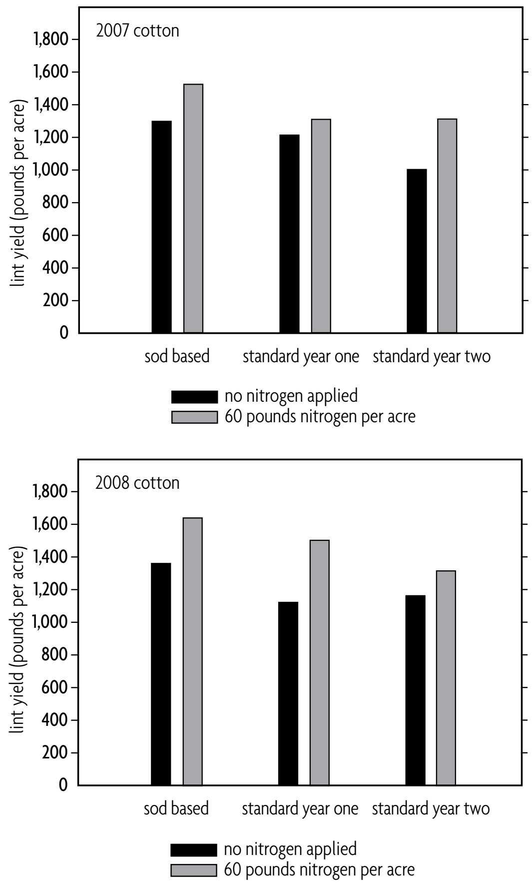


FIGURE 8.8. Cotton-yield response to the rate of nitrogen applied in 2007 and 2008 in the sod-based rotation and standard conservation rotation.

A sod-based rotation may make the most sense for dryland production. Farmers without irrigation often say that about 20 percent of their cropland is marginal or breakeven, but they continue to farm it each year since it is part of the fields being cropped. The marginal areas have often been cropped for 10, 20, or 30 years or longer. They are the areas that get “extra” fertilizer if it is left over after field application. Even after added fertilizer, these areas seldom produce a profit due to pest, fertility or other problems. Put these areas into continuous sod for two years or more before planting cash crops and they will likely produce much higher yields with less pest pressure.

A diversified farm with sod, livestock grazing, row crops and winter cover crops provides a buffer against losses due to unpredictable weather, such as droughts and hurricanes. An example is the impact of Hurricane Ivan on cotton in Florida, Alabama and Georgia (2004). The hurricane occurred during the boll-opening period and many farmers lost a large part of their crop. A farm with a sod-based rotation would have had only half the acres planted in cotton and peanuts, and the income from livestock grazing would not have been affected.

Weather is the key variable in determining yield each year, and a sod-based rotation is an effective risk-management strategy for limiting weather’s impact. Row crops grown in the Southeast need adequate soil water for establishment in May, good rainfall in July and August to produce the crop, and dry weather in late September and October for harvest. Most years have periods of drought or excessive rains that affect row-crop yields. If part of the farm is in bahiagrass or another deep-rooted perennial grass, the grass would survive hurricanes handily and would

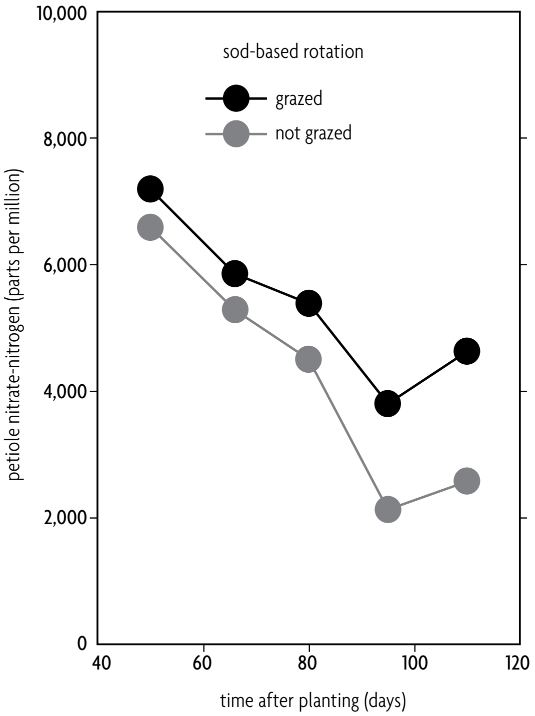


FIGURE 8.9. Petiole nitrate-nitrogen in cotton from squaring to maturity with and without cattle grazing in a sod-based rotation. Winter grazing occurred after peanuts. Squares are the buds that later bloom into flowers. Squaring happens five to eight weeks after planting.

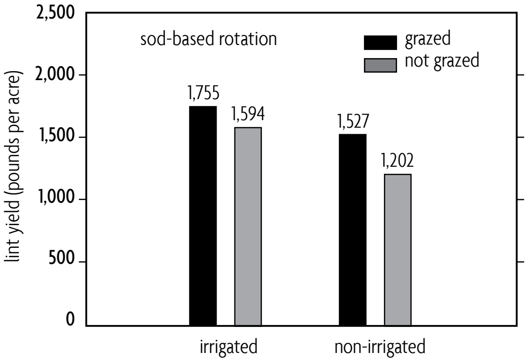


FIGURE 8.10. Cotton-yield response to winter livestock grazing and irrigation in a sod-based rotation.

survive droughts without much effect. Livestock do well anytime that good quality grass is present. Livestock and perennial grass also reduce economic risks by reducing yearly variations in returns [26, 38].

Farming becomes a year-round occupation when sod and livestock grazing are added to row-crop rotations. With winter grazing, all fields are utilized for the entire year instead of for 125–155 days during the summer growing period. Farmers must start slowly with livestock if they do not have experience. Fencing will have to be installed. Likewise, cattle producers may find it difficult to terminate bahiagrass after only two seasons of grazing. However, the system mitigates risk and increases profits for both row-crop and livestock farmers. Integrating livestock into row-crop enterprises can be challenging since it does increase labor requirements. The transition is easiest for established livestock producers and more difficult for pure row-crop farmers who will benefit from learning from their livestock-owning neighbors.

ECONOMICS OF THE SOD-BASED ROTATION

Table 8.2 shows the crops, costs and revenue for an example 200-acre farm transitioning to a sod-based rotation with livestock grazing. Prior to the first year, the farm used a standard conservation rotation with two-thirds of the farm in cotton and one-third in peanuts. The net returns for the standard conservation rotation are shown at the top of Table 8.2. The net returns during the transition are compared to the returns for a standard conservation rotation with an oat cover crop each winter.

For the first year of the transition, the 200-acre farm is divided into four 50-acre fields. A 200-acre farm is an economical size for small farms with limited available labor. The first year of the transition has 50 acres in bahiagrass, 100 acres in cotton and 50 acres in peanuts. The following years have 100 acres in bahiagrass, 50 acres in cotton and 50 acres in peanuts. Grazing the bahiagrass can begin 10–12 weeks after planting in the first year. The example in Table 8.2 assumes that grazing does not occur until the second year.

In the first year, net returns are low due to establishment costs for the bahiagrass, fewer acres of cash crops and no income from grazing. However, profits are still greater with the transitioning farm than with the standard conservation rotation. Revenue generated in the first year with bahiagrass assumes two harvests of hay, baled either square or round. Livestock grazing is added the second year and significantly increases income. Third-year returns are more than three-fold higher than the standard rotation due to the expected yield increase for peanuts. Depending on conditions, third-year net returns can be two to six fold higher than the standard rotation. In year four, net income is also more than three fold higher than the standard rotation. Fourth-year net returns can be three to six fold higher than the standard rotation. Additional increases in year four are due to increased cotton yields. The net income in the fourth year is the projected annual net income for this example.

Returns are greater when livestock graze on first-year bahiagrass throughout the season, as observed on a 99-acre farm in Florida. In this example, 81 head of livestock (cow/calf pairs) grazed on 49 acres of second-year bahiagrass as well as 49 acres of first-year bahiagrass. In another example, more livestock were supported on a 172-acre farm, with as many as 200 head on winter grazing in the sod-based rotation. Many more animals can be raised in a year-round cow/calf operation.

TABLE 8.2. Cost and return comparison of a standard conservation rotation and a four-year, sod-based rotation

STANDARD CONSERVATION ROTATION
Annual costs and returns with two-thirds of the acres in cotton and one-third in peanuts

	Crop	Yield	Units	Acres	Costs	Revenue	Profit
	Cotton	1,000	Pounds	133.7	$100,265	$108,297	$8,032
	Peanuts	4,200	Pounds	66.3	$51,408	$72,400	$20,991
			TOTAL	200	$151,673	$180,697	$29,024
					FOUR-YEAR TOTAL		$116,096

CONVERTING TO SOD-BASED ROTATION
Projected annual costs and returns for the four-year, sod-based rotation

YEAR ONE

Field	Crop	Yield	Units	Acres	Costs	Revenue	Profit
1	Bahia 1[1]	3	Tons	50	$18,554	$32,826	$14,272
2	Cotton	1,000	Pounds	50	$37,496	$40,500	$3,004
3	Peanuts	4,200	Pounds	50	$38,769	$54,600	$15,831
4	Cotton	1,000	Pounds	50	$37,496	$40,500	$3,004
			TOTAL	200	$132,315	$168,426	$36,111

YEAR TWO

Field	Crop	Yield	Units	Acres	Costs	Revenue	Profit
1	Cattle[2]	81	Calves	50	$34,139	$84,443	$50,303
2	Bahia 1	3	Tons	50	$18,554	$32,826	$14,272
3	Cotton[3]	1,200	Pounds	50	$41,246	$48,600	$7,354
4	Peanuts	4,200	Pounds	50	$42,519	$54,600	$12,081
			TOTAL	200	$136,459	$220,469	$84,010

YEAR THREE

Field	Crop	Yield	Units	Acres	Costs	Revenue	Profit
1	Peanuts[3]	5,200	Pounds	50	$42,519	$67,600	$25,081
2	Cattle	81	Calves	50	$34,139	$84,443	$50,303
3	Bahia 1	3	Tons	50	$18,554	$32,826	$14,272
4	Cotton	1,200	Pounds	50	$41,246	$48,600	$7,354
			TOTAL	200	$136,459	$233,469	$97,010

YEAR FOUR

Field	Crop	Yield	Units	Acres	Costs	Revenue	Profit
1	Cotton	1,450	Pounds	50	$41,246	$58,725	$17,479
2	Peanuts	5,200	Pounds	50	$42,519	$67,600	$25,081
3	Cattle	81	Calves	50	$34,139	$84,443	$50,303
4	Bahia 1	3	Tons	50	$18,554	$32,826	$14,272
			TOTAL	200	$136,459	$243,594	$107,135
					FOUR-YEAR TOTAL		$324,265

[1] "Bahia 1" refers to first-year bahiagrass.
[2] In each year, this row refers to the number of cattle grazing second-year bahiagrass.
[3] Cotton and peanut yields increase over time as the benefits of including them in a sod-based rotation are realized.

These examples show that livestock are important for profitability. Contract grazing of stocker livestock in the winter can achieve returns of $427–$1,373 per acre [6]. Research has also shown that livestock can add profitability to cropping systems without reducing the yield of winter wheat or the following sorghum row crop [4]. However, increased peanut and cotton yields provide the biggest economic impact in a sod-based rotation. When livestock are in the system, some of the increased yield is due to improved nutrient cycling [37].

If a grower does not have livestock, there may be opportunities to increase profitability by selling bahiagrass or bahiagrass seed. Many small row-crop farmers in the Southeast have livestock herds of fewer than 100 head and may buy hay instead of investing in hay planting and harvesting equipment. Or, they may contract graze their livestock on both winter cover crops and summer bahiagrass. These are possible market opportunities for farmers who want to use a sod-based rotation without owning livestock.

Finally, one of the aspects of increasing net return in this system is the year-round use of land and labor. Year-round use of the land provides opportunities for better returns. While labor requirements and costs increase, net returns typically do as well.

Livestock is one of the missing links in developing sustainable systems [14]. Livestock prices fluctuate, so there is potential for occasional high income with livestock in the system. This justifies including perennial forages in the rotation. A rotation with sod, livestock grazing, row crops and winter small grains is a highly productive, economically sustainable, energy-efficient and environmentally friendly farming system. This rotation has the potential to improve the profitability of medium- and large-scale farms while also offering an attractive model to small family operations and beginning farmers.

If economics is the dominant factor when deciding whether to adopt a sod-based system, compare the system to a standard conservation rotation, even though such an analysis can be complicated [23]. Income is lost when the area allocated to the most profitable crop is reduced. However, the effect on the bottom line ends up being less severe than the lost income because the grass requires fewer inputs in terms of water, fertilizer, pesticides, labor and energy. In addition, a diversified, sod-based rotation offers economic risk management with unpredictable or extreme weather. If only half the farm is in cash crops during damaging weather, losses are reduced compared to a standard conservation rotation where the farm is entirely in cash crops. A deeper root zone with the sod-based system provides access to more soil water that reduces the impact of short-term drought. Soil improvements with a perennial grass in the rotation improve growth and yield of the main cash crop.

The website for the North Florida Research and Education Center (NFREC) has an interactive business model for evaluating the feasibility of a four-year, sod-based rotation. The business plan is presented as an Excel spreadsheet with several tabs. The tabs include detailed cost estimates for bahiagrass, row crops, cover crops, livestock, irrigation and labor. Costs for a standard conservation rotation and a sod-based rotation are included. A summary sheet brings cost and income information together into a four-year business plan. Real farm data can be entered into the spreadsheet to determine if a sod-based rotation is feasible for the farm. The website address is http://nfrec.ifas.ufl.edu/sod-rotation/. The business plan changes with time as more research data is added.

TIPS FOR GETTING STARTED WITH A SOD-BASED ROTATION

Row-Crop Farmers

- Evaluate your land base and develop a potential rotation.
- Test the economics using the NFREC business model with and without owning livestock and fencing.
- Put marginal dryland areas into sod first.
- Explore market opportunities for hay or seed production.

- Begin fencing some fields and explore contract grazing with neighbors.
- Start slowly and gain experience with livestock management.
- If you will graze livestock, evaluate the potential for soil compaction and use strip tillage for row crops to offset the impact.

Row-Crop and Livestock Farmers Working Together

- Evaluate the land base and develop a potential rotation.
- Test the economics using the NFREC business model with and without installing additional fencing.
- Put marginal, dryland row-crop areas into perennial sod first.
- Explore market opportunities for increasing herd size with the added grazing.
- Don't be afraid to terminate perennial grass and put in row crops.
- Manage compaction using strip tillage.

SUMMARY

Rotating perennial grasses with row crops adds economic value, increases yields and has environmental advantages when compared to standard conservation rotations. You can think of it as the next step after adopting conservation tillage. Cropping systems need to be flexible to take advantage of economic opportunities and to adapt to the environment. The sod-based system exemplifies this principle by growing plants year round and by using livestock to harvest forage grown opposite summer cash crops.

The diverse, sod-based system reduces risk due to the temperature and weather extremes that are normal in the Southeast. Developing cropping systems that recover quickly from climatic extremes has been and continues to be a major challenge to farmers in the region. Standard conservation row-crop rotations are less resilient when stressed by weather extremes and may limit opportunities to take advantage of market conditions or government programs. The sod-based system can help achieve agricultural sustainability and meet future challenges from increasing human population, fossil-fuel dependence, climate change and globalization.

Despite the apparent increase in profits, adoption of the sod-based rotation system is expected to be slow since many row-crop farmers consider themselves row-crop farmers and not livestock/row-crop farmers. This holistic approach to farming will be taken up first by those who currently have livestock, and others will follow as they see the value and benefit of a systems approach. Less than 5 percent of the peanuts produced in Florida are preceded by bahiagrass. With about 80 percent of the farmland being rented in Florida, as well as nationally, it is difficult for growers to rent land for $100–$175 per acre when they might not see a return from bahiagrass for a year or two if they do not have livestock. Growers are often forced to operate on short-term economic returns, but as they learn that profits can be two to six times greater in the sod-based system and that environmental benefits are increased, they will begin to adopt the system.

Put another way, assume that the profit for the sod-based rotation with livestock grazing is four times that of the standard rotation. A 250-acre farm with a sod-based rotation would plant 125 acres of cotton and peanuts. If establishment costs are $760 per acre, the farm is risking $95,000. To achieve the same profit with a standard rotation, 1,000 acres of cotton and peanuts would need to be planted, and the farm would risk $760,000 on these crops. The standard-rotation farm risks eight times more than the sod-based farm for the same profit. The sod-based system with livestock grazing is the ultimate in risk management. When weather extremes cause reduced yields, the financial loss is lower. Livestock use forages in most weather conditions year round.

Most growers will need to adopt the sod-based system slowly to become comfortable managing the diverse interactions in a crop/livestock system. As growers gain confidence in managing the system, the financial and environmental benefits will become evident.

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CHAPTER 9

Planting in Cover Crop Residue

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Editor's note: Figures 9.10 through 9.17 appear at the end of this chapter.

In conservation tillage systems, cash crop seeds or transplants are placed in the soil through cover crop residues on the soil surface. The residue inhibits weed emergence, increases rainfall infiltration, conserves soil moisture, keeps the soil cool and prevents the soil erosion and nutrient loss associated with rainfall runoff. Soil compaction is reduced because the grower makes fewer passes over the field and can use lighter equipment. Cover crops are terminated at least three weeks before cash crop planting to avoid competition with the cash crop for water and nutrients.

In this chapter, equipment and strategies for rolling/crimping cover crops are described. Equipment modifications are detailed for combining herbicide application and rolling/crimping in one pass. Select equipment for planting field crops and vegetable crops through residue is described. Planting equipment modifications are discussed including row cleaners, shanks, closing wheels and seed firmers.

COVER CROP TERMINATION METHODS

Termination methods include rolling/crimping, herbicide application, mowing, burning and incorporation. Rolling/crimping results in a mat of cover crop residue on the soil surface. Plants are flattened by the roller and crimped at regular intervals in one pass. The objective is to discourage root growth by injuring the plant without cutting the stem. All the plants fall in the same direction, which reduces residue accumulation on equipment and improves seed and transplant placement.

Roll/crimp most cover crops when they are in the reproductive stage: for cereal grains, early milk to soft dough; for clovers, mid-bloom; and for vetch, early bloom. For other cover crops like cowpeas, sorghum or sunn hemp, there is not much research available. Roll/crimp these cover crops when they reach maturity. Allow tall growing covers like sunn hemp and sorghum to reach 3–3.5-feet tall before rolling. When selecting the termination date, consider the goal of maximizing biomass production as well as the needs of the following crop.

Figure 9.1 shows the termination rate for rye rolled/crimped at different growth stages. When cereal rye was roll/crimped in the early milk to soft dough stage, 90 percent or more of rye died three weeks after rolling/crimping. However, when cereal rye is roll/crimped during early growth stages such as flag leaf, only 20 percent of

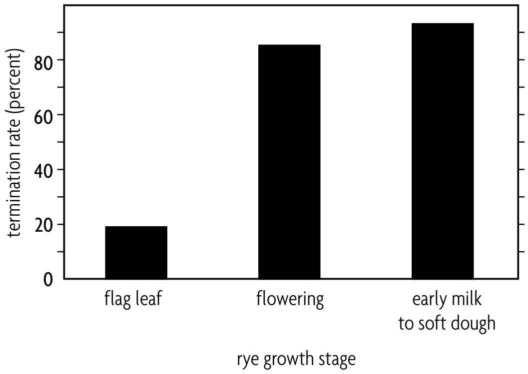

FIGURE 9.1. Roller/crimper termination rates at different growth stages for rye [1].

FIGURE 9.2. Brazilian-type roller/crimper with a detailed look at the height of the crimping bar.

the rye was killed three weeks after rolling/crimping. Under ideal weather conditions and with adequate soil moisture, rolling/crimping at the optimal growth stage allows cash crop planting into residue three weeks after rolling/crimping.

In the United States, cover crops are commonly terminated with herbicides, usually glyphosate. Spraying is fast, effective and inexpensive. Herbicide termination provides the flexibility to kill the cover crop in any growth stage. Spraying can be delayed to maximize cover crop biomass and gain the greatest benefit. When tall cover crops such as cereal rye, sudan grass or sunn hemp are terminated with herbicides, they fall in different directions. This results in seed or transplant placement problems, accumulation of residue on planting units, and frequent stops to clean the equipment.

Mowing is a popular method of cover crop termination in no-till vegetable and organic production systems. If mowing occurs early in cover crop growth, regrowth can occur and the cover crop will compete with the cash crop for nutrients and water. In addition, the residues decompose more quickly than rolled/crimped residues, which reduces the residues' effectiveness as mulch.

Although burning cover crops still occurs, cover crop benefits are completely lost. Heat from burning residue causes the soil surface to become hydrophobic, so rainfall infiltration decreases and runoff increases. Burning converts the carbon in the cover crop biomass to carbon dioxide so most of it is lost from the system rather than being stored in the soil. Toxic gases emitted to the atmosphere also make this method environmentally unfriendly. Incorporation preserves organic matter, but the soil surface is fully exposed. This leads to rainfall runoff and erosion.

ROLLER/CRIMPER EQUIPMENT AND EFFECTIVENESS

Traditional Brazilian-type rolling/crimping equipment consists of a steel drum with attached crimping bars equally spaced on the drum's surface (Figure 9.2). This has not been widely adopted in the United States because vibration from the crimper bars is transferred to the tractor and the operator. New types of rollers/crimpers

FIGURE 9.3. Rolling/crimping equipment: (left) spiral bar roller/crimper and (right) smooth roller with crimping bar.

have been developed that generate less vibration. The spiral roller/crimper (Figure 9.3a) does not generate adequate force to kill the plant, so supplemental herbicide application is necessary. Newer designs have a smooth roller to flatten the cover crop and a separate bar that crimps the cover crop at regular intervals, moving up and down as the roller goes forward (Figure 9.3b).

Some roller/crimpers have been designed specifically for raised-bed vegetable production. Figure 9.4a shows 8-foot wide equipment that simultaneously terminates cover crops on two row tops and three furrows. Figure 9.4b shows equipment that simultaneously terminates one row top and two furrows.

Figure 9.4c shows a 6-foot-wide two-stage roller/crimper designed to operate with smaller tractors (40 horsepower). Note this roller is not for raised beds. The 12-inch-diameter smooth drum flattens the cover crop and the 6-inch-diameter drum has six equally spaced, quarter-inch thick crimping bars on its surface. By adjusting the springs on either side of the small drum, the crimping force can be tailored to the cover crop and amount of biomass.

The two-stage roller/crimper has proven to be as effective as the original straight-bar roller. The percentage of the rye killed with the two-stage roller/crimper was the same as the straight-bar roller one week after rolling/crimping and better than the straight-bar roller two and three weeks after rolling/crimping (Figure 9.5).

TABLE 9.1. The amount of glyphosate spray solution and glyphosate formulation used for different treatments and termination achieved[1]

Treatment	Glyphosate spray solution applied (qt/ac)	Glyphosate formulation applied (qt/ac)	Glyphosate formulation amount of continuous spray, percent	Rye termination one week after rolling, percent		
				2006	2007	2008
Continuous spray	59.5	1.0	100	100	97	99
Spray every other crimp	17.2	0.3	29	97	94	97
Spray every fourth crimp	7.6	0.1	13	99	84	96

[1] The continuous spray application was calibrated to apply 1 quart (32 fluid ounces) of the glyphosate formulation per acre.

FIGURE 9.4. Roller/crimper for raised beds: (a) two rows and three furrows, and (b) one row and two furrows. A two-stage roller/crimper for smaller tractors (c).

Rolling/Crimping and Herbicide Application

Herbicide application may be needed if rolling/crimping does not terminate the cover crop in time to avoid competition with the cash crop. This typically occurs if there is a cold, wet spring, or if cover crop planting is delayed. Glyphosate is the most commonly used herbicide. It is normally sprayed continuously over the cover crop at a rate of 32 fluid ounces per acre. When combined with rolling/crimping, the glyphosate application rate can be reduced.

Figure 9.6 shows modifications to a smooth roller with a crimping bar. A custom-made boom is installed with a high-speed solenoid valve and five flat-stream discharge nozzles. Figure 9.7 shows additional modifications that result in a brief application of herbicide every second crimp. The yellow cam mechanism (C) shows that the bar crimps eight times for each drum rotation. Four engagement bolts (B) are fastened to the cam mechanism at equal intervals 4 inches from the center of the roller's rotation. As the roller rotates, the engagement bolts also rotate. When the bolt contacts the micro-switch arm (A), the solenoid valve is opened momentarily and glyphosate is discharged through the nozzles. Equipment can be modified in a similar way to apply herbicide every fourth crimp. In this case, two engagement bolts are installed.

Combining rolling/crimping with non-continuous spraying reduces herbicide application rates. Table 9.1 shows the rye termination rate when using a roller crimper in conjunction with three glyphosate treatments: continuous spray, spraying every second crimp and spraying every fourth crimp. Using this information, Table 9.2 was developed to compare costs. Spraying every second or fourth crimp results in reduced rates of glyphosate while achieving significant termination rates and cost savings.

Important note: The reduced rates of glyphosate application are only intended for cover crops that have been rolled/crimped. For effective weed control without rolling/crimping, follow the continuous-spray application rates recommended by Cooperative Extension or your appropriate state agency.

Tips for Successful Rolling/Crimping

- Plant cover crops early so they reach the growth stage optimal for termination without herbicide. Plant winter cover crops in October and November. Plant sum-

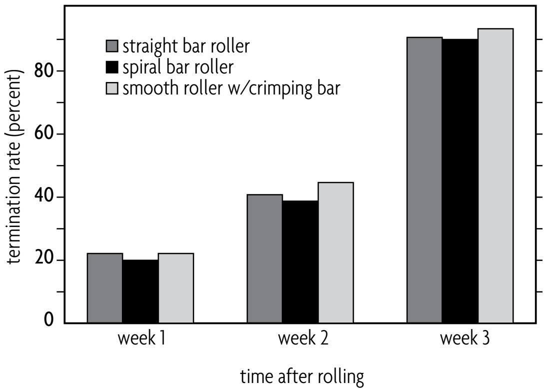

FIGURE 9.5. Rye termination rates at one, two and three weeks after rolling/crimping at the soft-dough stage for three types of equipment.

mer cover crops early enough for them to mature and be terminated before cash crop planting.

- Allow cereal grains to grow tall before termination. Rye less than 3 feet tall will eventually spring back and interfere with cash crop planting. Allow rye to reach 4 feet tall before rolling/crimping.
- Allow tall-growing covers like sunn hemp and sorghum to reach 3–3.5 feet tall before rolling/crimping.
- Successful crimping occurs when the soil surface is firm. Firm soil also prevents the cover crop from being pushed into the soil.
- Terminate cover crops at least three weeks before cash crop planting. This will prevent competition between the cash crop and cover crop for water and nutrients.
- Roll/crimp parallel to the cash crop rows to minimize planter-residue interference and buildup of residue on the planting units. Rolling perpendicular or diagonal to the cash crop rows slows emergence and lowers yields [4].
- When glyphosate application is combined with rolling/crimping, application rates can be reduced from the recommended continuous-spray application rates. Rolling/crimping equipment can be modified to allow non-continuous application of herbicide.

FIGURE 9.6. Back view of the smooth roller with crimping bar and the attached high-speed solenoid valve; (a) solenoid valve, (b) nozzle body and (c) nozzle.

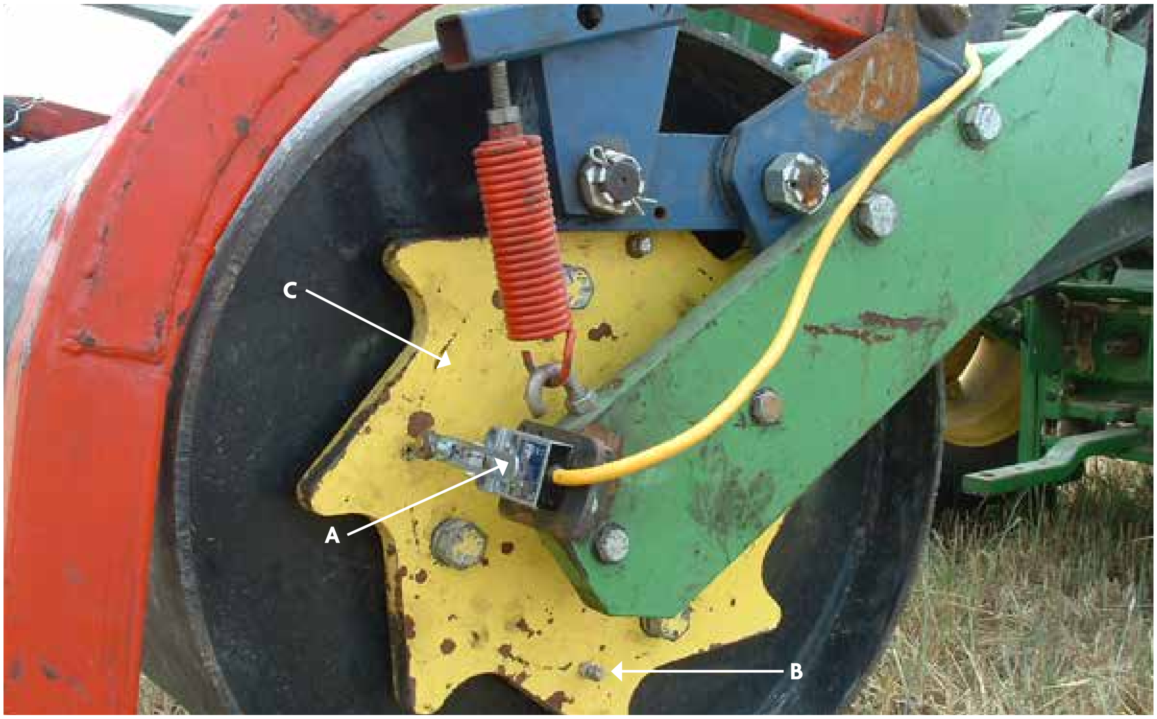

FIGURE 9.7. Side view of the smooth roller with crimping bar; (a) micro-switch, (b) engagement bolt with the switch's arm, and (c) eight-cam crimping bar control mechanism with clockwise rotation.

IN-ROW SUBSOILING COMBINED WITH PLANTING

In the Southeast, crops in conservation tillage systems are planted in combination with in-row subsoiling, usually 14–16 inches deep, when necessary to break up plow pans and other compacted soil. In-row subsoiling equipment is designed to cut through residue with minimal disturbance and perform non-inversion tillage in a narrow strip along the row. The equipment typically consists of a coulter that runs ahead of a shank to cut the residue. The coulter is followed by such attachments as additional coulters with or without row cleaners, rolling baskets, drag chains, or press wheels (Figure 9.8).

Row cleaners attached to in-row subsoiling implements can be used on cool, poorly drained soils to enable faster soil warming in spring. This allows earlier planting and helps ensure optimal plant emergence conditions. Row cleaners are available for most in-row subsoiling equipment and function much like row cleaners for planters: sweeping cover crop residue away from the row (Figure 9.9 and Figure 9.10). Adjustments for row cleaners on in-row subsoiling equipment are not as flexible as those for planters so they are not as popular.

The coulter must be sharp enough to completely cut residue without pressing it into the seed furrow. Residue in the seed furrow, referred to as "hairpinning," results in poor seed-to-soil contact and poor seed germination. One or more coulters are used depending on the desired degree of tillage. When in-row subsoiling through cover crop residue, position the coulter in line with the shank but as far forward as possible. This allows the coulter to operate on firm soil and enables it to completely cut residue ahead of the shank. If the coulter is too close to the shank, the soil near the coulter will be loosened by the shank and will not be firm. By cutting residue ahead of the shank, the shank can flow through the soil without residue wrapping around it and being dragged by the shank. Use a properly sized coulter with minimal wear to make residue cutting successful, to prevent hairpinning, and to achieve good seed-to-soil contact.

TABLE 9.2. Cost (dollars per acre) of various combinations of rolling and crimping with herbicide application, 2008[1]

Practice	Herbicide application without rolling/ crimping	Rolling/crimping and herbicide application as two separate passes[2]	Rolling/crimping with continuous spray	Rolling/crimping with spray every second crimp	Rolling/crimping with spray every fourth crimp
Roller/crimper[3]	-	$6.06	$6.06	$6.06	$6.06
Sprayer equipment[4]	$6.26	$6.26	$1.15	$ 1.15	$1.15
Herbicide[5]	$11.20	$11.20	$11.20	$3.21	$1.39
Total	**$17.46**	**$23.52**	**$18.41**	**$10.42**	**$8.60**

Source: [5]

[1] Costs include variable and fixed costs of application.
[2] This practice, not part of the study, was included for comparison purposes and is utilized in the Southeast.
[3] Based on the cost of a roller 9.1 feet wide from [6].
[4] Sprayer costs for experimental treatments are estimated based on the fixed cost, repair and maintenance, and hand labor costs when the sprayer is attached to the roller.
[5] Herbicide costs are based on rates taken from Table 9.1 and a cost of glyphosate of $11.20 per quart.

Fine-textured soils sometimes stick to and accumulate on the shank, disturbing too much soil and making the slit too wide. This can impede planter operations and is referred to as “blowout.” Plastic shields that fit over the shank prevent soil from sticking, therefore minimizing blowout (Figure 9.11).

Another way to reduce blowout is to install splitter points on the subsoil shanks. The splitter points look like shark fins that attach vertically upright to the tips of the shank points (Figure 9.8 and Figure 9.12). They fracture the soil at the bottom of the trench, preventing soil upheaval to the soil surface. The modifications discussed in this section are primarily for older-model in-row subsoiling equipment. Current equipment incorporates these modifications to improve performance in high-residue situations.

NO-TILL PLANTERS FOR FIELD CROPS

The objective when no-till planting in cover crop residues is adequate seed-to-soil contact at a desired seeding depth. Planters designed for operation in residues are heavier than conventional planters. The additional weight allows the planter to maintain the desired seeding depth in rough soil conditions and prevents the planter from floating across the soil surface, which results in uneven seed placement. Individual planter row units are typically equipped with heavy-duty down-pressure springs to maintain seeding depth in uneven soil conditions. In extreme cases, additional weight can be added directly to the planter.

Row cleaners sweep residue away from the opening disks of the planter units. They are useful when planting in heavy cover crop residue. There are different types of row cleaners for different types of planters (Figure 9.13).

Removing residue near the row reduces the chance of hairpinning. Adjust row cleaners to move residue without digging into the soil. If too much soil is disturbed, it will dry out and may crust over, which hinders emergence. In addition, disturbed soil can promote weed emergence in the row. Setting row cleaners too deep will cause residue to wrap around the row cleaners, which affects planting depth and seed coverage. Position row cleaners so that they rotate and “brush” residue away from the seed furrow.

When growing cotton after rye in a no-till system, the best cotton stand is obtained by rolling/crimping parallel to the cotton rows and using a

FIGURE 9.8. Wide-strip subsoiler. Picture shows (a) a narrow fluted coulter with attached row cleaners on the front of the shank, (b) splitter points attached to the shank, (c) additional coulters (ripper type) and (d) a drag chain sheet.

row cleaner, either Dawn™ or Yetter™. Rolling/crimping parallel to the row reduces accumulation of residue on the row cleaner as well as the time needed to clean the row cleaners. Cotton can be successfully planted into standing rye as long as row cleaners are used and rye is less than 3 feet tall with less than 1.2 tons per acre of dry biomass. If rye less than 3 feet tall is rolled/crimped, no row cleaners are needed for successful planting. Rolling/crimping is required when the rye height exceeds 4 feet.

Spoked closing wheels (Figure 9.14) can be helpful in poorly drained or fine-textured soils. They crumble the seed trench closed, which improves seed-to-soil contact and leaves the soil loose and friable for plant emergence. Traditional cast iron or smooth rubber closing wheels used on these soils can result in soil crusting that will hinder emergence. Spoked closing wheels can throw seed out of the soil, especially when planting depth is shallow. This usually occurs if the planter is running too fast, and the easiest solution is to slow down.

Additional planter attachments to ensure adequate seed-to-soil contact in rough soil conditions include V-slice inserts and seed firmers (Figure 9.15). V-slice inserts clean the seed trench created by the opening disks. Seed firmers press the seed into the soil at the bottom of the seed trench. These attachments result in additional costs but are cost effective in poorly drained or fine-textured soil.

Important note: Soil type, soil moisture, equipment condition and equipment settings affect the success of no-till planting. Select and set up equipment for existing field conditions and to combine field operations such as subsoiling and planting. Combining operations saves fuel and time but requires a high level of management and experience.

NO-TILL VEGETABLE TRANSPLANTER

Commercially available no-till vegetable transplanters are usually equipped with a coulter to cut through residue. The RJ transplanter, manufactured in Canada, is a typical example. It has a spring-loaded 20-inch, turbo-fluted coulter, followed by a double-disk opener and a shoe with a kicker mechanism to place the transplants in the soil. Angled steel press wheels push the soil firmly around the plant. The transplanter provides a uniform planting depth and there is no loose soil after closing the trench with the press wheels.

Some soils in the Southeast are prone to compaction not only due to equipment traffic but also due to natural soil consolidation. There are no commercially available subsoilers that attach to no-till vegetable planters. Transplanters can be modified by adding a subframe between the toolbar (with a mounted plastic tank for water/start-up fertilizer) and the transplanter (Figure 9.16a). The subframe is able to accommodate both commercially available subsoiling shanks as well as custom shanks. The shank disrupts compacted soil to a depth of 12–16 inches beneath heavy residue. Two driving wheels (one wheel on each side of the transplant row) replaced the original single drive wheel at the center of the row. This improves stability and helps minimize recompaction of the soil opening created by the shank. No-till transplanting of tomato plants into previously rolled/crimped rye is shown in Figure 9.16b.

The modified transplanter also includes a custom bracket, mounted to the subframe (Figure 9.17); it is used to attach row cleaners behind the fluted coulter. This helps eliminate residue accumulation on the transplanter. The row cleaners are especially necessary when thick cover crop residue is not rolled and lodges in different directions.

SUMMARY

- When rolling/crimping without supplemental herbicide, terminate the cover crop at the optimal growth stage and at least three weeks before cash crop planting.
- If weather in the spring is wet or cold, and cover crop termination is delayed, herbicide application is recommended to speed up termination.
- Application rates less than label rate are effective in terminating a cover crop if combined with rolling/crimping. Equipment can be modified to apply herbicide while rolling/crimping to save fuel and time.
- Roll/crimp cover crops parallel to the cash crop row. This minimizes or eliminates residue buildup on planting equipment. Diagonal and perpendicular rolling are not recommended because of increased residue buildup, increased planting time due to frequent residue removal stops, and decreased planting quality, such as skips in planting, “hairpinning” and slow emergence.
- Non-inversion tillage (subsoiling) is sometimes needed in the spring to alleviate soil compaction before planting of the cash crop. This operation is important to provide the best soil conditions for optimal seed emergence of the cash crop.
- No-till planters must be properly adjusted to assure a uniform seed planting depth and to minimize or eliminate residue buildup on the planting units. The adjustments are dependent on field conditions including soil moisture and the amount of residue on the soil surface.
- Set coulters as far ahead of the shank as possible so they are not cutting on soil disrupted by the shank. Keep coulters sharp so they can cut through residue.
- Row cleaners must not dig into the soil and should only brush residue away from the furrow. Setting row cleaners too deep will result in soil-surface disruption and residue accumulation on the row cleaners.
- Closing wheels optimize seed-to-soil contact. Spoked closing wheels must have an appropriate down-pressure setting to obtain adequate seed-to-soil contact and to provide necessary soil aeration without creating sidewall compaction. In addition to closing wheels, seed firmers are also utilized to improve seed-to-soil contact if needed.
- No-till vegetable transplanting involves cutting into residue using a transplanter equipped with a coulter with or without row cleaners. When compaction is a problem,

modify the transplanter by adding a subsoiler shank that reaches below the compacted layer.

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FIGURE 9.9. John Deere no-till planter for planting cotton seeds into rye residue using Dawn row cleaners.

FIGURE 9.10. John Deere no-till planter with attached Yetter row cleaners.

FIGURE 9.11. Plastic shield that fits over the shank to prevent soil from sticking to the shank, minimizing "blowout."

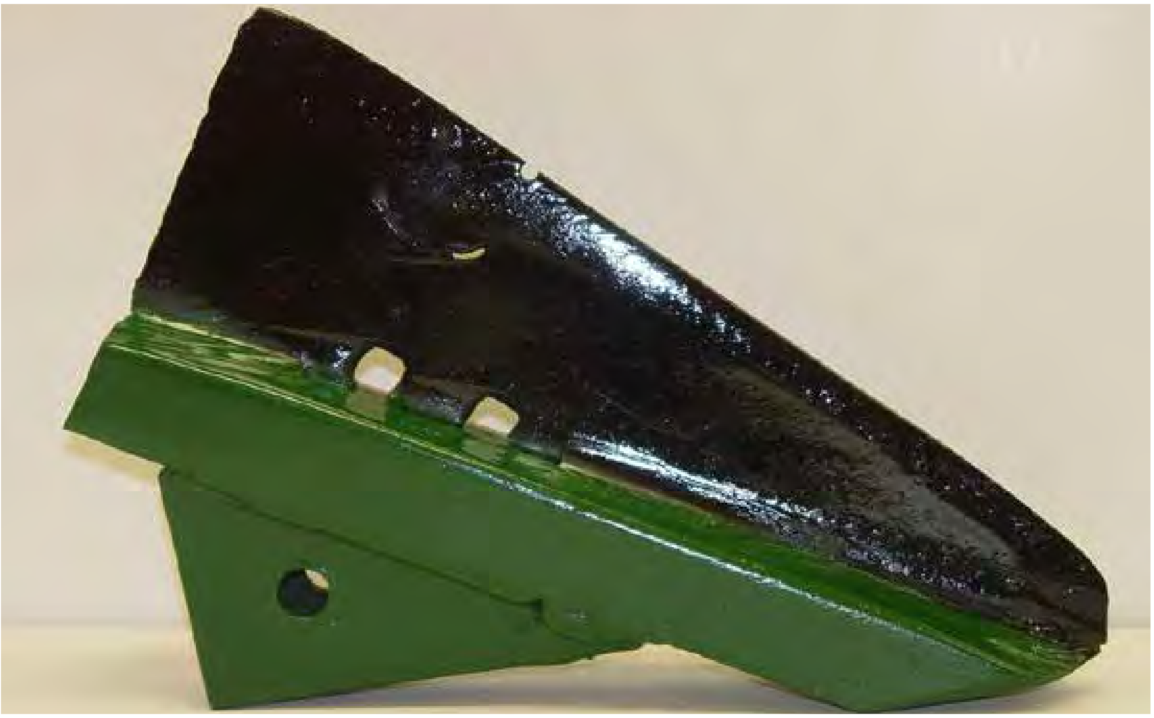

FIGURE 9.12. A splitter point is a black, sharp-edged plastic addition that looks like a shark fin and is attached directly to the tip of the shank point (see Figure 9.10).

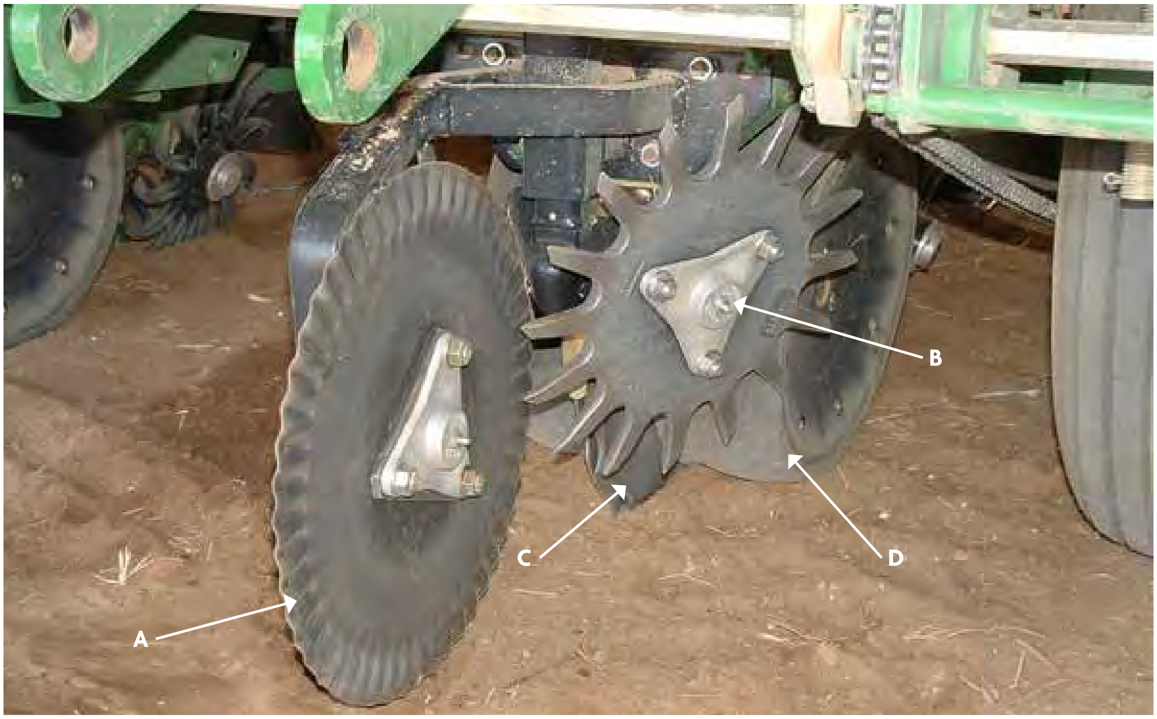

FIGURE 9.13. (a) Narrow fluted coulter with (b) the attached Dawn row cleaners for a John Deere planter. (c) Double disk openers and (d) gage wheels are also shown.

FIGURE 9.14. Top view of spoked closing wheels on a John Deere no-till planter.

FIGURE 9.15. This John Deere no-till planting unit shows (a) a disk opener with a planting tube knife, (b) seed firmer, (c) V-slice insert and (d) press wheels with rubber tire assembly controlled by (e) a downward pressure adjusting lever.

a

b

FIGURE 9.16. Side view of the modified RJ transplanter showing (a) the subframe with (b) the subsoiler shank and (c) two driving wheels to power the planting unit (left). Planting tomato seedlings into previously rolled/crimped rye using a modified RJ no-till transplanter from RJ Equipment Company (right).

FIGURE 9.17. Close-up of the RJ transplanter showing (a) the subframe for the subsoiler (subsoiler removed) with (b) an attached custom-made bracket for proper positioning of (c) the row cleaners behind (d) the fluted coulter.

CHAPTER 10

Soil Fertility Management

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Conservation tillage practices result in changes that affect soil fertility management on the farm. Application methods used in conservation tillage influence the distribution of lime and fertilizer in the soil profile and over the field. Soil samples sent to testing laboratories are evaluated the same whether from conventional or conservation tillage farms, even though there are subtle micro-environmental differences. Producers must design their own sampling and fertilizer management scheme since there are numerous variations of conservation tillage. Since surface-applied lime may not affect subsoil pH, pH must be measured in the subsoil to assure it will not inhibit root development. Nitrogen losses are greater when nitrogen is surface applied instead of incorporated. This chapter focuses on lime and fertilizer management issues to consider when adopting conservation tillage.

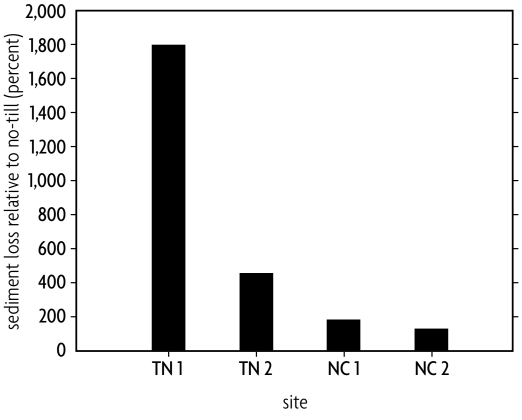

FIGURE 10.1. Sediment loss in conservation tillage as a percentage of sediment loss with no-till in Tennessee with full-season soybeans (TN 1) and double-crop soybeans (TN 2) [33], and in North Carolina with cotton (NC 1) or corn (NC 2) [9].

EFFECTS ON SOIL FERTILITY MANAGEMENT

Tillage and residue-management practices have numerous complex effects on soil. These effects are influenced by soil characteristics, tillage and residue-management practices (Table 10.1). Tillage intensity and cover crops influence the amount of soil mixing, site erodibility, nutrient loss, and soil structure, moisture, and temperature. Anything that changes infiltration, leaching, or runoff, or affects crop root development, could change site productivity and thus nutrient needs. On sloping land, erosion control may be the most visible benefit of conservation tillage (Figure 10.1), while enhanced infiltration and improved equipment access may be more important on flat land (Figure 10.2).

Residue and cover crop decomposition will be slower with less tillage (Figure 10.3), although this primarily influences organic-matter distribution in the soil profile rather than the total amount of organic matter remaining. More organic matter remains on the soil surface with no-till, while tillage incorporates residues deeper into the profile (Figure 10.4). Increasing total soil organic-matter levels is difficult regardless of the tillage system. This is especially true in southeastern sandy Coastal Plain soils due to the generally warm, humid and well-aerated conditions.

Successful use of conservation tillage requires producers to understand how their soils respond to traffic and reduced tillage, and how to establish crops in surface residues. Continuous no-till has been successful with some soils and rotations. However, some cropping systems, especially continuous cotton and silage corn, and some

TABLE 10.1. Examples of soil structural changes reported in different no-till studies where crop residues were left on the soil surface

Location	No-till duration (years)	Soil texture	Observations (contrasts between no-till and conventional till)
Tennessee [37]	4	Silt loam	More surface organic matter, less plow layer compaction with no-till than with disking
North Carolina [40]	3	Sandy loam	Bulk density increases over time while permeability decreases in trafficked interrows (only investigated no-till)
Kentucky [35]	10–25	Silt loam	More organic matter and moisture, lower surface bulk density with no-till
Maryland [42]	3	Silt loam	More stable aggregates and more glomalin[1] with no-till
Mississippi [32]	4–8	Silt loam	Aggregates were more stable, but less surface crust prone with no-till
Canada [1]	5–15	Sandy loam, silt loam	More small pores and faster infiltration with no-till
Brazil [23]	—	Clay	More stable aggregates with more total organic carbon with no-till
Australia [24]	8	Clay	More large pores and faster infiltration, less crusting with no-till

[1] Glomalin is a glycoprotein (carbohydrate plus protein) compound that contributes to soil particle aggregation and improved soil structure.

soils, especially those with low organic matter, experience soil compaction that must be alleviated with in-row subsoiling or strip tillage. Studies from both North Carolina [28] and Australia [5] describe increasing soil bulk densities with no-till where soil organic-matter concentrations are low. As bulk density increases, the soil hardens. In the sandy Coastal Plain soils of North Carolina that have 1 percent or less organic carbon, bulk density was found to exceed 1.5 grams per cubic centimeter with no-till, as shown in Figure 10.5. This is considered too high for successful crop growth because root growth is inhibited. The photographs in Figure 10.6 have the same variety, plant populations and planting date. They show less vigorous growth of soybeans in the no-till plots on a sandy Coastal Plain site [28].

Rotations with winter-grain cover crops may require a combine straw spreader to uniformly distribute residues. Uniformly distributed residues make it easier to achieve the desired seeding depth and seed-soil contact throughout the field for the subsequent crop. To minimize rutting and soil compaction, do not plant or harvest when the ground is too wet. Planting equipment designed for no-till systems is essential for good stand establishment. Use a no-till grain drill or a no-till planter with options for row cleaners and starter fertilizer band placement. When row cleaners are used, adjust them for minimal soil disturbance. These and other practices that contribute to uniform stands increase nutrient-use efficiency since yield is maximized and the rapidly growing crop canopy reduces nutrient losses.

SOIL TESTING AND FERTILITY MANAGEMENT

Soil testing is the basis for an effective soil fertility management program. The following standard principles apply whether using conventional or conservation tillage:

FIGURE 10.2. No-till management with a prominent residue layer and improved infiltration (left), contrasted with nearly bare soil and ponded water that has resulted under conventional tillage. The fields are at the North Carolina Tidewater Research Station in Plymouth, N.C.

- Prior to sampling, check with the laboratory for information concerning sampling depth, packaging, information forms, typical laboratory turnaround time, analyses performed and fees. Contact information for state laboratories in the Southeast can be found online through the Southern Extension and Research Activities Information Exchange Group. (Search for “sera6” to find the website.) Private laboratories provide similar analyses but may utilize different extractants and procedures. Be aware that there are regional differences in procedures and calibration databases. Verify that the lab’s testing methods have appropriate local interpretations.

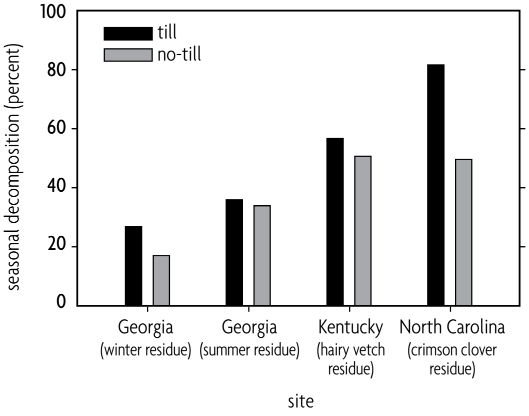

FIGURE 10.3. Cash crop and cover crop residues decompose more slowly with no-till. Georgia data is for cash crop residue. Hairy vetch and crimson clover are winter cover crops. Data are from Georgia [15], Kentucky [39] and North Carolina [10].

- Use tools such as a stainless steel or chrome-plated sampling probe and a clean plastic bucket to avoid contamination.
- Samples must be representative of the field or portion of the field of interest. This requires planning to ensure that an adequate spacing and number of cores are collected from a consistent depth.
- Routine samples are easiest to interpret when collected at the same time of year or same point in the crop rotation.
- To diagnosis problem areas, more detailed sampling is useful. Collect separate samples from both problem and normal areas of fields, and from surface and subsurface layers.

See the North Carolina State University Extension publication *Soil Facts: Careful Soil Sampling—The Key to Reliable Soil Test Information* (AG-439-30) [29] or a similar publication from another state for more details. Search for “careful soil sampling” to find publications and websites that provide information on soil sampling.

Vertical Stratification

Surface application of lime and fertilizer to no-till fields often leads to nutrient stratification. Take this into account when sampling. Stratification means the upper few inches of soil contain most of the applied plant nutrients, whereas the subsoil

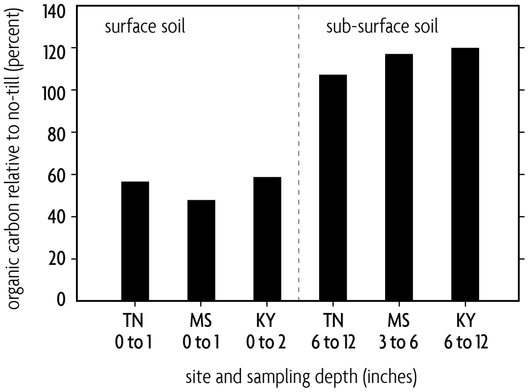

FIGURE 10.4. Organic carbon levels in conservation tillage as a percentage of organic carbon levels with no-till. Levels are higher near the surface with no-till, but higher in the underlying layer with tillage. Data are from Tennessee (TN) [37], Mississippi (MS) [32], and Kentucky (KY) [18].

contains fewer nutrients. This is especially true for phosphorus, which is relatively immobile in soils (Figure 10.7) [31, 16]. In practice, the biggest difference in stratification occurs between moldboard plowing and other less intensive tillage practices or no-till. Neither disk nor chisel plowing thoroughly mix nutrients into the profile (Figure 10.7). The effect of strip tillage will depend on the width and depth of tillage and whether lime and fertilizers are broadcast or banded in the tillage zone.

In conservation tillage fields, take soil samples at a shallower depth than in conventionally tilled fields [20]. Crop responsiveness to phosphorus or potassium fertilizer is better correlated with soil nutrient levels in the enriched surface soil than with the underlying soil [41]. Crop rooting is usually more prolific in the surface soil layer [26], and acidity due to the nitrification of surface-applied nitrogen fertilizers can be localized in this layer [21]. Although more crop roots may be present in the nutrient-enriched surface soil, nutrient stratification is not a problem if there are enough deep roots to acquire needed moisture from the subsoil.

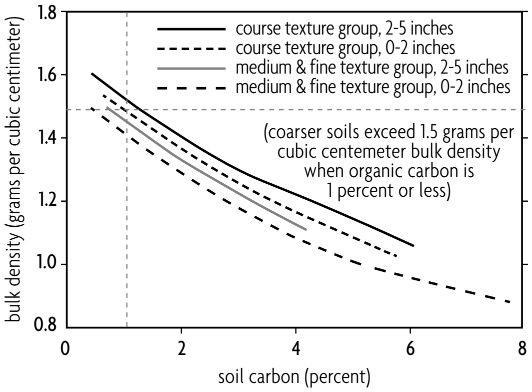

FIGURE 10.5. Soil bulk density increases as organic carbon decreases in fields managed with no-till, with highest bulk density in sandy soils [28].

Two contrasting factors influence the nature of soil pH stratification. First, nitrification reactions generate acidity and reduce surface soil pH following nitrogen fertilization. Second, lime neutralizes acidity and increases surface soil pH. Soil pH stratification patterns vary depending on soil type and lime management (Table 10.2). If prior tillage management has incorporated lime to a depth of only 3 or 4 inches, low soil pH may limit root development in acidic subsoils. Several years may be required for surface-applied lime to neutralize subsoil acidity [6, 7]. In conservation tillage fields with low pH subsoils, incorporate lime and then return to conservation tillage practices or apply lime more frequently.

Occasional sampling to check for stratification in the soil profile is recommended. A simple way to collect samples from two soil depths is to use a soil probe and two buckets. If samples are desired from 0–4 inches and 4–8 inches, probe to 8 inches, divide the soil core in half, and place the halves in separate buckets. Most laboratories recommend sampling to a typical plow layer depth, usually 8 inches, but this varies with soil texture and actual plowing depth. With conservation tillage, especially continuous no-till, the recommended sampling depth is shallower, 0–4 inches. But, awareness of the type and degree of stratification can help producers decide if their optimum routine sampling depth is 2, 4, 6 or 8 inches. If soil pH is more acidic near the surface, a shallow soil sample will detect it. Deeper sampling is required to determine the pH below 4 inches.

Banding Fertilizer

Fertilizers are sometimes placed in bands near the crop roots to reduce the total amount applied.

FIGURE 10.6. Soybean growth is much less vigorous with continuous no-till (right) than with conventional tillage with a chisel and disk (left) in these soils with a low level of organic carbon [28].

Subsurface band placement also reduces surface runoff losses and nutrient stratification [43]. Spring-planted crops respond better to starter fertilizers with conservation tillage than with conventional tillage due to cooler soil temperatures. Cooler soil temperatures slow root development and thus limit the volume of soil explored by the roots of developing seedlings. An ideal placement for starter fertilizer bands is 2 inches to the side and 2 inches below the seed. Other fertilizer placements may also be adequate, such as surface banded or in the crop seed furrow. Sidedressed liquid nitrogen fertilizers can be banded by either subsurface placement behind a coulter/knife or by surface placement with an orifice, parallel-oriented flat-fan nozzle, or rubber-hose attachment to narrow the fertilizer stream.

Band placement can save on fertilizer input costs but may result in residual fertilizer band effects. Persistent fertilizer bands can result in uneven second-crop responses and may make the soil sampling process more difficult. Figure 10.8 shows this effect. In prior crop rows, wheat plants were more vigorous. Also, the soil pH and extractable phosphorus were higher in the row than in between rows. Starter fertilizer containing phosphorus had been applied near the row position, while sidedress nitrogen and associated nitrification reactions were concentrated between rows, lowering the pH. Use a random pattern of soil core collection to avoid bias due to over-sampling in the crop row or between rows [36].

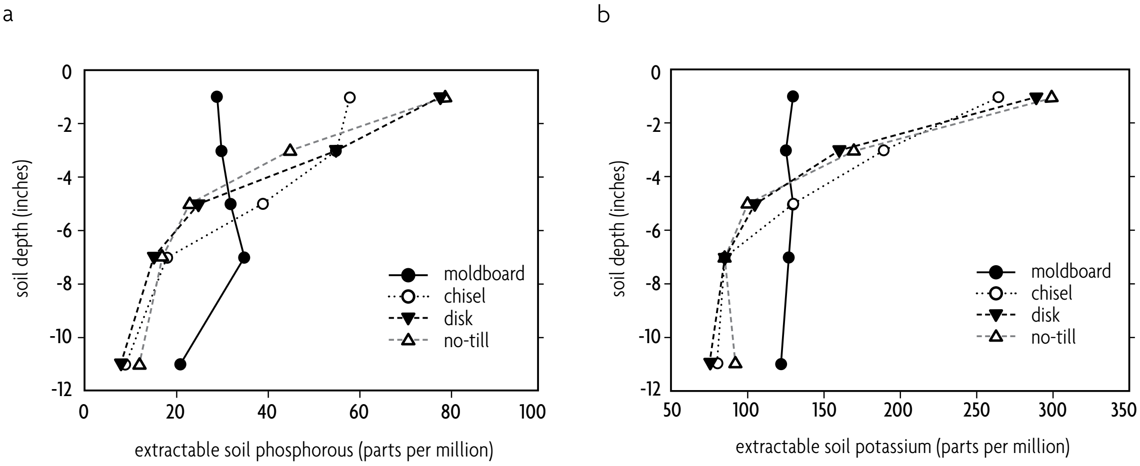

FIGURE 10.7. Effect of tillage system on soil mixing reflected in nutrient distribution: phosphorus (left) and potassium (right) [31].

TABLE 10.2. Soil pH stratification patterns reported in different studies

Location	Soil texture	Tillage type[1]	Tillage duration, years	pH stratification pattern
Georgia [14]	Sandy loam	CT, RT, NT	5	pH lower in subsoil with NT, similar at surface for all
Kentucky [2]	Silt loam	CT, NT	10	Limed: pH higher near surface with NT Not limed: pH lower near surface with NT
Maryland [22]	Silt loam	NT	2–3	If high nitrogen fertilizer rate (250 pounds of N per acre): pH lower near surface than in subsoil
Montana [19]	Silt loam, clay loam	CT, RT, NT	2–4	pH lower near surface with NT and RT
Kentucky [18]	Silt loam	CT, NT	20	pH higher near surface with NT
North Carolina [11]	Statewide, several soils	CT, NT	Less than 6 and more than 6 of NT	pH higher near surface with CT or NT less than six years, than with NT more than six years
Australia [6]	clay loam	CT, NT	8–12	pH higher near surface with NT
Brazil [3]	Clay	CT, NT	5	pH higher near surface with NT

[1] Tillage options are abbreviated: CT is conventional tillage (intensity varies by region); NT is no-till; and RT is one of several forms of reduced tillage.

Designing a Sampling Strategy for the Entire Rotation

An ideal soil-sampling program allows the producer to select appropriate lime and fertilizer rates and to monitor long-term soil fertility trends. For crop rotations of three years or shorter, sampling once per rotation, prior to the most sensitive crop, may be sufficient. Sample more frequently for soils with low cation exchange capacity (CEC), leaching conditions or low residual fertility. Sample annually to more closely monitor high-value crops. Sample at a consistent depth: typically 4 inches for continuous no-till or other conservation tillage practices that result in minimal soil mixing. Periodically sample the subsoil to a consistent depth: typically 4 to 8 inches to evaluate the fertility and pH of deeper soil. If most fertilizers are banded, blend sample cores taken from the crop row, between rows and intermediate positions to account for variability associated with residual fertilizer.

MINIMIZING NITROGEN LOSS

The nitrogen cycle describes the many ways nitrogen can change forms in the environment, including changes that occur on farmland (Figure 10.9). There are several common nitrogen fertilizer formulations. Most are granules or liquids containing urea, ammonium or nitrate. Manures, legume cover crops or residual plant nutrients from previous crops also supply nitrogen. Under the warm, moist, aerobic conditions common during most southeastern cropping seasons, rapid mineralization and nitrification reactions will transform most nitrogen inputs to nitrate. Nitrates dissolve easily in water and can be lost through surface runoff, subsurface leaching or denitrification. Surface-applied nitrogen fertilizers can be changed into ammonia and lost to the atmosphere in a process referred to as volatilization. Assess the farm's risk of losing nitrogen via these pathways and design a fertilization plan to minimize losses.

Volatilization Losses

Volatilization losses of ammonia are greatest with a high surface-soil pH and when nitrogen does not mix with the soil. Volatilization is of particular concern with conservation tillage systems since fertilizer is generally applied onto the soil surface or surface residue. Table 10.3 estimates likely percentages of fertilizer nitrogen losses for various soil, weather and fertilizer scenarios. For humid areas with a soil pH less than 7, expected ammonia volatilization losses are low, less than 5 percent, regardless of the nitrogen source or placement method. For sub-humid and dry areas with a soil pH less than 7, volatilization losses are a concern. In these areas, use nitrogen fertilizers with less urea and inject or incorporate urea-containing fertilizers. When the soil pH is greater than 7, incorporate all nitrogen fertilizers containing urea or ammonium regardless of climate. For either condition, urease inhibitors reduce the rate of conversion of urea to ammonium and may be effective at reducing volatilization losses when applied with fertilizers that contain urea. Using a urease inhibitor increases the likelihood that rainfall will move soluble urea into the soil profile before volatilization can occur.

Denitrification Losses

Denitrification is the conversion of nitrates to nitrogen gas. Denitrification losses are greatest in wet soils with high organic-matter content (Table 10.4). In fields with substantial risk of loss, optimize field drainage to reduce root-zone saturation. To reduce the likelihood of early-season nitrogen losses, apply most nitrogen fertilizer as a mid-season sidedress rather than applying all of it at planting. Consider the use of a nitrification inhibitor with urea-based or ammonium-based fertilizers. The duration of an inhibitor's effectiveness can be limited in southeastern soils with higher organic-matter content [4].

Leaching Losses

Leaching losses refer to the flushing of nitrates down through the soil profile by rain or irrigation water. Leaching losses can be substantial in humid regions and vary greatly depending on soil, climate and management of fertilizer and irrigation. Even though water infiltration is greater

FIGURE 10.8. Wheat crop exhibiting streaks associated with fertilizer bands applied to a prior cotton crop. The image illustrates both (a) the row positions of the prior cotton crop and (b) the inter-row positions of the prior cotton crop.

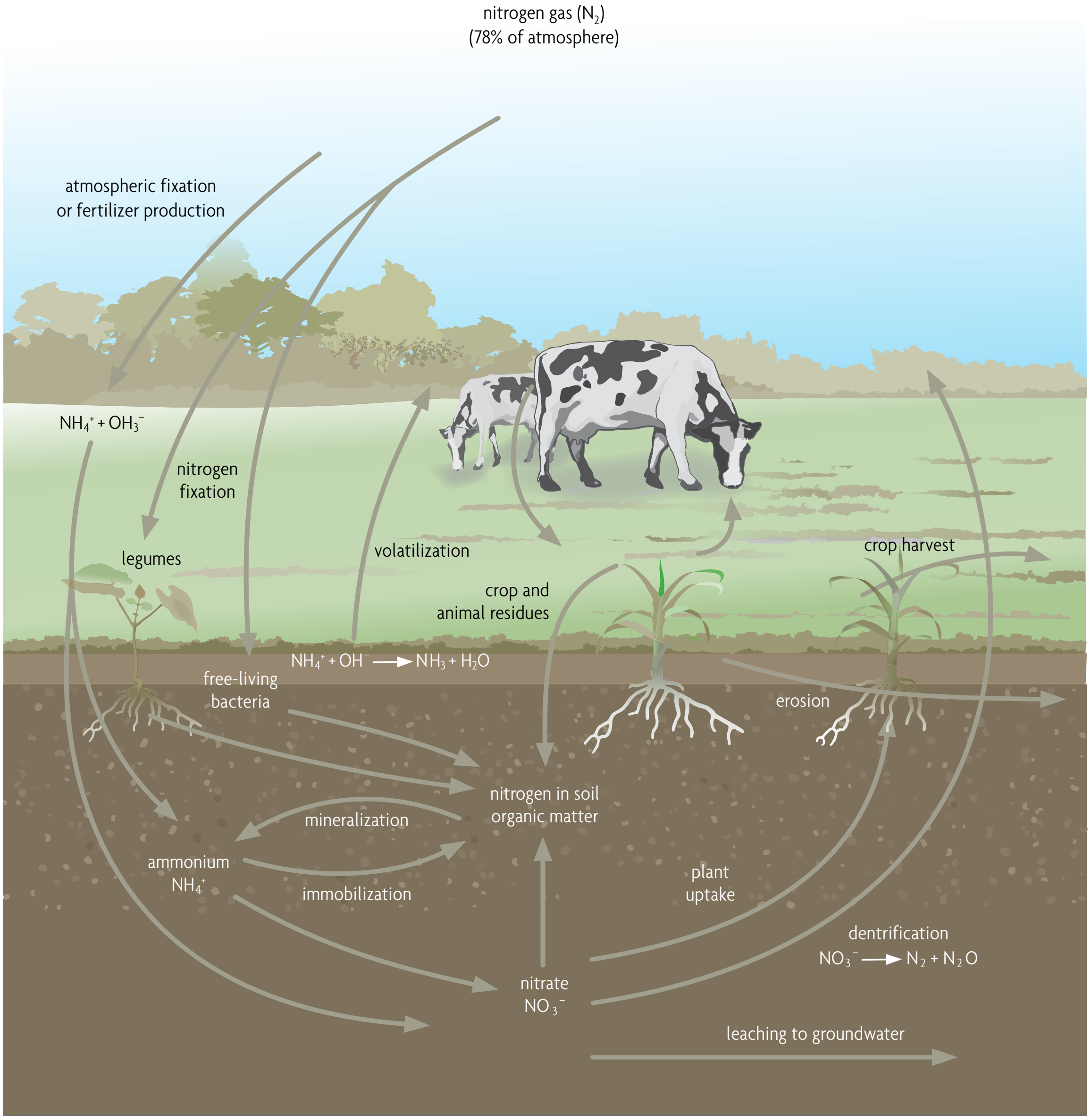

FIGURE 10.9. The nitrogen cycle.

with conservation tillage, studies from Tennessee [38], Iowa [34], Canada [12] and North Carolina [30] suggest that tillage has less influence on nitrate-leaching losses than crop rotation, nitrogen fertilizer rate and timing, and cover crops.

In fields with a substantial risk of leaching loss, apply most nitrogen fertilizer as a mid-season sidedress rather than applying all of it at planting. This application strategy results in a better match between nitrogen supply and crop demand, and reduces the risk of early-season nitrogen losses. Apply no more than the recommended amount of nitrogen, and plant small-grain winter cover crops such as rye to capture residual nitrate in the soil.

Surface Runoff

Surface runoff losses can be substantial if sheet or gully erosion is occurring or if nitrogen fertilizers are surface applied shortly before a rainfall. To reduce losses, use soil conservation best management practices (BMPs) including conservation

TABLE 10.3. Estimates of ammonia volatilization losses for different soil, weather and fertilizer scenarios as percentages of total nitrogen fertilizer applied

Soil pH	Rainfall	Fertilizer[1]	Placement		
			Broadcast	Surface band	Inject or incorporate
			Percent of total N lost via volatilization[2]		
Lower than 7	Humid[3]	Urea	0–5	0–5	0
		UAN	0–5	0–5	0
		AS or NH_3	0	0	0
	Subhumid[4]	Urea	5–30	2–20	0–2
		UAN	2–15	2–10	0–2
		AS or NH_3	0–2	0–2	0–2
	Dry[5]	Urea	5–40	2–30	0–2
		UAN	2–20	2–15	0–2
		AS or NH_3	0–2	0–2	0–2
7 or higher	Humid	Urea or UAN	0–20	0–15	0–10
		AS	0–40	—	0–10
		NH_3	—	—	0–2
	Subhumid	Urea or UAN	2–30	2–20	0–10
		AS	2–50	—	0–20
		NH_3	—	—	0–3
	Dry	Urea or UAN	2–40	2–30	0–10
		AS	5–60	—	0–30
		NH_3	—	—	0–5

Source: Modified from [25]

[1] Fertilizer abbreviations: UAN is any of the solutions composed of urea plus ammonium nitrate (28, 30 or 32 percent N); AS is ammonium sulfate; NH3 is anhydrous ammonia.
[2] For low-CEC soils (less than 10 meq per 100g) or if residue cover is more than 50 percent, use the upper end of the range. For high-CEC soils (more than 25 meq per 100g), use the lower end of the range.
[3] Rainfall of 0.5 inches or more within two days of fertilizer application.
[4] Rainfall of 0–0.25 inches of rain within seven days of fertilizer application.
[5] Little or no rain likely within seven days of fertilizer application.

tillage, no-till and cover crops; injecting or surface applying fertilizers in a band to facilitate passage through surface residue; and applying most nitrogen fertilizer as a mid-season sidedress when the established crop will control erosion and runoff.

ANIMAL WASTE MANAGEMENT

With no-till cropping systems, fertilizers and animal-waste nutrients are applied to the soil surface or surface residue and remain there until water infiltration carries them into the soil. The rate of microbial decomposition will be slower than with the conventional practice of incorporating animal waste, and this delays the availability of nutrients. As a result, nutrient losses due to surface runoff or volatilization may increase. Consider these factors when developing a farm nutrient-management plan.

In North Carolina's waste-management guidelines it is assumed that more of the nitrogen from animal wastes becomes available for uptake by the first crop if the waste is injected or incorporated into the soil rather than left on the surface (Table 10.5) [8]. In contrast, research from Alabama [27] and Nebraska [13] suggests similar nitrogen availability from animal wastes in conventional and no-till systems. In practice, follow BMPs developed for your area, realizing that the nutrient supply from organic sources is less predictable than nutrients from inorganic sources.

PLANT TISSUE ANALYSIS

Plant tissue analysis complements fertilizer management strategies based on soil testing. Search the web for "sampling for plant analysis" to find guides, such as North Carolina Department of Agriculture and Consumer Services' "Sampling for Plant Analysis" [17], to ensure the sample is from the appropriate plant tissue and growth stage. Following standard sampling guidelines will increase the usefulness of plant tissue analysis results by allowing for comparison with published critical nutrient levels. Use this information to make mid-season fertilizer decisions or to alter fertilization for the next crop.

TABLE 10.4. Estimates of denitrification losses for various soils

Soil organic matter content	Soil drainage classification[1]				
	Excess	Well	Moderate	SWPD	Poor
	Percent of inorganic N denitrified				
	Conventional tillage				
Less than 2	2–4	3–9	4–14	6–20	10–30
2–5	3–9	4–16	6–20	10–25	15–45
More than 5	4–12	6–20	10–25	15–35	25–55
	No-till				
Less than 2	3–9	4–14	6–20	10–30	10–30+
2–5	4–16	6–20	10–25	15–45	15–45+
More than 5	6–20	10–25	15–35	25–55	25–55+

Source: Modified from [25]

[1] Soil drainage classifications: excess is excessively well drained; well is well drained; moderate is moderately well drained; SWPD is somewhat poorly drained; poor is poorly drained.

TABLE 10.5. Manure nutrient availability estimates for North Carolina

Source	Nitrogen		All other nutrients
	Injected[1] or incorporated[2]	Broadcast or irrigated[3]	
	Availability coefficients for first crop[4]		
Broiler litter	0.6	0.5	1.0
Dairy manure slurry	0.6	0.4	1.0
Dairy lagoon liquid	0.6	0.5	1.0
Dairy lagoon sludge	0.6	0.5	1.0
Swine lagoon liquid	0.6	0.5	1.0
Swine lagoon sludge	0.6	0.5	1.0

Source: [8]

[1] Injected directly into soil and covered immediately.
[2] Surface spread, then plowed or disked into soil within two days.
[3] Surface spread, uncovered for one month or longer.
[4] To determine the amount available to the first crop, multiply the total applied by the availability coefficient.

SUMMARY

Crop nutrient needs are the same whether grown with conventional or conservation tillage. However, tillage methods result in different micro-environments that can change how nutrients become available for plant uptake. Know your region and soils to develop the best local strategy for sampling soils, applying fertilizer and monitoring crop nutrient status. In this way, the physical property benefits associated with conservation tillage can also result in sustainable soil fertility levels.

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11

CHAPTER 11

Weed Management and Herbicide Resistance

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Editor's note: Tables 11.4 through 11.8 appear at the end of this chapter.

Controlling weeds in any agricultural system can be a major challenge and cost, especially without advance preparation. Without a weed management plan in place before planting, weeds can easily emerge and out-compete crops. They can reduce yield, increase labor demands for last-resort weed control such as hand weeding, and hurt profits. Weed control is more challenging in conservation tillage systems than in conventional systems because control strategies common in conventional systems, notably tillage and cultivation, are not options.

The types of weeds change when a conservation tillage system is implemented. In addition to an herbicide program, an effective weed management plan should include appropriate cultural practices, especially the use of high-biomass cover crops and rotations of spring-, summer- and fall-planted crops. Diverse, year-round rotations can interfere with the life cycle of weed species, and they allow for an expanded range of herbicide options, which can help counter herbicide resistance in weeds. There are many practices that will improve a crop's competitive advantage over weeds. Giving a crop better access to water, light and nutrients than weeds will favor crop growth and can lessen the impact of weeds on yield. Reduced-tillage systems allow for mechanical control options in conjunction with herbicides and cultural practices, whereas mechanical control is not available in no-till [12].

This chapter begins with an overview of how the weed community changes in a conservation tillage system and is followed by a discussion of primary weed management strategies, including the combination of herbicides and such cultural practices as cover crops and crop rotation. The issue of herbicide resistance is discussed, as are reduced tillage in organic systems, remedial weed control strategies and some crop-by-crop considerations.

WEED POPULATIONS

When tillage is reduced or eliminated, the growing environment selects for different types of weeds, and anticipating these changes in the

TABLE 11.1. Common weeds in conservation tillage systems

Winter annuals	Summer annuals	Perennials
Carolina geranium	Common cocklebur	Bermudagrass
Cutleaf evening primrose	Crabgrass	Common pokeweed
Horseweed/marestail	Goosegrass	Johnsongrass
Pepperweed	Morningglory	Milkweed
Ryegrass	Pigweed	Morningglory
Wild mustard	Prickly sida	Nutsedge
Wild radish	Sicklepod	Trumpet creeper

REDUCED TILLAGE WITH COVER CROPS IN ORGANIC PRODUCTION

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Ronald D. Morse, Virginia Tech (emeritus)

Continuous no-till is difficult to achieve in organic production, but "rotational no-till" may offer a more feasible approach as part of an organic reduced-tillage system. Using this approach, fields are tilled after harvest and before planting a high-biomass cover crop, but both termination of the cover crop and the subsequent cash-crop planting are handled using no-till methods. This strategy provides weed management while offering some of the other benefits of growing a no-till cover crop, notably soil health improvements. The cover crop is usually killed by roll-crimping, flail mowing or winter kill, followed by no-till planting of transplanted or large-seeded vegetable or row crops. Examples of this strategy:

- transplanting tomatoes and peppers into roll-crimped winter rye and hairy vetch
- planting fall brassicas into flail-mowed summer foxtail millet and soybeans
- planting early spring vegetables into winter-killed oats and peas

Whereas a reduced-tillage system such as this can enhance soil quality, reduce annual weeds and give good yields, organic conservation tillage systems are not recommended for fields in which the population of weed seeds (weed seedbank) is extremely high and/or when perennial weed species such as Canada thistle, yellow nutsedge and Johnsongrass dominate the weed flora [18]. When they emerge from rootstocks, tubers or rhizomes, these weeds can grow through even a heavy cover crop mulch and compete severely with a no-till planted crop. Before attempting no-till cover crop management, first attempt to bring existing weed problems under control, as discussed in the section, "Remedial Practices for Improving Weed Management and Soil Health."

Other factors can influence the likelihood of success with no-till planting into a cover crop mulch.To generate an adequate weed-suppressing mulch: at termination, ensure the cover crop is mature (at heading/flowering with pollen shed); is nearly weed free (with less than 5 percent of aboveground biomass consisting of weeds); and has developed at least three tons of dry weight biomass. This level of biomass is usually achieved when the stand is solid and 3–4 feet tall, the ground cannot be seen when viewed from above, and thoroughly air-dried clippings from 1 square yard weigh about 1.5 pounds. Include cover crop species that provide a persistent mulch, such as a cereal grain or other grasses. Buckwheat, crucifer (e.g., radish or mustard) or all-legume cover crops tend to break down too rapidly to provide weed suppression.

New developments in non-chemical weed control tools and tactics can make rotational no-till more practical in organically managed fields with moderate weed pressure. Examples include high-residue cultivators, tractor-drawn weed pullers and thermal weed control based on hot water or steam rather than flaming, which can be a fire hazard in the presence of dry cover crop residues.

Also consider historic and current weed and pest issues in a field that may receive mechanical cover crop termination. If the field has been converted from sod to annual production within the previous year, bits of sod may be present that can regenerate and become perennial weeds without an herbicide to control them. Additionally, use caution if slugs, squash bugs and other pests that typically thrive in organic mulch have recently been a problem.

Considerations beyond weed management play a role in deciding whether to use organic no-till management. The type of soil will influence success with a crop following no-till cover crop termination, including whether the soil is heavy or clayey and slow to drain or warm up, or is light to medium in texture, well drained and quick to warm up. In addition, soil health plays an important role in successful organic no-till, as these systems rely on a vigorous and diverse soil biota (or soil food web) to release nitrogen (N) and other nutrients from cover crop residues. A no-till cover crop residue keeps the soil cooler and leaves more residue on the soil surface, which leads to a slower rate of N mineralization compared to incorporating the cover crop, or green manuring. So, a crop such as spring spinach or broccoli that requires a lot of N in a short amount of time early in the season when soil temperatures are lower may experience an N deficiency under no-till cover crop management, especially in heavier soils. Due to the slower start that a no-till residue gives to subsequent crops, it may not be ideal when trying to capture an early spring market for a particular crop such as tomatoes.

weed community is critical to developing a successful weed management plan. Table 11.1 lists weeds that can be problematic in conservation tillage systems. In reduced tillage, it is common to see a shift to small-seeded annual weeds. Annuals suited to the reduced-tillage environment have seeds that do not need to be buried to germinate and typically produce large numbers of seed. In conventional systems, small-seeded annuals are typically controlled with seed burial or pre-plant-incorporated herbicides. Other annual species prevalent in conservation systems are adapted to germinating in cooler temperatures and shaded areas, a typical environment in reduced tillage, especially in row middles. Annual weeds tend to grow rapidly and compete with a crop if not controlled. However, with reduced tillage, weed seeds remain on the surface instead of being buried as in conventional tillage systems. This may reduce the number of viable weed seeds since they are exposed to many factors that lessen viability.

Perennial weeds are more likely to become a problem in conservation tillage systems. In conventional systems, tillage disrupts perennial weed growth or buries the weeds too deep for regrowth. Although perennials often grow slower than annuals, they can be more difficult to control with available herbicides. Fortunately, the majority of perennials reproduce vegetatively, using stolons, rhizomes, roots, crowns and bulbs rather than reproducing by seed. This leads to patches of weeds that can be targeted for control.

Other management practices used in conservation systems, such as cover crops, also cause a change in the types of weeds present. Cover crops help suppress weed growth while they are actively growing, and with adequate biomass production the cover crop mulch can continue to provide some early-season weed control for the cash crop [18]. Thus, weeds that normally germinate and grow during the period of active cover crop growth are reduced due to competition with the cover crop. Cover crop residue is less effective than actively growing cover crops but can still suppress weed germination and early growth of weeds that germinate and grow during the cash crop season. Perennial weeds are generally not affected by annual cover crops.

Cover crops may also affect weed populations through allelopathy. During decomposition, some cover crops release allelochemicals, which have the greatest impact on germinating seeds, seedlings and young plants by retarding their growth, causing visible damage to roots or shoots, or even killing them outright. Because not all cover crops produce allelochemicals, and because not all weeds are impacted, a shift in weed populations can occur. Allelopathic effects strong enough to contribute significantly to weed control in field conditions have been documented for rye and other winter cereal grains, sorghum and sorghum-sudangrass hybrids, lablab beans, rapeseed, buckwheat and subterranean clover (Putnam and Tang, 1986; Rice, 1995; Boydston and Hang, 1995). Again, perennial weeds are generally not affected by cover crop allelochemicals.

WEED MANAGEMENT STRATEGIES

When tillage is either significantly reduced or eliminated, herbicides become one of the most relied-upon strategies for weed control, but they

TABLE 11.2. Common weeds that have demonstrated resistance to various herbicide mode of action groups

Weed name	Mode(s) of action resistant to[1]	Example herbicides from this group
Horseweed/marestail	2: ALS inhibitors 5: Photosystem II inhibitors 7: Photosystem II inhibitors 9: EPSP synthase inhibitors 22: Photosystem I inhibitors	Chlorsulfuron Atrazine Chlorotoluron Glyphosate Paraquat
Italian ryegrass	1: ACCase inhibitors 2: ALS inhibitors 3: Mitosis inhibitors 15: Mitosis inhibitors 9: EPSP Synthase inhibitors	Sethoxydim Chlorsulfuron Benzamide Acetamide Glyphosate
Wild mustard	2: ALS inhibitors	Chlorsulfuron
Common cocklebur	2: ALS inhibitors	Chlorsulfuron
Crabgrass	1: ACCase inhibitors 4: Synthetic auxins	Sethoxydim 2,4-D
Palmer amaranth (pigweed)	2: ALS inhibitors 3: Mitosis inhibitors 5: Photosystem II inhibitors 9: EPSP synthase inhibitors 14: Protox inhibitors 27: Carotenoid biosynthesis inhibitors	Chlorsulfuron Benzamide Atrazine Glyphosate Oxyfluorfen Topremazone
Waterhemp	2: ALS inhibitors 4: Synthetic auxins 5: Photosystem II inhibitors 9: EPSP synthase inhibitors 14: Protox inhibitors 27: Carotenoid biosynthesis inhibitors	Chlorsulfuron 2,4-D Atrazine Glyphosate Oxyfluorfen Topremazone
Prickly sida	2: ALS inhibitors	Chlorsulfuron
Johnsongrass	1: ACCase inhibitors 2: ALS inhibitors 3: Mitosis inhibitors 9: EPSP synthase inhibitors	Sethoxydim Chlorsulfuron Benzamide Glyphosate
Nutsedge	2: ALS inhibitors	Chlorsulfuron

Source: [5]

[1] Mode of action groups are according to the Weed Science Society of America classification system.

must be used in conjunction with appropriate cultural practices. There is no single “big hammer” solution to weeds; rather, a strategy involving “many little hammers,” or cultural weed control practices such as cover crops, crop rotations and tactics that improve a crop’s competitive advantage, are essential to ensuring successful weed management [8]. Switching to conservation tillage requires increased management intensity to develop an integrated weed control plan suitable for the farm.

Herbicides

Herbicide effectiveness is reduced when it is intercepted by surface residue or not incorporated through tillage. This is especially true for pre-emergent and pre-plant herbicides. With the loss of many soil-active herbicide options in high-residue systems, residual weed control is also lost. This can result in reliance on post-emergent herbicide applications. Repeated applications of post-emergent herbicides may be necessary to successfully reduce weed competition.

In many cases, the cheapest and easiest way to achieve good weed control is to grow herbicide-resistant corn, cotton and soybeans, and to use non-selective herbicide for post-emergent weed control. However, with the increased use of the related herbicides, herbicide-resistant weed populations have been noted across the Southeast.

To avoid herbicide-resistant weed infestations, different herbicides are incorporated into the weed management plan along with cultural weed control practices. The use of post-emergent herbicides with different modes of action reduces the risk of developing herbicide-resistant weeds. A diverse crop rotation expands the range of herbicide options, including modes of action, because herbicide recommendations vary by crop. An herbicide's mode of action describes the way in which it controls weeds; it usually refers to the biological process that is interrupted in susceptible plants but can also include a description of the injury symptoms the herbicide causes. The Weed Science Society of America organizes herbicides into 30 groups (as of 2016) based on their mode of action. Information about a product's mode of action and its group may appear on the product label, or it can be found by contacting a local Extension office or by visiting the Weed Science Society of America online at www.wssa.net.

Although pre-emergent herbicides can sometimes have reduced efficacy, sequential applications of different pre-emergent, soil-applied herbicides can reduce the need for multiple post-emergent applications. Pre-emergent applications on fields without high residue levels, such as fallow systems, are fairly effective. If there is residue on the surface, the application rate is increased to account for herbicide interception by residue. When strip tillage is used, the herbicide can be banded over the row. If heavy cover crop residue is left on the soil surface, weed seed germination may be suppressed. But again, it is still advisable to use a pre-emergent herbicide to help reduce the need for herbicide applications later in the season. In areas with high amounts of residue, early post-emergent applications may not reach emerging weed seedlings, so scouting for surviving weeds is important.

Early control of weeds can help reduce problems later in the season and prevent infestations in the following years. Control of weeds before they go to seed, through either a spot-spray application (if they have been missed with a broadcast herbicide application) or through hand removal, can reduce the risk of a larger problem the following year. If a weed population is suspected to be resistant, it is even more critical to remove plants early to avoid future infestations that cannot be controlled with herbicides or hand removal.

Herbicide-Resistant Weeds and Resistance Management

Weed resistance to herbicide modes of action develops when only one herbicide is used for weed control. This has recently been proven true for the non-selective herbicide glyphosate and to a lesser degree with 2,4-D and dicamba. After the introduction of glyphosate-tolerant crops, implementation of conservation tillage became much easier. Successful weed control could be achieved with a single herbicide and relatively little planning was needed. However, an overdependence on glyphosate in both conventional and conservation tillage systems has resulted in resistant weed populations. For example, a number of weeds commonly found in conservation tillage systems have demonstrated resistance to glyphosate, including Palmer amaranth, Italian ryegrass and horseweed (Table 11.2). These and other weeds that have developed resistance to glyphosate can develop resistance to other modes of action as well. With the release of crops that are resistant to 2,4-D and dicamba herbicides, there is concern that resistance to these will also increase, reducing their ability to be used as alternatives to glyphosate [4]. For reduced-tillage systems, this is especially serious since other effective herbicide alternatives are limited, and it underscores the important role of non-chemical strategies in a successful weed management plan.

To prevent the development of herbicide resistance or to manage resistant weed populations, weed management tactics should be diversified to include cultural management practices in addition to a rotation of herbicide modes of action. Cultural practices such as crop rotation and cover crops can aid in resistance management and are discussed in the following sections of this chapter. Crop rotation, especially a multi-year rotation, ensures that a variety of herbicides can be used for weed control and limits a weed population's repeated exposure to a single herbicide. Including pre-emergent and post-emergent herbicides, as well as selective and non-selective herbicides, in a weed management plan further reduces the risk of over exposure to similar modes of action. Extension and research staff have developed herbicide recommendations for crops and weeds in states affected by herbicide resistance. These recommendations provide growers with effective, alternative plans that can reduce dependence on one herbicide. Additionally, scout fields early and often to find and properly identify weeds that have escaped an herbicide application. Maintain clean equipment, since machinery can carry weed seeds from one field to another. Remedial strategies for restoring weedy, unproductive fields are outlined later in this chapter.

Cover Crops

There is a great deal of information available about the benefits of cover crops. In addition to reducing water runoff and erosion, increasing soil organic matter and providing a means to sequester carbon, cover crops can also reduce weed seed germination and growth. Winter cereal crops, legumes and brassicas are typical cover crops in the Southeast. They provide weed control through a mulch effect as well as through the release of chemicals that inhibit plant germination or growth, referred to as allelopathic compounds. Many times, a grass cover crop like rye or black oats is the best option if the primary goal is weed control. These covers produce high amounts of biomass that break down less quickly than some broadleaf cover crops such as legumes. This helps to suppress weed growth longer into the season. Since some problem weeds such as pigweed can easily grow under high-shade conditions, high amounts of cover crop residue are preferred to provide a barrier to weed growth. Planting winter cover crops early allows time for sufficient biomass production and increases weed suppression potential. In Alabama, a conservation tillage system using rye or black oat cover crops eliminated the need for post-emergence herbicides in soybean and cotton. Including rye or black oats increased yields of non-transgenic cotton in two of three years, compared to conservation tillage without a cover crop [16].

There are drawbacks to growing cover crops if they are not managed properly. One drawback related to weed management is that the release of allelopathic compounds poses an injury risk to the cash crop as well as to weeds. Temperature and rainfall can change the impact on weeds and subsequent crops, and not all cover crops contain allelochemicals. The risk of crop injury from allelopathic compounds may be reduced by terminating cover crops early, but early termination reduces the amount of biomass and therefore the mulch effect on weeds. Additionally, if cover crops are not completely killed, they compete with the primary crop for light and nutrients. Because of this, non-selective herbicides are used for cover crop termination to ensure complete kill. Since this practice adds to the risk of developing herbicide resistance, research continues with the use of rollers/crimpers for cover crop termination (see Chapter 9). Although concerns have been raised as to whether cover crops reduce the efficacy of pre-emergence herbicides, it has been suggested that any loss in weed control due to herbicide interception is offset by the control that cover crop residue provides.

Crop Rotation

Regardless of tillage practices, crop rotation can be employed to help control weed populations. In crop rotations, the life cycle of problematic weeds is disrupted as the growing environment changes due to the timing of both field operations and crop growth. This reduces weed infestations that might otherwise result if the same crop were continually planted. By rotating crops, the environment and herbicide plans are modified enough to keep problematic weeds in check. Select crops that combine with herbicides with different modes of action. Otherwise, the risk for developing herbicide resistance increases. Additionally, rotations can help control weeds through competition. For example, wheat and other fall-seeded cereal grains will be well established

TABLE 11.3. Pre-cropping plan for remediation and restoring weedy unproductive fields, in transition to conservation tillage production of cash crops

Season	Production practice	Expected results (effects)
Year one		
Early to mid-spring	Flail mow (1–3 times) all existing vegetation: pasture, cover crop, cash crop, weeds	Kill weeds; reduce weed seed production
Late spring, summer	Deep till (chisel, subsoil, plow); incorporate summer residues; employ stale seedbed techniques (6–12 weeks) using flamers, herbicides[1] or cultivators to kill weed seedlings	Alleviate soil compaction[2]; kill weeds and reduce weed seedbank; deepen rooting zone (increase the effective soil profile)
Summer, fall	Apply and incorporate soil amendments (manure, compost, lime, fertilizers) based on detailed soil analysis; drill a cover crop of winter rye plus hairy vetch or Austrian winter peas	Increase active soil organic matter (SOM) and balanced nutrient availability; reduce nutrient leaching
Years two and three		
Mid-spring	Flail mow and shallow incorporate weed and cover crop residues	Increase active SOM; reduce weed seedbank
Option when weed levels and soil health are adequate		
Late spring	Seed summer cover crop of foxtail millet and cowpea	Grow high-biomass cover as mulch for production of fall broccoli; reduce growth of summer weeds
Mid-summer	Kill foxtail millet/cowpea cover crop; plant broccoli in killed mulch, using no-till equipment to establish broccoli transplants	Grow high-quality fall broccoli; minimize production of weed seeds
Option when additional remedial practices are needed		
Mid- to late-summer	Employ stale seedbed techniques (6–12 weeks) or drill summer cover crops (foxtail millet/cowpea, buckwheat, etc.)	Prevent production of weed seeds; reduce weed seedbank
	After using stale seedbed techniques	
	Zone-drill (strip interseed) forage radish in grow zones and winter rye in alleyways	Grow high-biomass cover in preparation for planting spring vegetables next year
	OR drill perennial legume sods (alfalfa, red clover, white clover) that will grow over the next 12–18 months	Grow high-biomass sods in preparation for producing vegetables next summer or the following spring
Early fall	After employing stale seedbed techniques or growing summer cover crops, drill winter cover crops (winter rye or triticale, plus hairy vetch or Austrian winter peas)	Increase SOM; reduce weed seed production; produce N and mulch for next year's summer vegetables; reduce nutrient leaching

Source: [13]

[1] In all situations outlined above, growers have the option to apply either organic or chemical fertilizers and herbicides to increase and maintain soil fertility levels and to kill weeds and cover crops.

[2] With compacted soils, growers can opt to erect permanent raised beds to improve drainage and deepen the effective soil profile.

when spring-germinating weeds begin to emerge, causing those weeds to suffer from severe competition [12]. Crop rotation over several growing seasons has been shown to increase yields when compared to monoculture systems, so the benefits are not limited to weed control alone [6].

When including pasture or forage crops in a rotation, mowing can be an effective strategy for managing some weed species. Mowing every 30–60 days can reduce competition from perennial weeds and can prevent many types of weeds from producing seeds. Mowing can also be used to keep some cover crops from becoming weeds that compete with the primary crop. To provide control, mow legume cover crops such as hairy vetch after the first flowers appear, and mow cereal grains such as cereal rye after heading [2]. However, in humid climates, mowed residues break down faster, negating some of the residue benefits of conservation tillage [7].

Other Cultural Practices

Other planting practices can be manipulated to help reduce weed competition. Improving a crop's competitive advantage is especially important when weeds are abundant and more likely to escape other control methods [12]. Using narrow row spacing allows the crop canopy to close more quickly than when using rows with normal spacing. As the canopy closes, shading from the crop hinders weed seed germination. Yields with narrow row spacing have been shown to be similar to yields with normal row spacing. However, late-season weed control may be hampered if it is unfeasible to cultivate and apply herbicide with a shielded sprayer [9]. As a general rule, crops are more competitive against weeds the closer they are planted to a square grid arrangement. In addition to row spacing, row orientation may play a helpful role in managing weeds. Mathematical models have shown that a crop's exposure to sunlight during the growing season can be maximized when rows are planted in a north-south orientation rather than east-west. Maximizing the amount of light a crop captures will minimize the amount that reaches weeds growing near the soil surface. The effect increases as one moves farther south in latitude. In contrast to the growing season, winter crops would receive more light exposure if planted in an east-west orientation, due to the sun's lower rise in the sky. However, determining row orientation based on the potential for weed control would probably never outweigh the importance of planting across slopes for the sake of soil conservation [12].

Planting date also affects weed pressure in row crops. Delayed planting of some crops allows for control of early-germinating weeds with cultivation or herbicide applications. Early planting so that a crop becomes established prior to weed germination could be possible if frosts are not a threat. Soil temperatures will likely be cooler under heavy residue, and this may initially slow crop growth.

The use of banded fertilizer applications or subsurface drip irrigation can also limit the germination and growth of weeds by directing nutrients and water toward the crop, making them less likely to reach weeds. Nutrient sources can also influence the competitiveness of crops over weeds. Highly available forms of nutrients, such as chemical fertilizers and organic fertilizers that decompose rapidly, tend to favor weeds. On the other hand, green manures and compost provide slow-release nutrients that tend to favor crops. Aim to achieve the right balance of nutrients for each stage of crop growth; a low level of nutrients may slow crop growth while allowing weeds to dominate, and excessive nutrients may accelerate crop growth without benefiting crop vigor [12].

Carefully choosing varieties and ensuring uniform establishment can also give the crop an edge over weeds. While factors such as yield, market demand and disease resistance play a major role in variety selection, consider any features that could contribute to weed suppression. Characteristics to look for include vigorous early growth, speed of canopy closure, height and foliage density. If growing several varieties of a particular crop, consider planting varieties with competitive characteristics on weedier fields and planting varieties with fewer competitive characteristics on fields with fewer weed problems [12].

Although every practice described here may not be suitable for every farm, valuable weed management tools may be found by evaluating each practice. Tactics that reduce weed problems by only a small amount may prove to be vital parts of an overall control plan if they are cheap and easy to implement [12].

Reduced-Tillage Systems

In reduced-tillage systems, tillage can be used to control weed germination on a limited area of the field, such as with strip tillage. When combined with herbicide applications, this practice can control weeds that thrive in reduced-tillage environments. Ridge tillage, in which crops are planted on a ridge or raised bed, is another option. Cultivation to maintain the ridges and control inter-row weeds can decrease the amount of herbicides needed. At planting, the top two inches of the ridge are scraped into the inter-row area by an attachment ahead of the planter. This eliminates small weeds growing immediately near the row and moves their seeds to the inter-row area where they can be controlled more easily through cultivation and ridge-building upon their emergence. A winter cover crop can slow weed growth in the spring, increasing the ability of ridge-till planting to eliminate them. The system is typically used for crops planted in 30-inch rows [1, 12].

Less-aggressive cultivation using a high-residue cultivator is also an option. This implement is a sweep that runs underneath cover crop residue in the row middle. This disrupts the upper soil layer while leaving cover crop residue on the soil surface intact. Two passes with the cultivator may be necessary when attempting to reduce the number of herbicide applications. When using a cultivator, make sure that the crop's roots are not disrupted along with the weed's roots. Cultivation in combination with other weed control strategies can help to control small-seeded annuals and disrupt the growth of perennial weeds.

REMEDIAL PRACTICES FOR IMPROVING WEED MANAGEMENT AND SOIL HEALTH

In highly weedy fields, an 18- to 36-month remedial covered-fallow period that uses integrated weed management strategies can lower the weed seedbank and improve the soil, creating an environment in which crops can thrive. Conventional tillage practices have been suggested for areas with heavy infestations of resistant weeds, but for several reasons, many researchers do not recommend converting lands back to conventional tillage to control resistant weeds. If tillage is used, not all of the weed seed will be buried, and resistant weeds will continue to germinate after tillage. If weed seed is buried, continued tillage will bring resistant weed seeds back to the surface where they will germinate. Even if tillage provides enough seed burial to control heavy infestations, if neighboring lands are not managed for resistance, the resistant weeds can easily reestablish. In these situations, the long-term benefits from conservation tillage practices are lost and the resistant weed is still not controlled [13].

A recommended remediation plan to prepare fields for conservation tillage vegetable production is outlined in Table 11.3. Using cultural practices and, when appropriate, chemicals, to improve weed management and restore the soil health and productivity of a field, this plan pursues three objectives:

1. Reduce the weed seedbank by stimulating consumption (germination, decay and predation) and preventing production of weed seeds [17].
2. Increase soil organic matter by applying lime and nutrients, compost and high-biomass cover crops as needed [10, 15].
3. Increase the effective water- and nutrient-holding capacity by increasing vertical soil distribution of organic matter, lime and nutrients [19].

The plan incorporates proven integrated weed management strategies. Fast-growing perennial sods or a series of annual high-biomass cover crops will smother weed growth, and foster decay and insect predation of weed seeds [3, 15]. Stale seedbed techniques will stimulate weed seed germination so that the subsequent seedlings can be destroyed with shallow cultivation, flamers or herbicides. Applying recommended soil amendments and implementing conservation tillage practices will enhance soil health [15].

Stale Seedbed

The stale seedbed technique can help manage a large weed seedbank. It is based on three premises: cultivation promotes the germination of weed seeds; only a small percentage of weed seeds are non-dormant and able to germinate quickly; and the vast majority of weeds only emerge from seeds in the top 2.5 inches of soil. Prior to planting the crop, the stale seedbed technique involves intentionally creating an environment that is ideal for the germination of weed seeds and killing emerging weeds without disturbing those seeds that are deeper in the soil. Begin a few weeks prior to cash-crop planting by preparing a firm seedbed that is free of competing plants or weeds, typically by using tillage. Adequate moisture near the soil surface is necessary, so irrigate if the soil is too dry [11].

Emerging weeds are terminated using either flame weeders or herbicides. A variation of the stale seedbed technique is the “false seedbed,” which uses shallow cultivation to terminate weeds. If using cultivation to kill weeds, soil disturbance must remain shallow so that weed seeds deeper in the soil are not brought to the surface where they can germinate and compete with the crop during the growing season.

The amount of time between preparing the stale seedbed, terminating weeds and planting the crop will depend on a few factors. Most annual weeds germinate quickly, and this will happen faster in warm soils compared to cool soils. In addition, using a stale seedbed approach, the crop can be drilled into the emerging weeds, which shortens the delay. In this case, give very careful attention to the timing of weed termination. The aim is to terminate weeds as close to crop germination as possible but not after the crop has germinated, which could cause severe damage. In a false seedbed system, or if using transplants, planting must wait until after weeds have been killed with cultivation. In general, weeds will be terminated about two weeks after preparing the stale seedbed, and crop seeds can be drilled one week prior to termination. The process may take three weeks in cooler climates [11].

CROP-SPECIFIC CONSIDERATIONS

Corn

While the potential for yield and profitability is strong, a major limiting factor to adopting reduced tillage in corn production is the concern of less-effective weed control. Because adequate nitrogen availability is essential for corn development, use a legume cover crop that provides both weed control and nitrogen fixation, such as hairy vetch, red clover or medics. Use a burndown herbicide prior to corn planting for early-season weed control when using cover crops. To broaden the number of weed species controlled as well as to extend control into the season, apply a residual herbicide in conjunction with the herbicide used for cover crop termination. A number of pre-emergence herbicides are available that can be applied without incorporation into the soil and that are effective even with plant residue on the soil surface. These herbicides and post-emergence herbicide choices that can be successfully utilized in conservation-tillage corn with cover crops are listed in Table 11.4.

Cotton

When glyphosate-resistant cotton was made available, reduced tillage became practical since a broad spectrum of weed species could be controlled with a single herbicide. Extensive research on conservation-tillage cotton has demonstrated yield benefits. Moreover, with herbicide-resistant cotton varieties, weed control has been as successful as conventional-tillage cotton. Because of this success, conservation tillage has been widely adopted in the Southeast. This dependence on a single herbicide, however, has led to the appearance of herbicide-resistant weed species that now threaten the feasibility of reduced-tillage cotton production. Currently, research efforts focus on identifying ways to ensure the long-term viability of conservation tillage while controlling established populations of herbicide-resistant weed species and reducing the risk of future development of resistant weeds. Cover crops, along with multiple herbicide modes of action and rotation, have been shown to effectively control weeds in reduced-tillage cotton. Pre-emergent herbicides are especially important in early-season weed control to ensure management of weed species that are difficult to control later in the season. See Table 11.5 for a number of herbicide choices available for use with conservation-tillage cotton.

Soybeans

The vast majority of soybeans in the United States are produced with conservation tillage. This can be attributed to the environmental and economic benefits achieved with reduced-tillage as well as to the commercial availability of herbicide-tolerant soybeans, which have made successful chemical weed control achievable with the use of fewer herbicides. Studies of conservation-tillage soybeans have reported equal or improved yield compared to conventional systems. Studies of soybean systems planted behind wheat or a cover crop such as rye have noted improved weed control compared to fallow and greater yield with a cover crop than with just the previous crop's stubble. Table 11.6 provides a partial list of herbicides that can be utilized in reduced-tillage soybeans with cover crops.

Peanuts

Concerns over the peanut's response to reduced tillage, due to its growth habits, have prompted studies to identify successful means of using conservation tillage for peanut production. Inconsistent peanut yield in conservation tillage systems has been reported. Some studies have reported that yields of conservation-tillage peanuts are reduced or equal to conventionally tilled peanuts, while others have reported equal or greater yields in a conservation tillage system. Weed control in peanuts, regardless of the tillage system, can be problematic due to the extended growing season and the crop's unique growth habits. Generally, peanut production requires an incorporated residual as well as a post-emergent herbicide to provide effective weed control under the slow-closing canopy of peanuts. Moreover, in-season cultivation for weed management cannot be implemented due to the potential to damage developing peanut pods. Studies have shown effective weed control with cover crops in strip-tillage peanut systems that use a dinitroaniline pre-emergent herbicide over cover crop residue. Other effective herbicides used in conservation-tillage peanut systems are listed in Table 11.7.

Wheat

Much research has been conducted to evaluate wheat productivity in conservation tillage practices. Reports reveal similar or increased grain yield for reduced-tillage compared to conventional tillage systems. With little or no tillage operations, some chemical applications are required in order to achieve successful levels of weed control; however, with herbicide applications, weed species have been effectively controlled below levels that could reduce yield. To offset the herbicide needs in conservation tillage, evaluations of cover crops as ground cover have been conducted. Cover crops such as mustard, peas and lentils have proven to be good choices with little yield differences. Table 11.8 lists many of the herbicide options for use in conservation tillage systems for wheat production.

SUMMARY

Conservation tillage systems can be environmentally and economically beneficial for growers in the Southeast, but weed species and management will be different than in conventional tillage systems. Although weed control can be challenging when converting to conservation tillage, there are many weed control options for producers to evaluate when developing their management plan. The use of several management strategies, including multiple herbicide modes of action as well as crop rotations, cover crops and other cultural practices, can provide effective weed control while limiting the risk for developing herbicide resistance. With planning and timely management practices, producers can have successful weed control in conservation tillage systems.

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TABLE 11.4. Herbicides for use in reduced-tillage corn production

Herbicide		Application timing	Weed species controlled
Common name	Trade name[1]		
Glufosinate	Liberty®	Preplant burndown	Emerged weed species
Glyphosate	Roundup WeatherMAX®		
Paraquat	Gramoxone®		
2,4-D	Agri Star® 2,4-D		
Atrazine	Aatrex®	Preplant or PRE[2]	Broadleaves such as kochia (*Kochia scoparia*); suppression of foxtail (*Setaria* spp.), velvetleaf (*Abutilon theophrasti*). Can also be applied POST
Flumioxazin	Valor®		Broadleaf species such as horseweed (*Conyza canadensis*); suppression of grass species such as panicum (*Panicum* spp.) and goosegrass (*Eleusine indica*)
Pendimethalin	Prowl®		Germinating, small-seeded grass and broadleaf species such as crabgrass (*Digitaria* spp.) and common lambsquarters (*Chenopodium alba*)
S-metolachlor	Dual Magnum®		Grass and broadleaf species such as foxtail and *Amaranthus* spp.
Carfentrazone	Aim®	POST[3]	Certain broadleaf weed control; tank mix with atrazine or dicamba
Bromoxynil	Buctril®		Broadleaf weeds such as burcucumber (*Sicyos angulatus*), giant ragweed (*Ambrosia trifida*)
Dicamba	Banvel®		Annual broadleaf species as well as certain perennial species such as dock (*Rumex* spp.) and wild onion (*Allium* sp.)
Mesotrione	Callisto®	POST	Broadleaf species such as wild mustard (*Sinapis arvensis*), nightshade (*Solanum* spp.) and Canada thistle (*Cirsium arvense*)
Tembotrione	Laudis®		Broadleaf and grass species such as common chickweed, purple deadnettle (*Lamium purpureum*), *Amaranthus* spp., and large crabgrass (*Digitaria sanguinalis*)
Ametryn	Evik®	POST-directed spray	Grass species such as Texas panicum, goosegrass and foxtail

TABLE 11.4 continues on the next page.

TABLE 11.4 continued

Herbicide		Application timing	Weed species controlled
Common name	Trade name[1]		
Linuron	Lorox®		Broadleaf and grass species such as dog fennel, common ragweed (*Ambrosia artemisiifolia*), velvetleaf and annual ryegrass (*Lolium multiflorum*)
Clearfield Corn			
Imazethapyr + Imazapyr	Lightning®	POST	Broadleaves, grasses and sedges such as kochia, ragweed, quackgrass (*Elytrigia repens*) and nutsedge (*Cyperus* spp.)
LibertyLink Corn			
Glufosinate	Liberty®	POST	Broadleaf and grass species; ragweed, horseweed, johnsongrass seedlings
Roundup Ready Corn			
Glyphosate	Roundup WeatherMAX®	POST	Nonselective control of some broadleaf and grass species
Glyphosate + *s*-metolachlor + atrazine	Expert®	PRE or POST	Annual broadleaves and grasses; perennials such as quackgrass, dandelion (*Taraxacum officinale*) and Canada thistle

[1] Trade names listed are representative of available herbicides. Inclusion of a particular product does not imply endorsement by the USDA, the SARE program or the authors. Exclusion does not imply a negative evaluation.

[2] PRE: pre-emergence.

[3] POST: post-emergence.

TABLE 11.5. Herbicides for use in reduced-tillage cotton production

Herbicide		Application timing	Weed species controlled
Common name	Trade name[1]		
Dicamba	Banvel®	Preplant burndown	Emerged weed species
Flumioxazin	Valor®		
Glufosinate	Liberty®		
Glyphosate	Roundup WeatherMax®		
Paraquat	Gramoxone®		

TABLE 11.5 continues on the next page.

TABLE 11.5 continued

Herbicide		Application timing	Weed species controlled
Common name	Trade name[1]		
Clomazone	Command®	Preplant or PRE[2]	Grasses and broadleaves such as crabgrass (*Digitaria* spp.), panicum (*Panicum* spp.), velvetleaf (*Abutilon theophrasti*) and Florida beggarweed (*Desmodium tortuosum*)
Fluometuron	Cotoran®		Grasses and broadleaves such as signalgrass (*Brachiaria sp.*), horseweed (*Conyza canadensis*) and sicklepod (*Senna obtusifolia*)
Pendimethalin	Prowl®		Grass and broadleaf species such as foxtail (*Setaria* spp.), panicum, and *Amaranthus* spp.
Prometryn	Caparol®		Annual grass and broadleaves such as groundcherry (*Physalis* sp.), Florida pusley (*Richardia scabra*) and panicum
S-metolachlor	Dual Magnum®		Grass and broadleaves such as barnyardgrass (*Echinochloa crus-galli*), crabgrass and Florida pusley
Clethodim	Select®	POST[3]	Grass species such as crabgrass, panicum and foxtail
Quizalofop	Assure®		Annual and perennial grasses such as foxtail, goosegrass (*Eleusine indica*) and bermudagrass (*Cynodon dactylon*)
Sethoxydim	Poast®	POST	Grass species such as foxtail, crabgrass and panicum
Trifloxysulfuron	Envoke®		Broadleaf and grass species such as coffee senna (*Senna occidentalis*), barnyardgrass and Florida beggarweed
Diuron	Direx®	POST-direct sprayed	Broadleaf and grass species such as sicklepod, velvetleaf and crabgrass
Linuron	Linex®		Broadleaves and grasses such as morningglory, Florida pusley and panicum
MSMA	Target®		Grass and broadleaf species such as crabgrass, Florida beggarweed and *Amaranthus* spp.
LibertyLink Cotton			
Glufosinate	Liberty®	POST	Broadleaf and grass species such as *Amaranthus* spp., morningglory and goosegrass
Roundup Ready Cotton			
Glyphosate	Roundup WeatherMax®	POST	Grass and broadleaf species such as Florida beggarweed, crabgrass, foxtail, groundcherry and velvetleaf

[1] Trade names listed are representative of available herbicides. Inclusion of a particular product does not imply endorsement by the USDA, the SARE program or the authors. Exclusion does not imply a negative evaluation.

[2] PRE: pre-emergence.

[3] POST: post-emergence.

TABLE 11.6. Herbicides for use in reduced-tillage soybean production

Herbicide		Application timing	Weed species controlled
Common name	Trade name[1]		
Glufosinate	Liberty®	Preplant burn-down	Emerged weed species
Glyphosate	Roundup WeatherMax®		
Paraquat	Gramoxone®		
2,4-D	Agri Star® 2,4-D		
Clomazone	Command®	PRE[2]	Grasses and broadleaves such as crabgrass (*Digitaria* spp.), panicum (*Panicum* spp.), velvetleaf (*Abutilon theophrasti*) and Florida beggarweed (*Desmodium tortuosum*)
Dimethenamid	Outlook®		Grass and broadleaf species such as foxtail (*Setaria* spp.), panicum and *Amaranthus* spp.
Flumioxazin	Valor®		Broadleaf species such as horseweed (*Conyza canadensis*); suppression of grass species such as panicum and goosegrass (*Eleusine indica*)
Imazaquin	Scepter®		Broadleaf and grass species such as morningglory (*Ipomoea* spp.), velvetleaf and foxtail
Metribuzin	Sencor®		Broadleaf and grass species such as *Amaranthus* spp. and broadleaf signalgrass (*Brachiaria platyphylla*)
Pendimethalin	Prowl®		Grass and broadleaf species such as panicum and *Amaranthus* spp.
S-metolachlor	Dual Magnum®		Grass and broadleaves such as barnyardgrass (*Echinochloa crus-galli*), crabgrass and Florida pusley (*Richardia scabra*)
Bentazon	Basagran®	POST[3]	Broadleaf weeds such as coffee senna (*Senna occidentalis*) and velvetleaf
Chlorimuron	Classic®		Broadleaf weeds such as Florida beggarweed and morningglory
Cloransulam	FirstRate®		Broadleaf weeds such as common cocklebur (*Xanthium strumarium*) and velvetleaf
Fluazifop	Fusilade®		Annual and perennial grass species such as crabgrass and bermudagrass (*Cynadon dactylon*)
Imazethapyr	Pursuit®		Broadleaf and grass species such as morningglory and crabgrass
Lactofen	Cobra®		Broadleaf species such as croton (*Croton* spp.) and Florida beggarweed
Sethoxydim	Poast®		Grass species such as foxtail, crabgrass and panicum

TABLE 11.6 continues on the next page.

TABLE 11.6 continued

Herbicide		Application timing	Weed species controlled
Common name	Trade name[1]		
LibertyLink Soybean			
Glufosinate	Liberty®	POST	Broadleaf and grass species such as *Amaranthus* spp., morningglory and goosegrass
Roundup Ready Soybean			
Fomesafen + Glyphosate	Flexstar®	POST	Broadleaf and grass species such as morningglory, velvetleaf and broadleaf signalgrass
Glyphosate	Roundup WeatherMax®	POST	Grass and broadleaf species such as Florida beggarweed, crabgrass and groundcherry

[1] Trade names listed are representative of available herbicides. Inclusion of a particular product does not imply endorsement by the USDA, the SARE program or the authors. Exclusion does not imply a negative evaluation.
[2] PRE: pre-emergence.
[3] POST: post-emergence.

TABLE 11.7. Herbicides for use in reduced-tillage peanut production

Herbicide		Application timing	Weed species controlled
Common name	Trade name[1]		
Glyphosate	Roundup WeatherMax®	Preplant burndown	Emerged weed species
Paraquat	Gramoxone®		
2,4-D	Agri Star® 2,4-D		
Diclosulam	Strongarm®	PRE[2]	Broadleaf species such as eclipta (*Eclipta prostrata*) and *Amaranthus* spp.
Flumioxazin	Valor®		Broadleaf species such as horseweed (*Conyza canadensis*)
Pendimethalin	Prowl®		Grass and broadleaf species such as foxtail (*Setaria* spp.) and *Amaranthus* spp.
Acifluorfen	Ultra Blazer®	POST[3]	Broadleaf and grass species such as coffee senna (*Senna occidentalis*) and velvetleaf (*Abutilon theophrasti*)
Bentazon	Basagran®		Broadleaf species such as morningglory (*Ipomoea* spp.) and velvetleaf
Chlorimuron	Classic®		Broadleaf weeds such as Florida beggarweed (*Desmodium tortuosum*) and morningglory
Clethodim	Select®		Grass species such as panicum, foxtail and crabgrass (*Digitaria* spp.)

TABLE 11.7 continues on the next page.

TABLE 11.7 continued

Herbicide		Application timing	Weed species controlled
Common name	Trade name[1]		
Imazapic	Cadre®	POST[3]	Broadleaf and grass species such as morningglory, *Amaranthus* spp. and crabgrass
Imazethapyr	Pursuit®		Broadleaf, grass and sedge species such as Florida pusley (*Richardia scabra*), crabgrass and nutsedge (*Cyperus* spp.)
Paraquat	Gramoxone®		Grass and broadleaf species
Sethoxydim	Poast®		Grass species, foxtail and panicum
2,4-DB	Butyrac®		Broadleaf species such as velvetleaf and prickly sida (*Sida spinosa*)

[1] Trade names listed are representative of available herbicides. Inclusion of a particular product does not imply endorsement by the USDA, the SARE program or the authors. Exclusion does not imply a negative evaluation.
[2] PRE: pre-emergence.
[3] POST: post-emergence.

TABLE 11.8. Herbicides for use in reduced-tillage wheat production

Herbicide		Application timing	Weed species controlled
Common name	Trade name[1]		
Carfentrazone	Aim®	Preplant burn-down	Non-selective control of emerged broadleaves and grasses
Glufosinate	Liberty®		
Glyphosate	Roundup WeatherMax®		
Paraquat	Gramoxone®		
Chlorsulfuron + Metsulfuron	Finesse®	PRE or POST[2]	*Bromus* species, annual ryegrass (*Lolium multiflorum*) kochia (*Kochia scoparia*)
Pyrasulfotole + Bromoxynil	Huskie®	Early POST	Emerged broadleaf seedlings such as dandelion (*Taraxacum officinale*); suppression of established dandelion and henbit (*Lamium amplexicaule*)
Thifensulfuron + Tribenuron	Harmony® Extra	POST	Actively growing broadleaves, wild garlic (*Allium vineale*); suppression of Canada thistle (*Cirsium arvense*)
Clearfield wheat			
Imazamox	Beyond®	POST	Broadleaves henbit and chickweed (*Stellaria media*), grasses barnyardgrass (*Echinochloa crus-galli*) and jointed goatgrass (*Aegilops cylindrica*), volunteer cereals (non-Clearfield types)

[1] Trade names listed are representative of available herbicides. Inclusion of a particular product does not imply endorsement by the USDA, the SARE program or the authors. Exclusion does not imply a negative evaluation.
[2] PRE: pre-emergence.
[3] POST: post-emergence.

CHAPTER 12

Plant-Parasitic Nematode Management

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Conservation tillage systems leave crop residue on the soil surface to reduce soil erosion and soil compaction. The practice of conservation tillage has increased in recent decades partially due to the rising cost of petroleum products and concern over soil erosion [34]. There are multiple benefits of conservation tillage systems, but changing to conservation tillage results in new pests and management concerns. Historically, conventional residue-incorporating tillage systems buried the previous crop's residues while turning the root zone layer of the soil. This practice reduced plant pathogens colonizing the root residues of the previous crop. Conservation tillage systems that do not disturb the soil and leave plant residues on the soil surface may increase plant diseases, particularly those caused by soilborne pathogens including plant-parasitic nematodes.

In this chapter, several terms are used to describe nematodes and the symptoms of nematode infection. If a nematode is described as economically important or as an economic pest to a region or crop, it means that the nematode is reducing yields. If a symptom is described as distinctive it means that the symptom is an indicator of nematode infection. Non-distinctive means symptoms seen on the plant could be caused by nematodes or other problems such as moisture stress or nutrient imbalances. If a symptom is described as diagnostic it means that signs of the nematode are usually present, for example the nematode or its eggs are visible on the roots. A non-diagnostic symptom is one that does not include signs of the nematode and that could be caused by other factors.

Plant-parasitic nematodes are microscopic, worm-like animals that feed on plant root systems. In the southeastern United States, the most economically important plant-parasitic nematodes associated with field crops include the root-knot nematode (*Meloidogyne incognita* races 3 and 4), peanut root-knot nematode (*Meloidogyne arenaria*), reniform nematode (*Rotylenchulus reniformis*), soybean cyst nematode (*Heterodera glycines*), lance nematode (*Hoplolaimus spp.*) and lesion nematode (*Pratylenchus* spp.) [2, 20, 38]. The estimated economic impact of these nematodes has increased as their distribution and yield losses have been recognized.

The primary indication that a crop is suffering from a nematode problem is often a decline in yield over time. Generally, a lack of crop-yield response when optimal applications of fertilizer, pesticides and water are used may be attributed directly to plant-parasitic nematodes. Plant symptoms of nematode diseases are generally not distinctive and will not facilitate the identification of a specific nematode. Two general symptoms of nematode damage are yellowing

FIGURE 12.1. One of two general symptoms of nematode damage is shown here: stunted plants with uneven heights in irregular areas across a field. This cotton is growing in a field infested with reniform nematodes.

of the foliage (chlorosis) and stunted plants with uneven heights in irregular areas across a field [30] (Figure 12.1). Most plants also have a reduced root mass, but this is a general symptom and is not diagnostic of nematode problems. The root-knot nematode produces galls on the root system that are distinctive and diagnostic in most crops including cotton and soybeans. Root-knot galls on corn are generally very small and difficult to detect. With the soybean cyst nematode, the mature white females and tan cyst stages are both large enough to be seen on the root system without a hand lens (Figure 12.2). The feeding activity of the lesion and lance nematodes can result in lesions or necrotic (dead) darkened areas on or within the root system. The reniform nematode does not produce distinctive symptoms but rather a general reduction in the plant's root mass.

FIGURE 12.2. Mature white females of the soybean cyst nematode are visible on the soybean root.

GENERAL LIFE CYCLE

The life cycles of most plant-parasitic nematodes are similar and start with an egg [5, 6]. The egg undergoes embryonic development resulting in a first-stage (J1) juvenile nematode. Depending upon the nematode species, the J1 may hatch from the egg or molt within the egg, forming a second-stage juvenile (J2). The majority of plant-parasitic nematode species will hatch at the J2 stage. There are four juvenile developmental life stages (J1, J2, J3 and J4) that are separated by molting and conclude with an adult nematode. The complete life cycle from egg to egg requires three to six weeks depending on the nematode species, the soil temperatures and soil moisture. The reproductive potential of plant-parasitic nematodes in southeastern field crops is exponential, with multiple generations during the long growing season. Depending on the species, each nematode female can lay dozens to hundreds of eggs in her life span.

The life stage at which nematodes infect plants varies by nematode species. All juvenile stages, as well as the mature adult of the lesion and lance nematodes, are capable of infecting a crop's root system. The lesion and lance nematodes are migratory and will feed from the inside of the root [3]. The lesion nematode feeds on the root surface but will also enter the root and feed while migrating from cell to cell. The female lesion nematode lays eggs individually in the soil or in the root system as it feeds and moves through the root system. Once the eggs hatch, the juveniles start feeding. The female lance nematode lays its eggs individually in the soil as it migrates and feeds.

The root-knot and soybean cyst nematodes infect crops at the J2 stage (Figure 12.3), while the female reniform nematode does so at the young adult stage (Figure 12.4) [5, 11]. The J2 will hatch from the egg and swim in the moisture layer surrounding soil particles in search of a root. No juveniles or adult males of the reniform nematode have been observed feeding on a plant's root system. The root-knot nematode enters roots just behind the root cap while the reniform and soybean cyst nematodes enter at any point on the root system [5]. After entering the root, all three species migrate through the root system to the vascular tissue. There, the nematode becomes sedentary and forms specialized feeding sites referred to as giant cells [15]. The giant cells are created by the feeding activity of the nematodes, and they act as a nutrient sink and feed the nematode throughout its life cycle.

The root-knot nematode becomes stationary once it begins feeding inside the root system, where it completes its respective molts and forms the adult [9, 11, 13, 38]. When the adult stage is

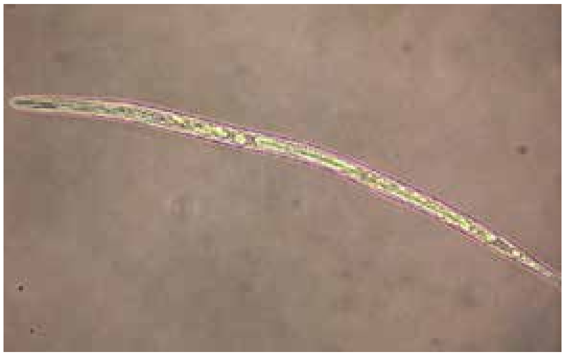

FIGURE 12.3. The infective stage of the root-knot nematode, *Meloidogyne incognita*, at 400x magnification.

FIGURE 12.4. The infective stage of the reniform nematode, *Rotylenchulus reniformis*, the immature female, at 400x magnification.

reached, the mature female begins laying eggs. Males are rarely produced and if formed, will leave the roots and no longer feed. In most southeastern species, male root-knot nematodes are not required for reproduction.

The soybean cyst and reniform nematodes require both males and females to complete their life cycle [9, 11, 31]. The mature soybean cyst male becomes vermiform (worm-like) at the last molt and leaves the root in search of females. The female remains sedentary in the root, but as it grows in size its posterior will push out of the root. After mating, the female will begin laying eggs. Figure 12.5 shows signs of the reniform nematode on a cotton root at 60x magnification. The small soil-covered swellings are the posterior portion of the reniform nematode, bearing a kidney shape. These can be seen on an infected plant with a 10x hand lens.

FIGURE 12.5. Symptoms and signs of the reniform nematode on cotton roots, at 60x magnification.

The root-knot nematode, soybean cyst nematode and reniform nematode all lay eggs outside the female's body during most of the life cycle. However, when conditions become unfavorable, the soybean cyst nematode will begin producing eggs within the protective body cavity, and this will develop into a visible cyst. The nematode egg is resistant to desiccation and is the primary overwintering structure for most nematode species. However, the juvenile or adult stages may also overwinter in some temperate regions of the Southeast.

NEMATODE SAMPLING

The most accurate method for detecting nematode infestations is soil sampling [3, 4, 30]. A nematode analysis will determine the genera of nematode in a field and will provide an estimate of the population densities of each genus. Collect soil samples when soil moisture is adequate for good plant growth, not during dry periods. Irrigation may be necessary to have sufficient soil moisture for sampling.

Divide each field into 10- to 25-acre sections with uniform soil texture and cropping history to provide an accurate representation of the field. Collect soil with a 1-inch diameter probe to a depth of 8 inches within the crop root zone. Collect at least 10–20 soil samples in an arbitrary manner across each section. Thoroughly mix the soil samples from a section and put approximately one pint in a plastic bag. Seal the bag to prevent drying and label it to identify the field location.

Keep the composite soil samples out of direct sunlight and heat. Place samples in a cool ice chest for transport to a state or private diagnostic laboratory.

Diagnostic services that identify nematode genera are available at most land grant universities and at multiple private laboratories in crop production regions. The nematode population levels, which vary widely between regions and soil types, can be compared with established economic threshold numbers for a specific crop in each state. The economic threshold is the nematode population density at which the value of the crop damaged is greater than the cost of the nematode-control method. Thus, nematode-control methods have an economic return.

Populations of plant-parasitic nematodes exhibit an uneven distribution across the field. Numbers often range from high to low or undetectable in different sections across a field. For this reason, if an area is suspected to have a nematode problem, keep samples collected from the area separate from other samples [4, 30]. Studies have shown that the reniform nematode is distributed evenly in conventional tillage systems [11, 14].

The time of year significantly influences nematode population densities. Nematode populations are generally at their maximum levels when the crop is at its greatest biomass stage. Thus, samples are usually collected immediately after harvest. Soil samples collected in the late winter after frost or in the early spring often contain low or undetectable nematode levels as populations decline with cold weather.

NEMATODES IN THE SOUTHEAST

This section provides descriptions of the plant-parasitic nematodes of economic importance in the southeastern United States. Host range, soil texture preference, impact of tillage and potential yield reductions are reviewed for each nematode species.

Root-Knot Nematode (*Meloidogyne* spp.)

There are four common species of root-knot nematodes (*Meloidogyne* spp.) known to parasitize field crops in the United States: the southern root-knot (*M. incognita*), the peanut root-knot (*M. arenaria*), the javanese root-knot (*M. javanica*) and the northern root-knot (*M. hapla*)

FIGURE 12.6. Symptoms of root-knot nematode galling on cotton roots, at no magnification.

[30]. The southern root-knot nematode is the most widespread, most commonly encountered and most economically important plant-parasitic nematode on cotton, corn and soybeans in the Southeast. Cotton, corn and soybean yield losses in the Southeast have been reported as high as 72 percent, 35 percent and 90 percent, respectively [20]. This nematode is commonly found in sandy soils and has a broad host range. The southern root-knot nematode does not survive in cold climates.

The peanut root-knot nematode is the most important root-knot nematode in peanut production. It is also a major pathogen of soybeans, particularly in regions where peanuts are produced [13]. This species is abundant in warmer regions and seldom found where temperatures frequently reach freezing.

The javanese root-knot is an economic species on soybeans and is the second most common *Meloidogyne* species [30]. It is more prevalent in hot, dry regions and does not survive in cold climates. The northern root-knot nematode usually occurs in cooler environments and is rarely found in Southeastern cropping regions [30]. The northern root-knot has a wide host range but does not parasitize grassy plants such as rye, wheat and oats.

For Southeastern field crops, yield losses caused by root-knot nematodes vary in economic intensity depending upon the nematode species, population levels, cultivar tolerance and environmental stress caused by excessive or inadequate moisture and temperatures. The greatest yield losses for root-knot nematodes on all field crops are reported on sandy, light-textured soils. Populations of the southern root-knot nematode were reported to be unaffected by tillage methods in a corn production system [8]. The weed host range for root-knot nematodes is extensive, thus rotations must be kept weed free to reduce populations [27].

Root galling is the classic symptom of root-knot nematode infections (Figure 12.6). Root galls vary in size and number depending upon the host crop, the level of the initial infection and the root-knot species [30]. Above-ground foliar symptoms may include a slight stunting to severely suppressed growth, which often occurs in irregular patterns in the field (Figure 12.7 and Figure 12.8). Yellowing (chlorosis) of the foliage may also occur. Generally, plant death is not associated with root-knot nematodes unless they are combined with a fungal disease such as Fusarium wilt. In cotton and soybeans, early-foliage senescence has also been associated with root-knot nematode infections.

Reniform Nematode (*Rotylenchulus reniformis*)

There are nine species of the reniform nematode, but only *Rotylenchulus reniformis* is considered

FIGURE 12.7. Symptoms in recently infested fields include areas of stunted and uneven plant growth, giving the field an irregular, jagged appearance. Often weeds are seen later in the season due to poor canopy coverage. This cotton is growing in a field infested with root-knot nematodes.

FIGURE 12.8. Nematode foliar symptoms in soybeans may include a slight stunting to severely suppressed growth, which often occurs in irregular patterns in the field. This is referred to as the wave effect. These soybeans are growing in a field infested with root-knot nematodes.

an economic pest to cotton and soybeans in the Southeast [11]. This nematode was initially identified in Hawaii, later found in South Carolina, and more recently found from Virginia to Texas. It is tropical to subtropical and has not been reported in areas with extended freezing temperatures. The distribution of the reniform nematode is not limited by soil type. No consistent relationships have been determined between the presence of the reniform nematode and soil texture, soil pH or soil moisture. In general, the finer-textured silt and clay soils support larger reniform populations than the coarser-textured sandy soils [14, 29]. The lack of water stress during crop production appears to facilitate higher reniform population levels during the growing season. The host range of the reniform is extensive, including many dicotyledonous weed plants such as morning glories, amaranths, sidas and sickle pods [10,15, 29]. However, corn, wheat and peanuts are not considered hosts for this nematode.

Cotton yield losses of 50 percent and soybean losses of 33 percent have been reported [9, 11, 15]. Losses vary depending upon initial reniform population levels, crop cultivar tolerance and environmental stress during crop production. In the Mississippi Delta region, it is not uncommon to find reniform numbers as high as 40,000 to 60,000 per pint of soil following cotton production [17]. However, in many soil types across the Southeast, reniform populations may only reach 5,000 to 20,000 per pint of soil.

The reniform nematode has a debilitating effect on the growth and yield of cotton and soybean plants. Symptoms in recently infested fields include areas of stunted and uneven plant growth, giving the field an irregular jagged appearance [11, 20, 29]. After fields have been infested for years or tilled frequently, the populations become more evenly distributed and stunted plant growth is not obvious. Chlorosis is not generally evident with reniform disease but with high nematode populations, mature leaves may exhibit interveinal yellowing resembling a potassium deficiency [11] (Figure 12.9). The reniform nematode does not produce root galls, thus symptoms are non-distinctive. Infected root systems are often small with limited secondary root development.

FIGURE 12.9. Interveinal yellowing resembling a nutrient deficiency associated with nematode infection in Alabama soils.

This nematode is often overlooked in the field because root galls are not produced. Soil particles adhere to the egg mass, making visual observations of infection difficult.

Soybean Cyst Nematode (*Heterodera glycines*)

The soybean cyst nematode *(Heterodera glycines)* is the most serious nematode pest of soybeans in the United States [20]. It was first found in North Carolina in 1954 and has been identified in 27 central and southern soybean-producing states. The soybean cyst nematode is a sexually reproductive nematode with multiple defined pathogenic races or types. These different races can cause different amounts of stress to the plants, with some races being more yield limiting than others [24, 28]. Physiological races are subspecies of plant parasitic nematodes that are morphologically identical but may infect and reproduce on a given set of plant hosts in different ways. The soybean cyst nematode is a temperate nematode and does poorly in warmer areas including the panhandle of Florida.

A minimum yield loss of 5 bushels per acre may be expected from a soybean cyst nematode infection, although a higher yield loss is common [31]. The abundant physiological races make crop rotation the primary management option. Rotations with non-host crops including cotton, peanuts and corn reduce soybean cyst nematode numbers. Resistant and susceptible-but-tolerant soybeans are incorporated into the cropping sequences to maintain the genetic diversity of the soybean cyst nematode population. Do not plant the same soybean cultivar in the same field two years in a row. This will reduce the probability of producing a strain of soybean cyst nematode for which there is no resistance.

Foliar symptoms of slight to severe stunting and chlorosis are often seen with soybean cyst nematode infections. The foliar symptoms are non-distinctive and resemble those of other soybean pathogens and environmental stresses. The immature white females or tan cyst stage can be observed on the root system to confirm the presence of the nematode in a field (Figure 12.2). The irregular zigzag lines on the cyst cuticle can be seen with a hand lens and aid in identification.

Lance Nematode (*Hoplolaimus* spp.)

There are multiple species of the lance nematode but only *Hoplolaimus columbus*, *H. galeatus*, and *H. magnistylus* are considered economic pests to cotton, soybeans and corn in the United States [25]. *Hoplolaimus columbus* is considered the most pathogenic lance species on cotton and soybeans [9, 11]. This nematode has been reported to reduce cotton and soybean yields by 70 percent in Georgia, North Carolina and South Carolina. *Hoplolaimus galeatus* and *H. magnistylus* are the most frequently identified lance species in Alabama, Arkansas, Louisiana, Mississippi and Tennessee. These two species have been reported to cause damage to cotton and corn [38]. Lance nematodes can feed as migratory parasites on the exterior or interior of root systems, with all life stages present in the root system and soil. Sandy soils are most often associated with higher lance nematodes populations.

The most common symptoms of lance nematode infection are unexplained yield losses and stunting. A slight yellowing of the foliage may occur on cotton with severe chlorosis on soybeans. Due to its migratory nature, root systems are discolored or necrotic, with a truncated taproot and reduced number of feeder or secondary roots. A necrotic root system is indicative of lance nematode infestations. This nematode cannot be seen without the aid of a dissecting microscope. The severity of the damage in a crop is most often dependent on population numbers, soil type and soil moisture.

Lesion Nematode (*Pratylenchus* spp.)

Multiple species of the lesion nematode, *Pratylenchus* spp., cause economic damage to corn, soybeans and wheat. Significant yield losses in corn in the Midwest are more frequently caused by *P. hexincisus*, *P. penetrans* and *P.scribneri*, while *P. zeae* and *P. brachyurus* are the predominant species of the Southeast [38]. The five species common on corn, *P. alleni*, *P. coffeae*, *P. neglectus*, *P. safaensis* and *P. vulnus*, can cause yield losses in a soybean crop. In wheat, *P. neglectus* and *P. thornei* are the principle species considered to limit yields. All lesion nematodes are migratory and feed inside the root cortex. However, they will also leave the root to migrate to other roots, and will feed on roots from the exterior.

Symptoms are predominantly the result of feeding and migration through the root system, causing lesions and necrosis of the fibrous and coarse roots on corn and wheat, and of the secondary and taproot on soybeans. Heavy infestations cause root tissues to slough off. The nematode feeding areas serve as infection sites for soilborne pathogens that often enhance disease severity and further reduce yields. Foliar growth appears stunted and often chlorotic in localized patches in the field. When soil moisture is limited, yield reductions are often increased.

Yield losses in corn are estimated to average 26 percent when infested with *Pratylenchus* spp. Cultivars of corn, soybeans and wheat vary in susceptibility. Often, resistance to other nematodes, such as the soybean cyst nematode in soybeans, does not impart any resistance to the lesion nematodes. The multiple species of the lesion nematode increase the potential host range and makes rotations problematic.

Sting Nematode (*Belonolaimus longicaudatus*)

This nematode is widely distributed across the Southeast in sandy soils, usually those with 85 percent or greater sand content [3]. Multiple species are known but *B. longicaudatus* is considered the most damaging to crops. It has been reported to cause serious economic damage to cotton, soybeans and peanuts at population numbers as low as 10 per pint of soil at planting. Population numbers of this nematode are often higher in the soil profile, at 6–12 inches deep.

Plants parasitized by the sting nematode are often stunted, with a limited root system. Affected plants are found in clusters throughout the field. Corn, soybeans and peanuts may appear to be suffering from a nutrient deficiency, with chlorotic foliage on a stunted plant that wilts readily in the heat [9, 13, 38]. Roots may have sunken necrotic lesions and are often shortened and thick. Watermelons and tobacco are considered good rotation crops for fields infested with the sting nematode.

Stubby root nematode (*Paratrichodorus minor* and *P. porosus*)

The stubby root nematode is often found in sandy soils in the southeastern United States where corn is grown. It was considered an economic pest of corn before the use of granular nematicides. The rise in corn acreage in the Southeast has increased the presence of this nematode [3, 38]. The main symptom of infection, as suggested by its name, is a stunted stubby appearance to the root system that can be incorrectly diagnosed as herbicide damage. The shoot of the corn plant may appear stunted with chlorotic foliage. The nematode is often found in large irregular areas in a field. Tillage tends to reduce numbers of this parasite, as does rotation to peanuts or soybeans.

NEMATODE MANAGEMENT

The options available for plant-parasitic nematode management include sanitation, resistant and tolerant varieties, crop rotation, cover crops, conservation tillage and nematicides. In most cases, a combination of these practices will be needed to keep nematode numbers below the economic threshold. Only use nematicides when other options are not feasible or do not reduce populations below the economic threshold.

Sanitation

If plant-parasitic nematodes are not present in a field, take preventative measures to reduce the chance of introducing an infestation [11, 30]. Wash planting, cultivating and harvesting equipment to remove all soil residue when moving from field to field. For example, the spread of reniform nematodes has been linked to movement of equipment from field to field as producers enlarge their operations by leasing new lands. Soil clods clinging to equipment have been shown to transport reniform nematodes, with thousands occurring in a pint of soil. Reniform and soybean cyst nematodes can remain viable for three and 10 years, respectively, in dry soil.

Preventing the introduction of damaging nematodes eliminates the need to manage them. Once nematodes are present, they cannot be eradicated and must be managed. Wash all equipment to remove soil residues before use on nematode-free fields. Remove soil residues from all contract harvesting equipment as well as from any newly purchased equipment.

Resistant and Tolerant Varieties

Plant-parasitic nematodes are capable of reducing crop yields in an infested field. Therefore, it is important to maintain low nematode population densities. The most important and often most economical management tool is the use of resistant or tolerant cultivars [33]. Tolerance is defined as the ability of a crop to produce an adequate yield in the presence of the nematode. Resistance is the ability of a plant to limit nematode population increases and is determined in greenhouse studies that evaluate nematode populations over time. New cultivars are constantly being developed for all crops in various crop production regions. Evaluations of nematode tolerance in field crops are made through field trials that examine yield.

A resistant variety will not allow a nematode population to increase. Nematologists define resistance based on a nematode reproductive factor, Rf, which is the final nematode population, Pf, divided by the initial nematode population, Pi. Rf=Pf/Pi [6, 19]. A host variety with an Rf value less than one is considered resistant and does not allow the nematode population to increase. A value of greater than one indicates the nematode population increases in the presence of the host plant. However, plant breeders will often determine resistance as a ratio between the variety being evaluated and a standard cultivar [33]. If the variety has a lower final population than the standard, it is considered moderately resistant or resistant.

Nematode numbers following a tolerant crop will generally be higher than those following a resistant crop. Do not plant a tolerant variety in the same field two years in a row. In an Alabama study, PhytoGen 565 WRF produced a seed cotton yield of 3,133 pounds per acre with 1,585 root-knot eggs per gram of root [32]. This cotton variety is considered root-knot tolerant. It produces a good yield while supporting a nematode population above the established economic threshold. In the same study, PhytoGen 367 WRF produced 3,467 pounds per acre of seed cotton with only 382 root-knot eggs per gram of root. This variety was considered resistant and nematode numbers should be lower for the following season's crop.

Many universities across the Southeast conduct variety trials on cotton, corn, soybeans and small grains in the various production regions of their states. The annually updated yield and disease ratings are published on their websites. These are some examples: www.alabamacrops.com and www.msucares.com. Variety trial information is available online at the American Phytopathological Society website: www.plantmanagementnetwork.org. (Search for plant disease management reports.)

The resistant reaction of crops to infection by plant-parasitic nematodes is complex. To better understand host resistance, new technologies are being used at the feeding site. Technologies such as laser capture microdissection, in concert with microarray analysis and other genomic analysis methods, are identifying genes that are specific to not only the susceptible or resistant reaction, but also to the different resistant reaction types [12]. These technologies allow for identification of common strategies that plants use to combat plant-parasitic nematodes. The impetus is the development of meaningful gene annotation databases that are publicly available and easy to mine so that many labs have the ability to explore the function of genes in functional genomics analyses [12]. Once this goal is met, solutions to agricultural problems presented by plant-parasitic nematodes will become available.

Crop Rotations

Crop rotations are effective in reducing nematode populations [7]. The production of corn, grain sorghum or peanuts for one year may sufficiently reduce reniform nematode numbers to allow the production of cotton or soybeans the following season [7, 9, 11, 13, 38]. Although rotations with corn, grain sorghum and peanuts will reduce reniform numbers, they may increase root-knot numbers. Knowing the type of nematode present and the crop host status is important for planning the cropping sequence (Table 12.1). Plant-parasitic nematode types and population levels shift with the crop grown. Therefore, planting a rotation crop that is resistant to one species may increase another nematode species that will become the dominant pathogen. Sampling is important in understanding the dynamics of the different species present in a field. Weed populations in all crops must be controlled to eliminate nematode increases on weed host plants [19, 27]. It is common to find an increase in reniform numbers during the non-host corn and grain sorghum rotation since these nematodes feed on weeds often present late in the growing season [19].

If a resistant cultivar is available, do not grow it in the same field for two or more consecutive years. If a resistant cultivar is grown in the same field for multiple years, it allows for the selection of nematode strains that will be able to feed and reproduce on the resistant cultivar. The number of these nematodes will increase in the field and the resistant cultivar will no longer have any resistance to the nematode strain. This practice is common in soybean production where a resistant soybean cultivar is rotated with a non-host such as corn or grain sorghum, or a susceptible-but-tolerant soybean cultivar [9, 31]. The

TABLE 12.1. General host status of field crops for the common southern plant-parasitic nematode species

Nematode Common name Genus species	Cotton *Gossypium hirsutum*	Soybeans *Glycine max*	Corn *Zea mays*	Peanuts *Arachis hypogaea*	Wheat *Triticum aestivum*
Southern root-knot	Host[1]	Host[1]	Host	Non-host	Non-host
Meloidogyne incognita race 3, 4					
Peanut root-knot	Non-host	Host	Host	Host[1]	Non-host
Meloidogyne arenaria race 1					
Javanese root-knot	Non-host	Host	Host	Non-host	Non-host
Meloidogyne javanica					
Reniform	Host	Host[1]	Non-host	Non-host	Non-host
Rotylenchulus reniformis					
Soybean cyst	Non-host	Host[1]	Non-host	Non-host	Non-host
Heterodera glycines					
Lesion	Host	Host	Host	Host	Host
Pratylenchus spp.					
Lance	Host	Host	Host	Non-host	Host
Hoplolaimus spp.					
Sting	Host	Host	Host	Host	Host
Belonolaimus spp.					
Stubby-root	Non-host	Non-host	Host	Non-host	Host
Paratrichodorus spp.					

[1] Resistant or tolerant cultivars may be available for these crops. Check with your state Extension service or seed supplier for the most recent information on cultivars.

susceptible-but-tolerant cultivar allows the nematode population to increase but still produces an economically acceptable yield. Multiple cropping sequences are possible, including summer and winter crops.

Cover Crops

Winter cover crops are typically sown after the fall harvest with such goals as reducing soil erosion, competing with weeds, increasing soil organic matter and providing a niche for nematode-antagonistic microflora. Microflora may consist of fungi, bacteria and predatory nematodes. The most common winter-cover grain crops are rye, wheat and oats, while vetch and clovers are the typical legumes employed. These winter cover crops do not effectively suppress all plant-parasitic nematodes.

Many winter cover crops are hosts of plant-parasitic nematodes and may actually increase populations of nematodes for the summer crop when soil temperatures warm in the spring [10, 37]. Root-knot nematode numbers were lower on corn following rye and oat winter cover crops in Florida tests. Cowpeas, crotalaria, joint vetch, and sunn hemp were shown to be poor hosts to root-knot nematode and are good winter cover crops in Florida and the Gulf Coast region [23]. In Georgia, “AU Early Cover” hairy vetch and common hairy vetch increased root-knot nematode numbers and subsequent cotton-root galling [35]. Rye and Cahaba white vetch did not increase root-knot galling on cotton.

In Alabama, 31 winter cover crops were evaluated for reniform nematode management in cotton [10]. Crimson clover, subterranean clover and hairy vetch were determined to be good hosts for the reniform nematode. They could increase reniform numbers if spring soil temperatures are warm before cotton planting. Although, in field trials over two years, cotton yields were not affected by the winter cover crops as compared to winter fallow.

Winter cover crops benefit nematode management by competing with host weeds and increasing soil organic matter that supports nematode-antagonistic microflora. The common winter cover crops rye, wheat and oats compete with weeds, suppressing alternate hosts that can increase nematode numbers in the spring. These grasses also are suspected to increase the natural microflora that can suppress but not eliminate plant-parasitic nematodes. Suppression of the nematodes is not below the economic threshold levels of these pests. Practices in combination with cover crops are required to reduce nematode numbers below economic thresholds.

Reduced-Tillage Practices

Plant-parasitic nematode populations are affected by reduced-tillage practices but results have been inconclusive and differ between species. Nematode numbers are also known to be affected by soil type, soil moisture, location and host crop, which are all factors that interact with tillage practices. In soybeans, nematode populations reach their peak in conventionally tilled soybean monocultures. Further studies have reported that soybean cyst nematode’s J2 (the infective stage) numbers in the soil were highest in conventionally tilled soybean monocultures. Soybean cyst nematode numbers were reduced by natural fungal pathogens more frequently in no-till systems than in disked or chiseled tillage systems [4]. Rotations with any winter or summer crop reduced soybean cyst nematode numbers in these infested fields [34]. Lesion nematode numbers were reported to decline with reduced tillage or no-till as compared to conventional tillage [8]. However, reports from Georgia corn fields indicated nematode numbers were not affected by tillage [1]. Soil type may be a determining factor in nematode population potentials. Reniform nematode numbers were reported to decline with conventional tillage, although the mechanical stirring of the soil facilitates the nematode’s spread across the field [11, 36]. Root-knot in corn may not always be affected by tillage systems, although tillage in the spring and fall reduced root-knot numbers in corn compared to a no-till or ridge-till system [22, 36]. However, lesion nematodes in these studies had greater numbers in tilled soils. In addition, common crop production practices will not reduce the populations to levels that will eliminate plant injury and yield reductions. Uprooting crops or turning the soil after harvest exposes nematodes to sun, and the drying reduces their numbers. Tillage and late-season applications of herbicides kill the regrowth of cotton and late-season weeds. These practices are effective in reducing the overwintering population. Note that organic residues increase the microbial biomass of the soil, which then increases the soil microflora, natural predators of soilborne nematodes [21]. No-till systems increase microbial biomass. Thus, as the soil organic matter increases from reduced tillage, plant-parasitic nematode numbers may decrease.

Nematicides

Nematicides are defined as chemicals that kill nematodes. They first became widely and economically available in 1943 with the discovery that a mixture of 1, 3-dichloropropene and 1, 2-dichloropropane was effective in controlling plant-parasitic nematodes [20]. This was coupled with an increase in crop yields. Ethylene dibromide and dibromochloropropane were reported in 1945 and 1954, respectively, to be effective in the management of root-knot nematodes. These discoveries led to the subsequent increases in the use of halogenated hydrocarbons and other volatile compounds for nematode management. In the late 1960s, volatile compounds were followed by a new generation of nematicides. These included the carbamates and organophosphates that were non-volatile and easier to apply. These compounds generally are active against both insects and nematodes, depending on the distribution of the material around the root.

There are four main chemical groups of nematicides: the halogenated aliphatic hydrocarbons, methyl isothiocyanate compounds, organophosphates and carbamates. More recently an additional group of nematicides have been introduced [17]. These are biological products that exhibit nematicidal activity toward plant-parasitic nematodes.

Nematicides can be further subdivided into two broad categories based on movement through the soil. The fumigant nematicides that include methyl bromide, chloropicrin, 1, 3-dichloropropene and metam sodium are chemicals that are formulated as liquids and vaporize after application. The gas moves through the soil pores and mixes with the soil moisture film surrounding the soil particles. The second category is the non-fumigant nematicides. These nematicides are either liquid or granular and move downward in the soil with water percolation. They may be contact or systemic nematicides. Contact nematicides kill nematodes by contact. Systemic nematicides are taken up by the plant and affect the nematodes when they feed. The non-fumigant nematicides include products such as Meymik, Mocap, Vydate and Counter.

Due to the inherent toxicity of nematicides to animals and the environment, only use them when other options are not available. This would include situations where there is a lack of cultivars with resistance or where crop rotation is not economically feasible. Nematicides also have their limitations. Nematicides do not give 100 percent nematode control [17]. Use them with crop rotations and other management practices in a total nematode management program [6].

Base the decision to use a nematicide on a strategy to reduce the initial nematode inoculums, to reduce the rate of nematode development, and to reduce the population density increases on the host plant [11, 17]. The initial nematode population is the nematode population that is in the soil from the previous year's crop. They survived the winter and serve as the primary inoculums for the current year's crop. The use of a pre-plant fumigant nematicide (Telone II, Vapam, Kapam), in-furrow products (Meymik, Counter, Velum Total) or seed treatment nematicides (Avicta, Aeris, Votivo, N-Hibit) at the time of planting are effective in reducing the initial nematode inoculum (Table 12.2).

Reducing the rate of nematode development during the season can be accomplished with post-plant nematicide applications. These are applied after the plant has sufficient leaf and root mass to allow root uptake of the product from the soil (side-dress Meymik). For foliar sprays (Vydate C-LV), foliar absorption is followed by downward translocation to the roots where it will affect the nematode's feeding activity [17]. Each of the products mentioned will vary in their effectiveness. Consult local county and state agricultural

TABLE 12.2. Nematicides registered on cotton, corn and soybeans

Chemical name	Trade name	Formulation	Label application rate
1, 3-dichloropropene	Telone II	Fumigant	3–6 gallons per acre. Apply as a broadcast or row treatment with a fumigant shank. Shank trace should be sealed with soil to prevent loss of fumigant. Leave soil undisturbed for 7 days after application.
Sodium methyldithiocarbamate (anhydrous)	Vapam HL	Fumigant	37.5–75 gallons per acre depending on crop, target pest and soil conditions. Apply post harvest and 14–21 days prior to planting a new crop.
Potassium N-methyldithiocarbamate	K-pam	Fumigant	30–60 gallons per acre depending on crop, target pest and soil conditions. Apply post harvest and 14–21 days prior to planting a new crop.
Ethoprophos	Mocap	Liquid and granules	0.75–1 pound of active ingredient of a 15 percent material per 1,000 feet of row in a band 12–15 inches wide over the row. Mix with the top 2–4 inches of soil with mechanical equipment right after application.
Terbufos	Counter	Granules	6–8 ounces per 1,000 feet of row for any row spacing. Do not exceed 8.7 pounds per acre.
Aldicarb	Meymik	Granules	3.5–10 pounds per acre. Drill granules just below seed line or place in the seed furrow and cover with soil. If rate exceeds 7 pounds per acre, apply granules in a 4- to 6-inch band and work into the soil or cover with soil. Plant seed in or above the zone. Sidedress granules 8–16 inches to one or both sides of the plant row at 2–5 inches deep at a rate of 5–14 pounds per acre.
Oxamyl	Vydate	Liquid	17 ounces per acre. Foliar applications must follow a pre-plant soil fumigant or an at-planting band or in-furrow application of a contact nematicide. Vydate C-LV can be applied as a single or a sequential broadcast rate of 8.5–17 ounces. The initial application in the 2nd to 5th true leaf stage and repeating 7–14 days later.
Thiodicarb and Imidacloprid	Aeris and Gaucho	Seed treatment	0.75 mg ai/seed + 0.375 mg ai/seed. All seed-applied components are applied by the manufacturer.
Abamectin and Azoxystrobin and Fludioxonil and Mefenoxam and Thiamethoxam	Avicta and Dynasty and Cruiser	Seed treatment	0.15 mg ai/seed + 0.34 mg ai/seed +0.03mg ai/seed. All seed-applied components are applied by the manufacturer.
Fluopyram and Imidacloprid	Velum Total	In-furrow spray	10–18 fluid ounces per acre. Apply as an in-furrow spray at planting.
Harpin protein	N-Hibit	Seed treatment	3 ounces per hundredweight of seeds. Apply to seed in a sufficient amount of water to provide good coverage up to 24 hours prior to application.
Paecilomyces lilacinus	Nem-Out	Soil drench	0.15–0.30 pounds per acre applied as a soil drench in 30–40 gallons of water
Pasteuria spp.	Clariva Elite	Seed treatment	5.6 fluid ounces per hundredweight of seeds
Bacillus firmus	VOTiVO FS	Seed treatment	7 fluid ounces per hundredweight. All seed-applied components are applied by the manufacturer.

officials to determine if the nematicide will work in a region. Microbial degradation has occurred with some nematicides so continuous use of a single nematicide is not advisable and may reduce its efficacy [16].

Variable-Rate Nematicide Applications

Precision agriculture has become a widely accepted practice in the Southeast. One important aspect of the technology is variable-rate applications of nematicides. In the field, plant-parasitic nematodes generally have a non-uniform, clustered spatial distribution [14]. The distribution varies with nematode species, soil texture and the crop grown. Variable-rate application or site-specific application is the application only to the areas where the nematode population has reached the economic threshold.

To implement a successful nematode management program, the nematodes present in the field and their location must be determined [14,15]. This is accomplished by collecting samples from a uniform, systematic grid across the field or through the use of zone sampling [26]. Zone sampling creates zones or areas of similarity from which samples are collected. Soil texture is one criterion for obtaining points from similar areas. Different nematode genera favor different soil textures, so soil texture will influence the damage resulting from infection. Each sample point is geo-referenced using a global positioning system (GPS). This type of sampling is popular because it maps the spatial information for a specific nematode pest [26].

One drawback to grid sampling is that it is time consuming and can be costly. Each sample must be processed to identify the nematode species present and the estimated total number present. Once the nematode population numbers are located and mapped, nematode contour maps can be developed to graphically represent nematode numbers in a field. The map can be overlaid with yield maps to determine problem areas in the field. Poor crop yields in combination with high nematode numbers are good indications that areas may require nematicide applications. A nematicide prescription map and predetermined application rates are then loaded into the application equipment's computer. The specified amount of nematicide is applied to the selected areas as the equipment moves across the field. To monitor that the correct dose is delivered, an as-applied map is created during application.

A representative number of soil samples is the key to success for any nematode management program. This becomes essential for variable-rate application of nematicides. The smaller the sample grid size (0.025–0.5 acre), the more detailed the nematode distribution map, resulting in better placement of the nematicide [14]. However, the more samples, the higher the laboratory cost to process them.

Remote sensing is being examined as a way to detect and estimate plant-parasitic nematodes associated with crops [14]. Remote sensing is the characterization of an object without coming into physical contact with it. The technique results in contour maps that represent a nematode's spatial distribution in a chosen area. From there, prescription maps are prepared. As the application equipment travels across the field, the rates are adjusted for each nematode management zone. These types of variable-rate applications are based on nematode population numbers.

The second means of variable-rate nematicide applications are based on soil textures and soil electrical conductivity [26]. Electrical conductivity is the ability of a material to conduct an electrical current, in this case soil. Recent studies have demonstrated that nematicides have been less effective in field locations with high clay content. Soil electrical conductivity data is collected utilizing a Veris soil electrical conductivity mapping system. The Veris cart is used in conjunction with a GPS receiver to georeference the collected data. The sensors measure a shallow soil electrical conductivity, 0–12 inches, and a deep soil electrical conductivity, 0–36 inches, and then store the data in the operating console. The data collected is converted to shape files for each soil depth and classed by specific electrical conductivity ranges. A nematicide prescription map is then developed based on management zones representing the electrical conductivity ranges. Preliminary results have shown that less nematicide is applied to the zones with higher electrical conductivity values.

SUMMARY

Plant-parasitic nematodes can become a greater challenge in fields after making the switch to a conservation tillage system. This occurs because the area in and near the crop's root system is left undisturbed throughout the year. In a conventional tillage system the practice of turning up the soil and exposing plant roots helps limit their populations. There are a number of nematode species present in southeastern soils that can cause considerable yield loss to cotton, corn, wheat, peanuts and soybeans (Table 12.1). These economically significant nematode species can have particular geographic ranges, and they exhibit different preferences for plant hosts and soil textures. Soil sampling for nematode populations and understanding the visible and diagnostic symptoms of nematode damage are key steps to maintaining a successful plant-parasitic nematode management plan. Typically, a combination of management practices is used to keep nematode numbers below the economic threshold. The best options include equipment sanitation, resistant and tolerant crop varieties, crop rotations, cover crops and conservation tillage. Conservation tillage results in a greater diversity of soil organisms that compete with parasitic nematodes and reduce their populations. Nematicides are another important tool but are used only when necessary to limit the economic impact of nematode damage.

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CHAPTER 13

Insect Pest Management

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The implementation of conservation tillage practices has led to dramatic changes in the management of some insect pests, particularly those that spend a portion of their life in the soil. Research on the responses of insects to reduced tillage has been conducted on all major field crops beginning with 1960s research on corn rootworm in Ohio [62]. While there are many advantages of reduced tillage when compared to conventional tillage, one potential disadvantage is an increase in insect-induced crop injury [26]. However, insect pests can also decrease in abundance or show no change under reduced tillage [62]. This chapter summarizes how conservation tillage practices change insect habitats and how those changes affect the associated major insect pests and their management.

CHANGES IN INSECT HABITAT WITH REDUCED TILLAGE

Tillage disrupts insect habitats and causes changes in the species and numbers of insects. Reducing or removing tillage as done in conservation tillage profoundly modifies the agroecosystem, which influences insect population and species. The degree of disturbance varies with the type of conservation tillage. Seedbed preparation can range from complete burial of plant residue to no-till. Reduced-tillage systems can be used on a continuous basis, from year to year, or on an intermittent basis. In addition, double cropping is particularly popular in areas of the Southeast and often involves conservation tillage. An example is planting a winter crop followed by a no-till, late-spring or summer crop. Both conventional and conservation practices modify insect habitat. The differences are described here.

Mechanical Disturbance of Soil

Soil disturbance exposes pests that live in the soil to predators and parasitoids. Parasitoids are insects that spend a portion of their lives in a pest host, ultimately killing the host. In addition, soil disturbance can crush pests in the soil or trap them by sealing exit tunnels. As a result, moldboard plowing or other soil inversion to bury crop residues and restructure the soil is traditionally recommended to control some soil insects. In conservation tillage, the destructive effects of this management tool are reduced or removed.

Crop Residue

Crop residue on the soil surface reduces erosion and adds to soil organic matter. With conservation systems, increased crop residue and soil moisture reduce soil temperatures when compared with conventional practices. This favors certain soil-dwelling and litter-dwelling insects.

Soil Structure

The soil structure is preserved under no-till, with increased moisture and aeration [29]. Residue covering the soil surface decreases soil temperature, which may slow the growth of plants that are susceptible to insect damage in their seedling stages, such as corn. The soil's long-term structural integrity may also increase the survival of soil-dwelling insects and other arthropods such as spiders.

Weed Diversity and Abundance

Reduced tillage or no-till can lead to changes in weed species, often fostering an increase in grassy, perennial weeds. Because many insects are associated with non-crop plants such as weeds, conservation tillage can lead to profound changes in insect abundance and diversity through changes in the weed community. Crop regrowth following harvest or termination with herbicides can also create changes in the numbers and types of insects present.

Planting Dates

Because many conservation tillage systems involve multiple cropping practices and because shading by residue can slow the warming of soil in the spring, the crop is often planted later than in conventional systems. This may shift the types of pests in the soil and their activity. This risks exposure to more damaging pest populations or pest species.

Cover Crops

Cover crops are an important part of conservation tillage systems and contribute to a greater diversity of vegetation. This can affect insect populations because insect outbreaks tend to be more frequent in systems with reduced vegetation diversity [6]. Cover crops can increase the diversity and abundance of beneficial insects by providing additional shelter, nectar, pollen or food sources. Increased beneficial insect populations result in reduced pest populations. However, cover crops can also provide critical resources for generalist pests when the crop cannot support pest populations. The cover crops provide a temporary refuge for the pest until the crop is suitable for attack.

CHANGES IN INSECT PEST STATUS

Conservation tillage can change the population dynamics of various insect pests. This can result in the pest status changing or staying the same, meaning more damage to a crop, less damage or no affect on crop damage. The direction and magnitude of change, however, are highly variable and depend on the crops, pest species, geographical locations and cropping practices. Therefore, each pest and crop situation is different and must be considered separately [4]. Comprehensive reviews of the responses of various vertebrate and invertebrate pests to conservation tillage are available [4, 62]. The following sections briefly review recent studies that examine the effects of conservation tillage on the abundance and damage of important pest species of the Southeast. Table 13.1 summarizes the effect that conservation tillage has on these pests. Relevant studies from other regions are also discussed.

Cotton

Conservation tillage has become an important practice in cotton production, especially with the advent of transgenic herbicide-tolerant varieties. These varieties have been engineered using molecular techniques to tolerate applications of herbicide that would harm a conventional variety. Various thrip species and cotton leafhoppers are less abundant in conservation tillage fields than in conventional tillage fields [3, 45, 50].

Other insect pests increase with conservation tillage. For example, in cotton fields that use conventional tillage, the tillage and residue burial typically kill many of the soil-inhabiting insects present. Post-season tillage is likely to destroy most pupae of tobacco budworm and cotton bollworm (also called the corn earworm) overwintering in the field [59]. However, the burial of infested cotton fruits by conventional tillage increases survival of boll weevils by protecting them from heat and desiccation on the soil surface [27].

The absence of tillage can lead to increased damage by cutworms, delayed maturation of plants and decreased seed-cotton yield [42]. The abundance and activity of red imported fire ants increases in conservation tillage. This in turn can lead to an increased abundance of cotton aphids [43]. The fire ants collect honeydew from the aphids and protect them from their natural enemies.

Cover crops can play an important role in attracting natural enemies of pests and reducing the

TABLE 13.1. Effects of conservation tillage relative to conventional tillage on selected insect pests of field crops

Insect common name	Scientific name	Crop	Tillage	Effect and reference[1]
Southern corn rootworm	*Diabrotica undecimpunctata howardi*	Corn	No-till	Reduced abundance, reduced injury [9]
Northern corn rootworm	*Diabrotica longicornis*	Corn	No-till	No consistent effect on abundance or injury [63]
Western corn rootworm	*Diabrotica virgifera*	Corn	No-till	Increased abundance; no consistent effect on injury [63]
Black cutworm	*Agrotis ipsilon*	Corn	No-till	Increased injury [63]
European corn borer	*Ostrinia nubilalis*	Corn	No-till	No effect [1, 63]
Lesser cornstalk borer	*Elasmopalpus lignosellus*	Corn	No-till	Increased abundance [41] or reduced abundance [1, 2]
Southern corn billbug	*Sphenophorus callosus*	Corn	Reduced tillage	Increased abundance [1, 4, 24, 56]
Flower thrips	*Frankliniella tritici*	Cotton	No-till	Reduced abundance [45]
Western flower thrips	*Frankliniella occidentalis*	Cotton	No-till	Reduced abundance [45]
Tobacco thrips	*Frankliniella fusca*	Cotton	No-till	Reduced abundance [3, 45]
Cotton aphid	*Aphis gossypii*	Cotton	Reduced tillage	Increased abundance [43]
Cutworm	*Agrotis* and *Peridroma* spp.	Cotton	No-till	Increased injury [42]
Corn earworm	*Helicoverpa zea*	Peanuts	Strip-till	Reduced abundance [16]
Granulate cutworm	*Agrotis subterranea*	Peanuts	Strip-till	Reduced abundance [16]
Velvetbean caterpillar	*Anticarsia gemmatalis*	Peanuts	Strip-till	Reduced abundance [16]
Lesser cornstalk borer	*Elasmopalpus lignosellus*	Peanuts	Strip-till	Reduced injury [16]
Wireworm	Various *Elateridae* species	Peanuts	Strip-till	Reduced injury [16]
Three-cornered alfalfa hopper	*Spissistilus festinus*	Peanuts	Strip-till (wheat residue)	Increased injury [16]
Green cloverworm	*Hypena scabra*	Soybeans	No-till	Increased egg laying [61]; increased abundance [66]
Seedcorn maggot	*Delia platura*	Soybeans	No-till	Increased abundance and injury [22, 32]
Hessian fly	*Mayetiola destructor*	Wheat	No-till	Increased abundance [17, 20, 52, 69]; no effect [13]
Cereal aphid	*Rhopalosiphum padi*, *Rhopalosiphum maidis*, *Schizaphis graminum* and *Sitobion avenae*	Wheat	No preplant tillage	Increased abundance [33]

[1] Abundance or egg laying refers to insect and injury to crop.

abundance of cotton pests. Heliothine caterpillars such as the cotton bollworm and tobacco budworm are more abundant in Georgia cotton plots under conventional tillage than in plots under conservation tillage with crimson clover or rye as cover crops [65]. Increased numbers of cotton bollworm and tobacco budworm predators under conservation tillage with cover crops may counteract the reduced mortality of their pupae in the soil. Similarly, the densities of thrips and associated damage were two to eight times higher in cotton plots without cover crops under conventional tillage relative to plots with cover crops under conservation tillage [49]. This illustrates the importance of cover crops in conservation tillage systems.

Corn

Studies on corn pests suggest that closely related insect species can have different responses to conservation tillage when compared to conventional tillage. Under reduced tillage, western corn rootworm populations increased [63], northern corn rootworm populations were unaffected [63] and southern corn rootworm populations decreased [9]. European corn borer abundance did not change under reduced tillage in Georgia [1], while it was reduced in Delaware [67]. Lesser cornstalk borer was more abundant in conservation tillage in Florida [41], but the opposite trend was observed in two studies in Georgia [1, 2]. Cutworm populations increased under conservation tillage [41, 63]. Fall armyworm does not respond [41] or is less abundant [1].

Populations of caterpillars are often associated with the availability of weed or cover crop hosts in the field. So, changes in the type or density of weeds or cover crops are expected to affect populations of these pests. Fall armyworm damage can be especially severe when herbicide applications kill a previous grassy cover crop or crop such as cereal rye, forcing the movement of caterpillars to the corn crop [4]. Corn becomes susceptible to fall armyworm infestations when the seedlings grow taller than the residue [4].

Soil-inhabiting beetles often become more abundant when plowing is reduced or eliminated. Southern corn billbugs are more abundant in reduced tillage [1, 4, 24, 56]. Increased southern corn billbug infestations are associated with the presence of grassy weeds that serve as host plants for billbug larvae [1]. The planting of small grains before corn also exacerbates the problem when small grains become larval hosts and/or overwintering habitat for the weevils [4]. Several wireworm species are favored with the cooler soil temperature, higher soil moisture and higher soil organic matter content under conservation tillage [4].

Peanuts

Researchers in the Southeast have only recently started studying peanut pests and their natural enemies under conservation tillage because of the historical notion that conservation tillage is incompatible with peanut production. In general, conservation tillage, most notably strip-tillage, reduces pest abundance and injury to peanuts [16]. Some of the pests that are less abundant and/or are less damaging to peanuts under conservation tillage include the corn earworm, granulate cutworm, velvetbean caterpillar, lesser cornstalk borer and various species of wireworms [16]. Similarly, thrips cause more damage to peanuts in fields with no residues than in fields with moderate to high amounts of rye residue [49]. Strip-tillage also reduces the incidence of tomato spotted wilt virus, a disease transmitted by thrips [16]. On the other hand, the three-cornered alfalfa hopper and the burrower bug complex are more abundant and damaging in peanuts in conservation tillage than in conventional tillage [15, 16].

Soybeans

The response of soybean pests to conservation tillage is inconsistent [31]. Studies in Kentucky and Louisiana suggested that eggs and larvae of green cloverworm are more abundant in no-till plots [61, 66]. In contrast, pre-plant tillage has little effect on the population densities of the foliage-feeding green cloverworm and the pod-feeding southern green stink bug, but it favors velvetbean caterpillar [23]. Southern green stink bugs and lesser cornstalk borers are more abundant in soybeans under conservation tillage but do not significantly increase damage to the seedlings [41].

Germinating soybean seedlings may be attacked by the seedcorn maggot. This is particularly true in no-till fields that incorporate manure, organic matter or cover crop residues [30, 32, 48]. High levels of organic matter in the soil are conducive to the egg laying and development of seedcorn maggots. In addition, the delayed germination of soybeans in the cooler soil of no-till plots allows prolonged exposure of seedlings to the maggots [4].

Wheat and Other Small Grains

Overall, the responses of small grain insect pests to reduced tillage are inconsistent. Hessian fly populations can increase in no-till wheat production systems [17, 20, 52, 69], perhaps due to an increase in infested surface residues and an increase in its survival rate [52]. However, a recent study in Idaho reported similar Hessian fly egg densities and variable pupae densities in conventionally tilled and no-till plots [13].

Additional surface residues in plots without preplant tillage may also increase the infestation of wheat and barley by cereal aphids [33]. In fields practicing a sorghum>cotton rotation and reduced tillage, the abundance and damage by corn earworms and rice stink bugs are lower [18].

MANAGEMENT OF INSECT PESTS

While control practices for insect pests are similar in reduced-tillage and conventional tillage systems, some practices may play a greater role with reduced tillage. An example is increased biological control caused by increased predation in no-till systems. Integrated pest management stresses the balanced use of biological, insecticidal, cultural and host-plant resistance tactics to manage insect pests, particularly over the long term [44]. The following section reviews selected practices for insect control in reduced-tillage systems.

Biological Control

Biological control is the reduction of pest populations by natural enemies such as predators, parasitoids and pathogens. In reduced-tillage systems, several factors influence the abundance of natural enemies. These include the crop, cover crop, timing of crop production, amount of residue left on the field, availability of alternate hosts/prey and the range of insects available for natural enemies to feed on.

Not surprisingly, natural enemies that live in or on the soil are generally more affected by conservation tillage and increased surface residue. Reduced tillage can increase the abundance and sometimes diversity of ground beetles [12, 14, 19, 36, 37, 53], although some species are more abundant with conventional tillage [12, 14]. The role of many ground beetle species in agricultural systems is still poorly understood, but some beetle species are valuable predators of important pests. The value of ground beetles as destroyers of weed seeds is becoming increasingly apparent [34]. Other ground beetles are omnivores [40]. As a result, producers can benefit by conserving these beetles since they consume pest insects.

Some species of ants are favorably affected by tillage while some are adversely affected [51]. In the Southeast, one of the most common ant species is the red imported fire ant, an active predator of numerous species. Conservation tillage typically increases the fire ant's abundance [46, 57, 65]. However, fire ants also consume the sweet honeydew produced by aphids and whiteflies. They will often protect these pests from their natural enemies in order to obtain this sugary food [39]. As a result, fire ants can exacerbate problems with aphids and whiteflies in a variety of crop systems. When these honeydew sources are not present or abundant, the ants will generally focus on their predatory activities that can be quite impressive against insect pests, particularly caterpillars.

Tillage can also dramatically affect the diversity and abundance of spiders. There is a tendency for the number of spiders to increase as ground cover increases [58]. Spiders are increasingly being recognized as significant natural enemies of insect pests in crop systems [55]. Practices that encourage their activity will presumably foster biological control and reduce pest infestations.

Reduced tillage can also affect the numbers of insect natural enemies above the soil. For example, conservation tillage systems increased the abundance of big eyed bug predators relative to conventional tillage systems [65]. Overall, however, such changes are quite variable and are very difficult to predict.

Tillage practices can also affect entomopathogens, organisms that cause a disease in an insect. In one study, spores of the pathogenic fungus *Beauveria bassiana* were more abundant under conservation tillage than under conventionally tilled corn [8]. This is not surprising given the more stable temperatures and more moist microhabitat that surface residues foster. But the surface residue also prevented spores from splashing up onto plants so that infections of insects in the plant canopy were reduced in conservation tillage [8]. Similarly, vegetable soils in conservation tillage had a greater abundance and activity of fungal insect pathogens than did conventionally tilled soils [38]. However, this was not the case for the entomopathogenic nematode *Steinernema carpocapsae*, which was not suppressed by tillage [38].

Although a number of studies have evaluated the diversity and abundance of natural enemies in conservation tillage systems, only a few have directly assessed the function of these natural enemies, and the results are variable. It is generally assumed that biological control is enhanced because of the increased diversity of the system [6], but most studies are based on correlations. This means that in conservation tillage systems, natural enemy populations were observed to be higher and some pest populations were observed to be lower. Unfortunately, few of these studies provide mechanistic explanations for these patterns,for example more spiders eating insect pests. Studies have shown that predation of European corn borer eggs by chewing predators was more common in conventionally tilled corn than in no-till corn, but predation by sucking predators (most notably green lacewings) was higher in no-till corn [7]. Similarly, the number of southern corn rootworm eggs was greater in no-till than in conventionally tilled corn, but increased predation on immature rootworm stages by predatory mites, beetles, centipedes and ants in no-till corn led to reduced pest pressure and increased yield [9]. Natural enemies in annual cropping systems tend to be generalists that can switch among several prey or host species. Conservation tillage systems can favor generalist activity by providing alternate prey and hosts as well as the modified habitat [10].

Chemical Control

Insecticides remain the dominant tool for pest suppression. There are numerous problems associated with insecticides, including the development of resistance, impacts on non-target organisms, outbreaks of secondary insect pests and hazards to applicators, as well as other human and environmental health issues. However, properly timed applications of insecticides can be part of a safe and effective pest management program. Only use pesticides as described on the label. To minimize unwarranted applications, economic thresholds are recommended. Economic threshold refers to the density of a pest population above which insecticide treatment is justified.

This chapter does not include guidelines for insecticide use because of the large number of chemicals available and the variability in pest-specific recommendations within the Southeast. In general, the same chemical recommendations are used in conservation tillage as in conventional tillage [4]. Refer to local production guides for appropriate insecticide recommendations.

Seeds are increasingly treated with insecticides such as neonicotinoids before planting [47]. For some crops such as corn it is becoming increasingly difficult to obtain seed without such treatments. Some pests are more problematic with conservation tillage, and seed treatments provide an easy and effective way to resolve these issues. Early-season pests can be major issues in no-till as the corn grows slower than in conventional tillage. High rates of the neonicotinoid insecticides clothianidin or thiamethoxam as corn seed treatments suppress insects such as cutworms, billbugs and grubs [11] that can have increased incidence in conservation tillage.

Cultural Control

Cultural control manipulates the environment to manage pests. Examples of cultural practices that can help manage pests include crop rotation, planting/harvest dates, cover crops, plant density, fertility rates, variety selection and irrigation.

Cover Crops

Cover crops can play an important role in controlling certain pests in conservation tillage. Combined with conservation tillage, cover crops can help reduce the disturbance of natural enemies by preserving their habitat. Leguminous cover crops can also provide increased levels of nitrogen by fixation and rapid decomposition early in the growing season. This promotes plant growth when plants are susceptible to many seedling pests [60].

Fire ants in particular are often enhanced by the use of cover crops [57]. Cotton research in Georgia showed that crimson clover and rye reduced infestations of tobacco budworms and cotton bollworms through increased predation by fire ants and big eyed bugs [65]. In a separate study, the number of thrips in cotton fields and the damage due to adult and immature thrips were two to eight times higher in plots without a winter cover crop than in plots with winter covers [49]. Conservation tillage also reduced thrips numbers and injury to cotton.

Planting into living cover crops may increase the risks from certain pests such as cutworms. Most recommendations suggest that cover crops or weeds be killed well in advance of cash crop planting to reduce pest problems and to minimize water and nutrient competition. Also, leguminous cover crops tend to exhibit a greater cutworm risk than do grass cover crops [25].

Planting Dates

Injury from many insects can be avoided by planting early in both conventional and conservation tillage systems. This is the case with the corn earworm and fall armyworm in corn [4]. In some cases, delayed planting may help to increase the growth rate of seedlings, thus avoiding some pests such as the seedcorn maggot in corn [4]. Planting dates can also affect the impact of reduced tillage on beneficial insects [21]. For instance, early planting of conventional soybeans provides predators with habitat and promotes early colonization, thus reducing the destructive effect of plowing on beneficial insects [21].

Physical Control

Tillage has historically been considered a mortality factor in controlling pests that pupate in the soil, such as the corn earworm [54]. In the absence of tillage, it was assumed that many such pest species would become more serious problems. This has generally not been the case for reasons not entirely understood. Increases in certain predator populations, such as ants, in conservation tillage systems have had some effect. A research review showed that 43 percent of the surveyed studies reported a decrease in insect damage under reduced tillage and 29 percent reported no impact [62]. For example, the absence of tillage can reduce the incidence of the lesser cornstalk borer in corn, sorghum and soybeans following a small grain [4].

Some insects are attracted to weeds or cover crops that occur in reduced-tillage fields. When insect infestations are heavy, consider tillage as an alternative to the use of insecticides. Tillage will bury the insects and prevent or reduce migration of insects to the following crop. For example, armyworms are frequent pests of corn when double-cropped with a small grain, as the larvae can move to corn from the small grain crop after an herbicide is applied in the spring [4]. Also, as noted above, reduced tillage can lead to increased ant abundance. The corn root aphid is strongly associated with fire ants, which use the aphids for honeydew. When this is the case, as in newly planted corn, infestations of aphids can be avoided by tillage to disrupt ant populations prior to planting [4].

Crop Rotation

Many insects require crop residues throughout the year. This happens, for example, with continuous corn production. Crop rotation can break the cycle and reduce pest damage. In continuous corn, the absence of tillage can lead to the buildup of soil insects. Rotation with a non-host crop can be effective in reducing pest infestations. For example, the southern corn billbug is a pest of corn but not a pest of soybeans. A rotation of corn and soybeans can help to reduce infestations in corn [4]. Soybeans also have reduced damage from lesser cornstalk borers in double-crop systems relative to corn or sorghum [4]. Therefore, soybeans are recommended in areas with historically high infestations. In addition to tillage, rotation has been suggested to reduce infestations of Dectes stem borer in soybeans [28].

Crop rotation effects may be different for different insect pests. For example, a rotation of sorghum with cotton can reduce the abundance of bollworm but can enhance populations of the rice stink bug [18]. Not all soil-associated insects are affected by rotation. For example, Colorado potato beetle numbers were the same whether or not tomatoes were rotated with other vegetable crops in both conventional tillage and no-till systems [68].

Varietal Selection

Advances in molecular biology allow plant breeders to insert genes that code for insecticides into plants. The plants then produce the insecticides themselves. Such plants are referred to as transgenic. The bacterium *Bacillus thuringiensis* (Bt) is commonly found in soils and produces toxins that can kill certain insects when ingested. Transgenic *Bt* crops have been engineered to express at least one *Bt* toxin. Transgenic crops expressing *Bt* toxins offer the same benefits in both conventional and conservation tillage systems. However, the value of such crops can be further enhanced in conservation tillage when late planting is necessary and late season insect pressure is likely. In corn, *Bt* hybrids can provide control of European corn borers, stalk borers and corn rootworms as well as suppression of cutworms, corn earworms and armyworms. Differences in efficacy among available transgenic traits underline the importance of choosing appropriate hybrids for the anticipated insect pests. In cotton, *Bt* varieties provide good control of bollworms, tobacco budworms and other caterpillar pests. These can be more abundant under no-till because of the absence of plowing, an important mortality factor for their pupae in the soil [35]. When planting a *Bt* crop, federal regulations require that a portion of the field be planted with a non-transgenic variety to act as a “refuge,” or a nearby area where the targeted pest species can avoid contact with the *Bt* toxin. The purpose is to lower the risk of resistance developing among the insect population. Refuge requirements vary by region and crop variety.

Fertilization

Seedling pests and other pests can often be avoided or their impact reduced by using fertilizer to encourage rapid crop growth and good plant health [5]. Given the tendency for slow seedling growth in no-till or reduced-tillage systems, modifications in fertility regimens may be beneficial. However, in a tillage study, applications of different rates of fertilizer had no effect on pest densities in sorghum under either conventional or reduced tillage [18].

Weed Control

Many insect pests are attracted to weeds that frequently grow in or around fields. Proper management of weeds can help to reduce many insects, including cutworms, armyworms, billbugs, stalk borers (late season weed control) and grasshoppers. Controlling johnsongrass in sorghum can help to reduce sorghum midge infestations [4]. However, herbicidal control of johnsongrass can be difficult. Herbicide use can also lead to increased insect damage to the crop by removing alternate hosts and driving pests towards the crop [64].

SUMMARY

Conservation tillage systems have a key role in increasing soil protection from wind and water erosion, and in decreasing fuel and labor costs. The impact of reduced tillage on insect pest abundance and associated damage can vary considerably among locations, from species to species and from crop to crop. In addition to insect pest herbivores, reduced tillage can have a strong impact on insect predators and parasitoids, and on insects associated with the decomposition of organic matter. Management of insect pests is, in general, similar in both reduced-tillage and conventional tillage systems. Ongoing research concerning reduced-tillage systems is aimed towards a better understanding of the interactions between the modified environment and the dynamics of pest and beneficial insects. Considerable work is still needed in order to better address the issues faced by growers making complex management decisions.

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14

CHAPTER 14

Water Management

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Hydrology is the study of the movement, distribution and quality of water. The central theme of hydrology is that water moves throughout the earth's crust and atmosphere by various pathways (Figure 14.1). Water evaporates from land and water bodies and rises into the atmosphere to form clouds. The clouds then produce precipitation that falls back on the land and water bodies. When water falls on the ground as rain, hail or snow, it can soak into the ground, a process known as infiltration. The infiltrated water is stored in the root zone where it is available to plants, in the unsaturated soil below the plant roots, or in porous underground rocks and sediments called aquifers. Water that does not infiltrate is absorbed directly by plants and plant residues, ponds at the soil surface, or runs off the land into rivers and lakes, eventually ending up in the oceans. Water on the land surface and in water bodies evaporates, and the cycle begins again.

The component of the hydrologic cycle that is important for crop production is rain that falls on fields and either runs off or infiltrates into the soil. The amount of rainfall that soaks into the ground depends upon the rainfall intensity, land slope, soil type, soil water content, compaction level and amount and type of vegetation or plant residue on the surface.

Rain tends to move into the soil most quickly at the beginning of a rainfall event unless the soil is saturated, meaning it cannot hold any more water. If the soil is not saturated at the beginning of a rainfall, it is able to absorb more water as well as transport water to lower portions of the soil profile. As the rainfall event continues, the capacity of the soil to hold additional water decreases until the soil is eventually saturated. When saturated, the rate that water can infiltrate is limited by the rate of downward movement of water within the soil. If rainfall intensity exceeds the rate of downward movement, excess rainfall will either run off or pond on the soil surface. If there is no downward movement of water, all rainfall will run off or pond just as if it fell on a paved surface.

Any water that infiltrates into the soil and does not move out of the root zone is available for crop use. Of the factors affecting the amount of infiltration, the ones that can be managed through agricultural practices include soil compaction, soil water content, and the amount and type of vegetation or plant residue on the soil surface. Agricultural practices that minimize runoff and erosion and that maximize infiltration and water-holding capacity are typically beneficial for crop production. Infiltration can be enhanced by reducing compaction caused when raindrops hit the soil surface, by increasing the soil's water-holding capacity and by increasing the rate that water can move into the soil. One practice that affects all three is conservation tillage. The positive and negative aspects of conservation tillage on water management, its impact on irrigation, and methods that can be used to monitor its impact on soil water are discussed in this chapter.

IMPACTS OF CONSERVATION TILLAGE

In conservation tillage, there is no cultivation of the soil, referred to as no-till, or a minimal amount of cultivation, referred to as reduced tillage. Consequently, all or a portion of the plant residues remain on the soil surface rather than being incorporated into the soil by plowing or

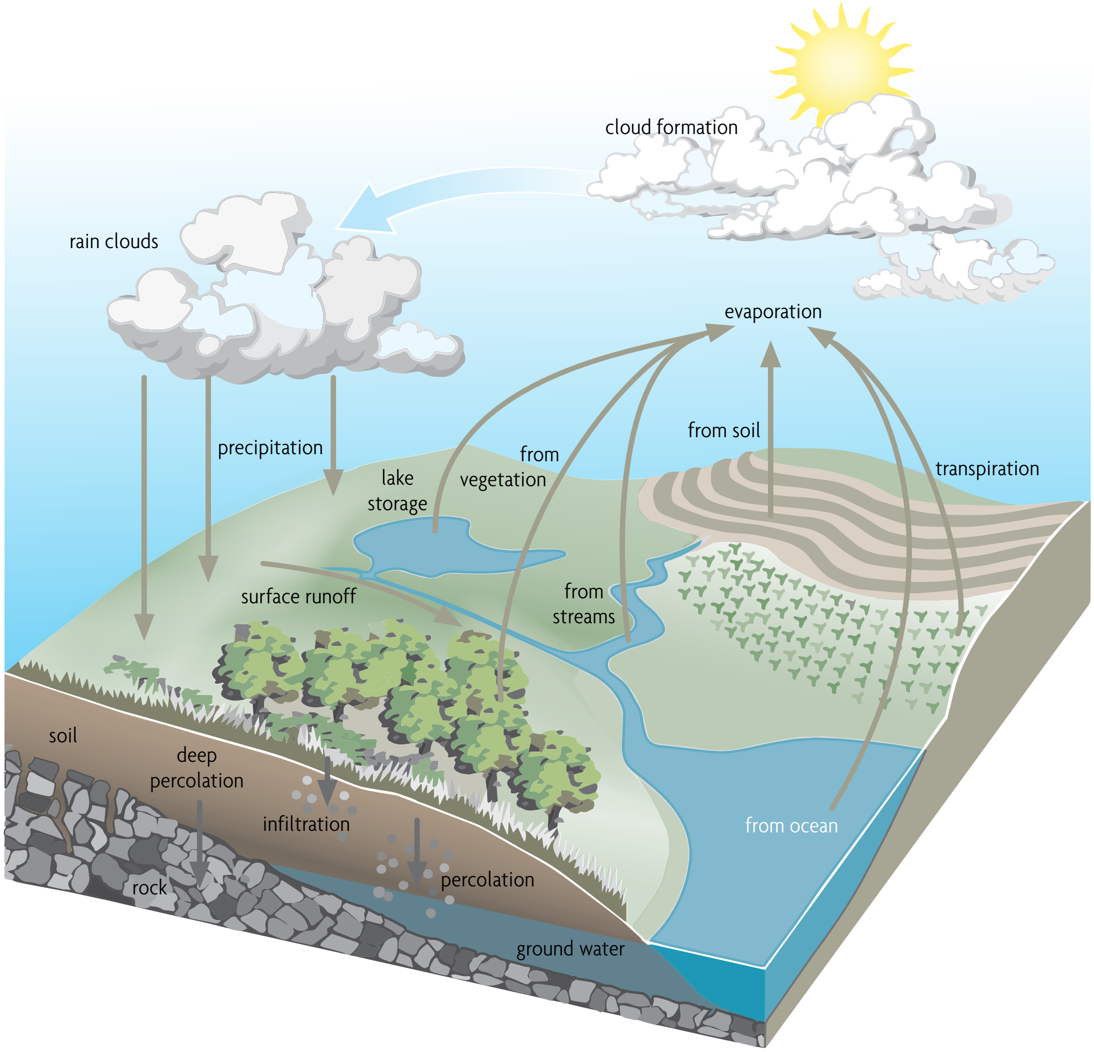

FIGURE 14.1. The hydrologic cycle. The transfer of water from precipitation to surface water and ground water, to storage and runoff, and eventually back to the atmosphere is an ongoing cycle. Source: [4]

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disking. The new crop can be planted directly into the plant residue or into small tilled strips, created using strip-tillage. Conservation tillage is typically defined as tillage that leaves a minimum of 30 percent of the soil covered by plant residue.

Cash crop and cover crop residues left on the soil surface protect the soil from the erosive effects of rainfall and wind. When raindrops hit bare soil, the energy is transferred to the point of impact. This can dislodge soil aggregates, compact the soil surface layer and lead to increased erosion and transport of soil. When raindrops hit growing plants or crop residue, the energy is dissipated, reducing erosion and compaction (Figure 14.2).

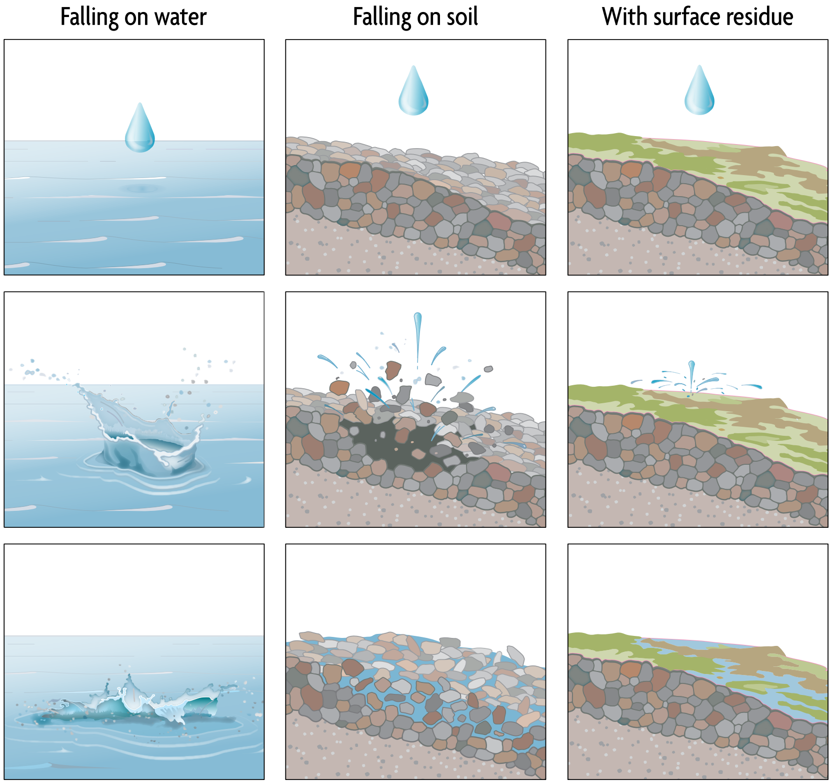
Along with reducing erosion, conservation tillage systems improve infiltration. Compaction reduces infiltration and, inevitably, restricts water flow to the root zone. The compaction caused by rainfall can be minimized by plant residue on the soil surface. Surface residue also slows runoff, which increases infiltration because water stays on the surface longer. In no-till and reduced-tillage systems, increased organic matter and the presence of macropores consisting of wormholes, cracks and root channels, improve the soil's structure.

Increased organic matter improves the soil's water-holding capacity, and better soil structure encourages infiltration rather than runoff. Tillage disrupts these transport pathways and reduces both infiltration and water-holding capacity. Keeping the soil covered with plant residue or a closed crop canopy is critical to reduce soil erosion and optimize infiltration.

The benefits of conservation tillage for reducing surface runoff are well documented. In the southeastern Coastal Plain on a loamy sand soil with a 3 percent slope, strip-tillage has been shown to reduce surface runoff by 55 percent compared to conventional tillage [1]. For a region that receives an annual rainfall of 48 inches, this can mean an extra 6 inches of rainwater for crops throughout the year. Another study found a 99 percent decrease in surface runoff from a no-till field on a 9 percent slope compared to a similar field in conventional tillage [2].

The increase in infiltration with reduced tillage varies by soil type [3]. The Natural Resources Conservation Service (NRCS) classifies soils into four hydrologic soil groups designated Groups A, B, C and D. Group A soils are sandy soils and have a high infiltration rate when wet and a high rate of water transmission, which is the rate of water movement through the soil when saturated. Group B soils have a moderate infiltration rate when wet and a moderate rate of transmission. Group C includes soils with a slow rate of infiltration when wet and slow transmission rates. Group C soils have a layer that impedes the downward movement of water or they are moderately fine textured to fine textured. Group D soils have slow infiltration rates when wet and very slow water transmission. Group D soils include clays, soils with a permanent high water

RAINDROP ENERGY AND SOIL MOVEMENT



During a rainfall millions of drops fall at speeds up to 30 feet per second. Without raindrops, little soil erosion would be caused by water.

Raindrops explode like tiny bombs, splashing water and soil particles as high as 3 feet and as far to the side as 5 feet, and breaking soil aggregates where the soil surface is not protected.

Small aggregates and soil particles can be carried down slopes and off fields where the soil surface is not protected. Crop residue on the surface can prevent most soil loss.

FIGURE 14.2. Impact of raindrop energy on the soil with and without crop residue. Adapted with permission from [5].

table, soils with a claypan near the surface, and soils that are shallow and over nearly impervious material.

A literature review revealed 19 studies on Group B soils and each documented decreases in water runoff with no-till. Runoff averaged 56 percent of that observed from the conventional till sites. Of the 26 studies of Group C soils, 22 (85 percent) documented reductions in runoff with no-till, with runoff averaging 67 percent of that from conventional tillage. Of the 11 studies on Group D soils, only one (9 percent) indicated a runoff reduction with no-till, but there was no difference in the average runoff from the two systems. No studies on Group A soils were found. The review concluded that no-till could be expected to reduce runoff on Group B and Group C soils but not on Group D soils (Table 14.1) [3].

Crop and cover crop residues on the soil surface dissipate raindrop impact, slow surface runoff and often increase infiltration. Residue also serves as a barrier against evaporative water loss from the soil and this increases the amount of water available for crops [14]. Crops that leave a lot of residue on the soil surface generally provide greater benefits. Winter cover crops generate considerable surface residue and keep the soil surface protected. In general, the more residue on the soil surface, the better the results.

CONSERVATION TILLAGE TRADE-OFFS

While conservation tillage can significantly enhance infiltration, there are trade-offs. The benefits of conservation tillage will vary depending on the crop being grown, soil characteristics, topography, surface cover, pest pressure, agrichemical use and weather. Normal agricultural practices such as spraying, planting and harvesting can lead to soil compaction. This is particularly true for soils with high clay contents. With conventional tillage practices this surface compaction is periodically disrupted. With reduced tillage, the compaction can build up over time and can actually lead to a reduction in infiltration. As a consequence, strip-till and other conservation tillage practices can lead to increased runoff and increased agrichemical and nutrient losses [7, 8, 12]. In high clay content soils, tillage may be required to alleviate soil compaction. In part, the compaction can be reduced through strip tillage [9] and through in-row subsoiling or paratilling [11, 15, 16]. Paratilling is a deep tillage technique in which the soil is loosened below the soil surface but not inverted [10]. Compaction can also be alleviated by certain deep-rooting cover crops, including some cereal grains and radishes.

The increased infiltration typically observed with conservation tillage can lead to increased subsurface water loss because infiltration amounts can exceed the soil's capacity to hold water. Many soils in the southeastern United States have subsurface layers that have lower hydraulic conductivity and restrict vertical percolation of water. This restriction can lead to saturated zones within the soil profile. Water within these zones will flow downslope away from cropped fields. Some of the infiltrated water also moves through the root zone and into subsurface aquifers. Driven by hydraulic gradients, this water also moves downslope away from the fields. If soils under conservation tillage

TABLE 14.1. Anticipated benefits of introducing reduced tillage for various hydrologic soil groups (summarized from [3])

Hydrologic Soil Group	Infiltration characteristics	Water transmission	Benefits from reduced tillage
A	High	High	Unknown
B	Moderate	Moderate	High
C	Slow	Slow	High
D	Slow	Very slow	Low

CONSERVATION TILLAGE IS BENEFICIAL WITH OR WITHOUT IRRIGATION

Conservation tillage systems add residue to the soil profile and over time the decaying roots add to the available channels for water to infiltrate deeper into the soil profile. Over time, the decaying biomass adds organic matter to the soil profile that causes it to better absorb and translocate water. Conservation tillage has benefits for farmers with and without irrigation. Two farmers benefiting from conservation tillage are Lamar Black and Clayton Anderson, both of whom are in east central Georgia.

Black has been using conservation tillage since 1993 and has irrigation. He says that with conservation tillage, he is able to apply less water, which allows him to supply enough water for all crops including corn. Furthermore, with the build-up of organic matter, he can apply more water per application without runoff, thereby reducing wear on the pivot.

Anderson has been using conservation tillage since 2000 and farms mostly dryland crops. Even without supplemental irrigation, he says that using conservation tillage enhances the water-holding capacity of his soils. This benefits the crops during dry periods in the summer. "During periods of extreme heat and continuous sunshine, the residue keeps soil temperature down and slows the evaporation process," says Anderson. "If we are lucky enough to get a rain or quick downpour, it stays in the field and is quickly absorbed by the soil," he adds.

Through the use of a conservation tillage system, farmers with irrigation as well as those without irrigation benefit from the improved ability of the soil to capture, translocate and store water resources.

become compacted and have a reduced capacity to hold water, total water losses can equal or exceed the total water losses typically observed with conventional tillage systems. In this case, water remaining in the soil profile when using strip-tillage may not contribute to an overall water gain for crop use and can potentially increase agrichemical and nutrient loss by increasing subsurface water flow [1].

Although there are disadvantages in some situations, the advantages of conservation tillage systems outweigh the disadvantages associated with soil compaction and increased subsurface water losses. Conservation tillage can lead to reduced erosion and increased infiltration. When used in conjunction with cover crops during the non-growing season, conservation tillage can also lead to increases in soil carbon. Some carbon from plant materials is returned to the soil through decomposition. Plants that leave higher residue levels can lead to greater soil carbon levels. Soils with higher carbon levels hold more nutrients, have improved water-holding capacity and exhibit better soil aggregation (see Chapter 3). Cover crops have the added advantage of enhancing infiltration and reducing soil erosion. Optimizing the biomass produced by the cover crop will yield the greatest benefits.

A reduced-tillage plan can be targeted to specific soil, land slope and crop production needs. Care must be taken to monitor soil compaction and periodic steps must be taken to alleviate the compaction (see Chapter 6). In addition, because of the potential for increased subsurface losses, attention must be paid to the management of soluble chemicals, particularly nitrate. Manage fertilization to minimize these losses by applying only what is needed for crop growth. Use split applications timed to meet crop needs and use cover crops to scavenge leftover nitrogen.

IRRIGATION AND WATER MANAGEMENT

No-till and reduced-tillage systems, with the inclusion of cover crops, increase infiltration. Additional causes of increased infiltration include increased porosity due to channels formed by rotting roots, earthworms, insects or tillage such as in-row subsoiling. In-row subsoiling breaks the hardpan while disturbing only a narrow strip of surface soil. Increased infiltration also increases subsurface water movement.

While cover crops and reduced tillage help with soil quality and infiltration, they do not affect the type of irrigation equipment used. In the Southeast, center pivot irrigation systems are typically used for large row-crop fields. These systems are compatible with conservation tillage systems. When cover crops are part of the rotation, soil organic matter may increase, increasing infiltration and the soil's water-holding capacity. This could increase the time between irrigation events, which would reduce the number of irrigation events in a season as well as the total amount of water applied. An exception to this occurs when soil porosity is reduced through compaction. This reduction is field specific and is affected by the amount of organic matter in the soil profile, soil type, land slope and compaction levels. For two Group B soils in Georgia, runoff reduction due to the introduction of conservation tillage ranged from 29 to 46 percent [13]. This reduction is equivalent to 2.6–4.3 days of crop water use for these soils. The use of a conservation tillage system that includes cover crops and crop rotation can increase the time between irrigation events but does not require a change in irrigation equipment. The increased time between irrigation events is a direct result of the increased infiltration and deeper infiltration of rainwater and irrigation water.

Even though there is no need to change irrigation equipment when transitioning to a conservation tillage system, water management needs to be considered. Managing water on the farm not only saves water resources but can also save nutrients such as nitrate. If the proper amount of water is applied for plant use, the water and associated nutrients stay in the root zone and are available for plant use. If the water added exceeds field capacity, the extra water can move below the root zone or flow downslope away from the field, carrying valuable nutrients away from the plants. If cover crops are incorporated into a conservation tillage system, some of these nutrients may be recovered and recycled by the cover crop. Another direct effect of increasing infiltration and water-holding capacity is that more water is

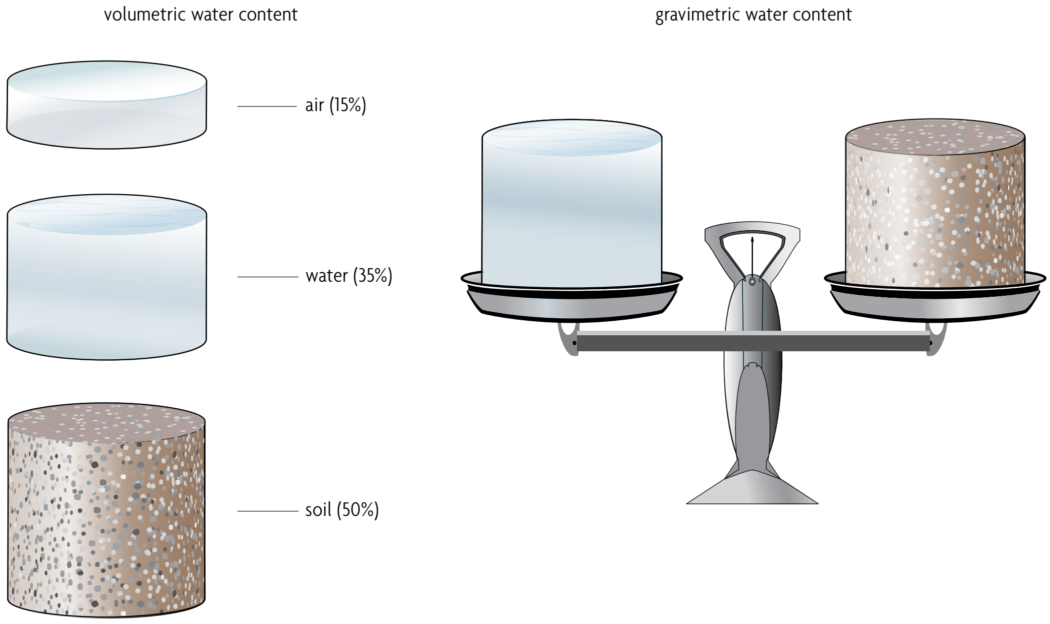


FIGURE 14.3. Ways of representing water content of a soil profile. Adapted from Decagon Devices Corporation presentation with permission.

available for other uses on the farm.

MONITORING SOIL WATER

Soil water monitoring assists the producer in determining if the soil water content is between the soil's field capacity and wilting point. Field capacity is the upper limit of water moisture that a soil can hold after it has been fully saturated and allowed to drain freely. This occurs when the water in the macropores has drained and has been replaced by air [6]. As plants use water and as water evaporates from the soil surface, the soil water content decreases. When the soil water content reaches the wilting point, plants can no longer pull water from the soil. Water contents near or below the wilting point will result in reduced yields. Saturated soils or soils with a water content above field capacity can also reduce yields. Sensors that assess the amount of water available help the producer determine when irrigation is needed and if the right amount of water is being applied. Sensors help the producer understand how many days the soil is at or below the wilting point or above field capacity. Soil water measurements can be made using either water content methods (quantity) or water potential (energy) methods.

Water Content Measurement

Water content can be measured by either weight (gravimetric) or volume (volumetric). Gravimet-

TABLE 14.2. A comparison of the advantages and disadvantages of both the direct and indirect methods of determining soil water content.

	METHOD	
	Direct Measurement	Indirect Measurement[1]
ADVANTAGES:		
Easy to use	X	X
Does not require calibration	X	
Low cost		X
Durable		X
Easy to install		X
Instant, high-resolution soil water content measurement		X
Allows for continuous data collection		X
DISADVANTAGES:		
Destructive	X	
Time consuming	X	
Requires oven and balance	X	
Sensitive to soil texture		X
Requires destructive installation		X
Sensitive to air gaps in soil contact		X
Requires calibration		X

[1] Some of the stated advantages and disadvantages of indirect measuring are dependent on the type of dielectric sensor used. In particular, ease of use, cost and sensitivity to soil structure can vary depending on the sensor. Discuss the options with a knowledgeable consultant or Extension specialist.

ric measurement only accounts for the water and soil, while volumetric measurement also accounts for the air (Figure 14.3). Gravimetric sampling typically involves collecting and drying soil samples. Volumetric water content can be measured in the field using various sensors.

Water content measurement methods can be either direct or indirect. There are advantages and disadvantages to both approaches (Table 14.2). Direct methods are destructive, meaning that a soil sample is collected in the field and transported to a testing facility on or off farm. It takes time to process these samples, and either gravimetric or volumetric water content can be measured. An advantage of direct measurement is that it gives the exact amount of water in the soil and can be used to calibrate indirect measurement devices.

Indirect methods are nondestructive, meaning that the soil profile is not disrupted. The measurements are taken in situ, and these measurements are available instantaneously. Data from indirect measurements can be recorded and stored in specified time intervals for further analysis if needed. Since the indirect measurements are nondestructive, these measurements rely on soil properties. For indirect methods, the sensors need to be calibrated. Indirect measurements of the soil water use one of three different soil properties: its dielectric constant, its radioactivity or its thermal properties. Measurement utilizing the soil's dielectric properties is discussed here because it is the most common.

Capacitance sensors are one of the most common indirect, in situ methods to measure volumetric water content. These types of sensors are based on the principle that soil can insulate or carry an electrical charge. The soil's ability to do this is related to its dielectric constant. Water has a dielectric constant that is more than 10 times greater than other soil components (Table 14.3). As the soil water content increases, the dielectric value of the soil profile changes significantly. Capacitance sensors utilize this characteristic to make measurements of soil water content.

Water Potential Measurement

Soil water measurements can also be based on the pressure or suction that exists within the soil. This suction contributes to the water potential energy within the soil, which can in turn be used to predict water content. Pressure-based sensors include tensiometers, gypsum block sensors and granular matrix sensors. They utilize material that comes into equilibrium with the suction in the soil.

The tensiometer works on the principle that as soil water content decreases, the amount of force required by the plant root to extract soil water increases. This is mimicked in the tensiometer by filling a cylinder, with an attached ceramic cup, with water. The ceramic cup is inserted into the soil at the depth of interest. As the soil dries, the water in the tensiometer is drawn into the soil profile. This movement of water into the soil profile causes a negative pressure or suction on the cylinder of water and the negative pressure is recorded on a vacuum gauge attached to the top of the tensiometer. The reading on the gauge is an indication of the amount of water in the soil (Figure 14.4).

Both gypsum block and the granular matrix block sensors use the principle of electrical resistance to measure or indicate water content. As the soil water content increases, the block gets wet and the resistance across two wire leads embedded in the block decreases, indicating a wetter soil. The reverse is also true. The amount of soil water is determined based on a calibration of the blocks. For granular matrix blocks, ceramic is used instead of gypsum. These types of sensors are relatively inexpensive and data readers are available for each type. The reader is calibrated so the resistance measured can be translated to soil water content.

TABLE 14.3. Dielectric constants for various components of the soil

Component	Dielectric Constant
Air	1
Soil minerals	3–7
Organic matter	2–5
Ice	5
Water	80

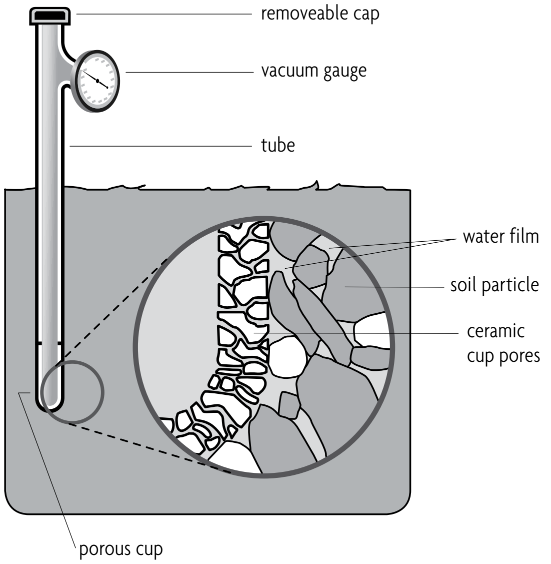


FIGURE 14.4. A schematic of how water is drawn from the tensiometer as the soil water content around the porous cup decreases. The image is provided by the Soil Moisture Corporation and is used with permission.

One disadvantage of the gypsum blocks is that in acid soils, the gypsum can dissolve, making the blocks ineffective for long-term use. The granular matrix blocks can be used in various soil types for longer periods of time.

Managing Sensors

The number of sensors, where to locate them and the type of sensor are determined based on field conditions and producer preference. The number of sensors needed in a field will be based on the cost of sensors, the number of soil types, variations in slope, whether there are wet or dry areas, and whether variable rate irrigation is used. If a field has two different soil types, for example an area with a sandy soil and an area with a more clayey soil, a sensor or sensors are placed in each area. With a variable rate irrigation system, the amount of water applied and number of irrigation events is determined for each area.

The type of sensor to use is affected by whether the sensors are installed by the producer or a consultant. For producer-installed sensors, the water content or water potential sensors described above can be used and the desired type of output data specified. Consultants most likely have a preferred sensor type or company they use. The producer is provided with the data needed to make irrigation decisions.

When sensors are used in row-crop production, they are normally installed after planting and removed before harvest. If the soil water content is of interest when cover crops are grown, the sensors are installed after planting and removed prior to harvest or termination. The installation method and tools required vary based on the type of sensor or sensor sets. Gypsum or granular matrix sensors can be installed with a small diameter tube driven into the soil to the desired depth. The sensor is inserted into the tube. Likewise, if you use a capacitance sensor set that is in a tube, then a small diameter tube, like a soil sampling tube, is driven into the soil to produce a hole than can be used for installing the sensor. For a capacitance sensor that has to be inserted into the soil, a small hole is dug to the desired depth and the sensor is inserted into the soil profile.

There are companies that have the ability to network sensors so that all information is transmitted to a single point on the edge of a field for easy data access. Other companies have a data link to cellular systems that will send data to an electronic device, or the data is made available on a company website that is accessible whenever and wherever needed.

Overall, the number and location of sensors will depend on the field, cost and sensor product. Some consultants have started using sensors as part of their practice, so ask if they use sensors to help manage the farm.

SUMMARY

The use of conservation tillage systems can increase infiltration and water movement into and below the root zone. However, conservation tillage can also lead to compaction in some soils and reduced water-holding capacity. If soil compaction is managed, then improved infiltration can provide more water for crop use. The use of conservation tillage systems does not require that irrigation equipment be changed. Conversation tillage can result in a reduction in the number of irrigation applications and thereby save money. Careful irrigation management will ensure ample water is available for plant use and that nutrients are not lost through leaching. Sensors in various locations in the field help monitor soil water content, making it easier to decide when irrigation is needed.

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CHAPTER 15

Conservation Economics: Budgeting, Cover Crops and Government Programs

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This chapter introduces the economics of conservation and provides tools for farmers and agricultural professionals to examine the benefits and costs of conservation tillage systems in the Southeast. The first section examines conservation economics, specifically the use of conservation tillage, and introduces two economic tools: partial budgeting and enterprise budgets. The second section provides an in-depth look at the economics of adding a cover crop to a conservation system. The final section examines government incentive programs that help farmers adopt and install conservation practices.

CONSERVATION ECONOMICS

Generally, the primary farm management objective is to maximize profits, and environmental stewardship can have a positive influence on profits. To achieve both objectives, producers must have an accurate and flexible understanding of expected revenues, production costs and how changes in field conditions and farm operations may affect revenue and costs. Tools available to assist in understanding revenues and expenses include partial budgeting and enterprise budgets. This section reviews these tools and how they can be used to examine the benefits and costs of adopting conservation practices. Conservation tillage is an effective tool used in the Southeast to address soil erosion and low soil organic matter. For farmers currently using the practice and for those who are considering adopting it, it is necessary to understand the economics of conservation tillage.

Partial Budgeting

Partial budgeting is used to analyze the effects of proposed changes in cropping systems or farm enterprises. Partial budgets only consider changes in revenue and expenses due to a management change or the adoption of a new technology. Aspects of production not affected by the change are excluded from the budget. Partial budgeting is used to determine if the proposed change will have a net positive or net negative impact on farm profits. The approach calculates the net change based on changes in revenues and costs.

In addition to the financial estimates derived from partial budgets, personal and social factors are considered. These include level of risk aversion, desired personal time for leisure and family, workload on employees and other factors that are difficult to quantify yet remain important to the overall success of the farm operation [14]. Personal and social factors are included in partial budgets as qualitative components.

The following six steps are needed to complete a partial budget.

Step 1: Identify the proposed change in the farm production system. For example, the proposed change might be to adopt no-till or to grow a bioenergy crop. If there are several changes, prepare a separate partial budget for each.

Step 2: Record additional revenues. List increases in current revenues and/or new revenue sources generated from the change.

Step 3: Record reductions in costs or cost savings from the change.

Step 4: Record additional or new costs resulting from the change.

Step 5: Record reductions in revenue resulting from the change.

Step 6: Calculate the net change by subtracting the negative effects (the sum of steps 4 and 5) from the positive effects (the sum of steps 2 and 3). Before calculating, ensure your numbers in steps 3 and 5 are recorded as positive numbers, not negative, even though they represent a reduction. Including negative numbers in this calculation can lead to inaccurate results. If the result of the calculation is a positive number, there is a net economic benefit or gain to adopting the change. If the result is negative, there is a net economic loss. If the difference is zero, the decision to adopt the change may be based on the personal or social factors described above.

To illustrate, consider the following example. Farmer Diane farms 400 acres of cotton conventionally and one of her long-term goals is to move to conservation tillage. She searches for data on the yield differences between conventional tillage and no-till production. She finds several publications comparing no-till yields to conventional yields and decides that a 50 pound per acre yield increase is a conservative estimate. She finds a no-till planter costing $25,000. The useful life of the planter is expected to be seven years with a $2,500 salvage value. Financing can be secured at 8 percent. Repair and insurance rates are 2 and 2.5 percent, respectively, of the average value, $13,750. (The average value is the actual cost plus the salvage value divided by 2.) Table 15.1 shows the partial-budgeting analysis for this example. The cost per acre of the new planter is expected to be $14.59 per acre. This is equal to the interest cost of $5 per acre ([$25,000 x 0.08]/400), plus repair costs of $0.69 per acre ([$13,750 x .02]/400), plus insurance at $0.86 per acre ([$13,750 x 0.025]/400), plus depreciation of $8.04 per acre ([$25,000-$2,500]/[7 x 400]).

Assuming the price of cotton lint is $0.70 per pound and there is a 50 pounds per acre increase in cotton lint yield, Diane expects an increase in crop revenue of $35 per acre. In addition, converting to no-till eliminates two tillage passes, reducing production costs by $22 per acre. Diane expects to plant a cover crop as part of her conservation tillage system at a cost of $18 per acre. In addition, herbicides and herbicide application costs are expected to increase by $13 per acre for cover crop termination in the spring. As shown

TABLE 15.1. Partial budget example for adopting no-till in a cotton production system

ADDED RETURNS	per acre	REDUCED RETURNS	per acre
50 pounds per acre yield at $0.70 per pound	$35		
Total Added Return	$35	*Total Reduced Return*	$0
REDUCED COSTS		**ADDED COSTS**	
Eliminate one disking	$10	Cover crop	$10
Eliminate one deep tillage	$12	Plant cover crop	$8
		Herbicides	$8
		Spray herbicide	$5
		Annual planter cost per acre per year	$14.59
Total Reduced Costs	$22	*Total Added Costs*	$45.59
(1) TOTAL ADDED RETURN AND REDUCED COST	$57	(2) TOTAL REDUCED RETURNS AND ADDED COSTS	$45.59
NET CHANGE IN RETURNS (1) minus (2) equals $11.41 per acre or $4,564 total per year.			

in Table 15.1, the net change in returns from adopting a no-till system on a per acre basis is the total added return and reduced costs ($35 + $22) minus the total reduced returns and added costs ($45.59). The net change in returns is $11.41 per acre or $4,564 for the 400 acres of cotton. Based on the partial-budget analysis and her goal to adopt conservation tillage, Farmer Diane decides to buy the no-till planter and adopt no-till.

Enterprise Budgeting

Enterprise budgets are the most common form of budgeting and analysis used by farm managers. Enterprise budgets are used to record the revenue, expenses and returns for a single crop or livestock enterprise on a per unit basis. For example, a unit can be an acre or head of cattle. Consistency among enterprise budgets allows comparisons between different enterprises. Enterprise budgets are specific to the levels of production and technology used, so separate enterprise budgets are developed for different levels and forms of technology. For example, different enterprise budgets are developed for conservation tillage and conventional tillage because the expected revenues, expenses and net income would be different between the two tillage systems.

The components of an enterprise budget include expected revenues and costs of production. Data needed to determine expected revenue includes expected yield, selling price and other sources of income related to the enterprise, such as selling crop stover in addition to the produced commodity. Costs include both variable and fixed costs. Variable costs are typically listed showing the input level and per unit cost of production and non-production inputs. Production inputs generally include seed, inoculants, pesticides, fertilizers, labor, fuel, repair and maintenance, supplies and services. Non-production inputs are defined as interest paid on operating capital, commodity checkoff payments, grading/classing fees and similar expenses. Fixed costs are associated with equipment, machinery and structures, and are prorated over several years. Fixed-cost categories include depreciation, insurance, taxes, interest and major repairs allocable to the enterprise. It is important to allocate annual fixed costs accurately to each enterprise to ensure that the true cost is reflected, and to be consistent over time.

Hidden costs also need to be included in enterprise budgets. These costs are often overlooked because they are not directly allocable to the enterprise. Examples of hidden costs include utilities, overhead and bookkeeping. Include the appropriate portion of these costs in the enterprise budget to ensure an accurate estimate of expenses. Enterprise budgets for the Southeast are available through local county Extension offices, Future Farmers of America (FFA), young farmer organizations or through the websites shown in Table 15.2.

Enterprise budgets serve as a guide to help producers determine their own costs. Data specific to the farm operation is entered for each input since yields, prices and costs vary by farm. Table 15.3

TABLE 15.2. Online enterprise crop budgets by state

STATE	WEBSITE ADDRESS
Multi-state	https://agrisk.umn.edu/Budgets
Georgia[1]	www.caes.uga.edu/departments/ag-econ/extension/budgets.html
Alabama	www.aces.edu/agriculture/business-management/budgets
Florida[1]	http://svaec.ifas.ufl.edu/featured-3-menus/extension/agricultural-economics/north-florida-enterprise-budgets
Mississippi	www.agecon.msstate.edu/whatwedo/budgets.asp
Tennessee[1]	https://ag.tennessee.edu/arec/Pages/budgets.aspx
South Carolina[1]	www.clemson.edu/extension/agribusiness/enterprise-budgets.html
North Carolina[1]	https://ag-econ.ncsu.edu/extension/budgets

[1] Denotes states that publish crop enterprise budgets for both conventional and conservation-tillage practices.

provides an example enterprise budget for cotton production utilizing strip-tillage without a cover crop.

Budget Analysis for Conservation Tillage

Conservation tillage systems have the potential to lower production costs and improve farm profitability. The agronomic benefits associated with conservation tillage, such as improved soil productivity, may increase crop yield and net returns from crop production [6, 18]. While this potential exists, profitability of the cropping enterprise depends on a number of additional factors, including effective management, soil suitability, pest pressures and climate.

Changes in the Costs of Production

Crop yields may decline during the transition to a conservation tillage system. However, with the addition of a winter cover crop, yields may be sustained or improved. During the transition, reductions in the costs of production may be enough to maintain or improve farm profitability. Enterprise budgets comparing conventional tillage systems to conservation systems with strip-till are provided in Table 15.4 for corn, cotton and peanuts. Costs for the conventional system are identified for each crop, and the changes in variable and fixed expenses are provided for a strip-till conservation system. A negative change refers to a savings, while a positive change refers to an increase in costs.

For this analysis, yields are assumed to remain constant when switching from the base system to the strip-till system.

In strip-till and no-till systems, production costs may increase due to increased pest pressures, termination of winter weeds, termination of cover crops and capital investments. Winter weeds are killed with herbicides. Cover crops are killed with herbicides and/or a roller/crimper. The additional trips across the field needed to manage a cover crop will represent a new production cost [3]. However, in total, conservation tillage systems usually result in labor and fuel savings (Table 15.4). Greater insect and disease pressures due to more biomass on the soil surface may further increase pesticide costs. However, the inclusion of high-residue winter cover crops may actually reduce weed pressure, thereby reducing herbicide requirements and costs [29]. The actual cost of adopting a conservation tillage system is site specific, and the decision to adopt is dependent on the overall farm goals.

While conservation tillage systems require less investment in machinery than conventional tillage systems, transitioning may result in additional costs associated with modifying existing equipment or purchasing new equipment. For example, existing planters may need to be modified to include row cleaners ($222–$459 per row), down pressure springs ($38 per row) and spike closing wheels ($96–$192 per row) to assist with planting through residue [4]. The total modification cost depends on the number of rows the machine plants in one pass. Another important cost to consider is management complexity. Conservation tillage systems are usually more complex than conventional systems and require more intensive management. A farm manager who is marginally profitable in a conventional tillage system may have difficulty handling the additional complexities of a conservation tillage system [8].

Cost savings with conservation tillage systems primarily stem from reductions in labor and machinery use. As seen in Table 15.4, the majority of cost savings both in the short and long term come from reductions in labor, fuel and machinery costs. These cost savings will likely differ from farm to farm due to differences in climate and farm characteristics such as farm size, as well as management approaches [38].

Reductions in fuel and machinery costs arise primarily due to fewer passes over the field, fewer pieces of equipment and using smaller, less powerful tractors. While additional pesticide applications may add to machinery and fuel costs, they are not likely to offset the savings from reduced-tillage practices. Machinery costs include fixed costs of the machinery, as well as repair and maintenance costs. A significant machinery cost savings in conservation tillage systems results from a decrease in diesel fuel consumption. Fuel savings (Table 15.4) range approximately $3–$11 per acre for in-field operations. Fuel savings will vary between operations based on the crop grown, geographic region, soil types, climate, soil moisture, amount and type of residue, condition of equipment and how the tractor is operated [8, 13, 27]. Additional fuel savings will result from fewer trips from the farm to the field. These savings can be substantial as many farms are increasingly fragmented and spread out [23]. Thus, fuel savings may be as high as two to three times the figures seen in Table 15.4. If fuel prices increase, fuel savings with conservation tillage systems will increase.

TABLE 15.3. Strip-till irrigated cotton enterprise budget, 2010

Expected Yield (pounds per acre) 1,100			Expected Price (per pound) $0.67		
Variable cost	Unit	No. of units	Price per unit	Cost per acre	Your cost
Land rent	Acre	1			
Crop insurance	Acre	1	11	11	
Boll Weevil Eradication Program (BWEP)	Acre	1	1	1	
Seed and tech fee	Bag	0.171	500	85.56	
Lime and spreading	Ton	0.33	32.50	10.73	
Fertilizers [1]					
Nitrogen	Pounds	90	0.45	40.50	
Phosphate (P_2O_5)	Pounds	70	0.25	17.50	
Potash (K_2O)	Pounds	70	0.50	35	
Chicken litter	Ton		35		
Boron	Pounds	0.5	5.40	2.70	
Weed controls [2]					
Pre-plant	Acre	1	9.40	9.40	
At planting or pre-emergence	Acre	1	21.22	21.22	
Post-emergence	Acre	1	14.45	14.45	
Post-emergence (direct or hood)	Acre	1	12.59	12.59	
Hand weeding	Acre	1			
Insect control					
In-furrow	Pounds	3.5	3	10.50	
Spray (worms)	Application	1			
Spray (stink bugs, other)	Application	2	4.25	8.90	
Scouting	Acre	1	10	10	
Nematicide	Acre	1			
Plant growth regulator	Ounce	16	0.11	1.76	
Boll opener and defoliant	Acre	1	14.44	14.44	
Custom work	Acre	1			
Machinery and equipment					
Fuel and lube [1]	Gallon	11.12	2.50	27.80	
Repair and maintenance	Acre	1	19.61	19.61	
Irrigation	Application	7	9	63	
Labor	Hours	1.98	11	21.78	
Custom harvest	Acre	1			

TABLE 15.3 continues on the next page.

TABLE 15.3 continued

Expected Yield (pounds per acre) 1,100			Expected Price (per pound) $0.67		
Variable cost	Unit	No. of units	Price per unit	Cost per acre	Your cost
Machinery and equipment					
Interest on operating (6 months)	439.44	0.5	7.25 percent	15.93	
Ginning and warehousing					
Ginning	Pounds	1,100	0.08	88	
Storage and warehousing	Bale	2.2	10.50	23.10	
Promotions, boards, classing	Bale	2.2	5.77	12.69	
Cottonseed (gin turnout: 39 percent)	Ton	0.72	120	-86.31	
Total variable costs				**$492.85**	
Net return above variable cost				**$244.15**	
Fixed Cost					
Tractors and sprayer	Acre	1	31.56	31.56	
Equipment/implements	Acre	1	8.93	8.93	
Picker/Boll Buggy/module builder	Acre	1	53.09	53.09	
Irrigation	Acre	1	100	100	
Owned land charge	Acre				
Miscellaneous overhead	Percent of variable costs	$492.85	5 percent	24.64	
Management	Percent of variable costs	$492.85	5 percent	24.64	
Total fixed costs				**$242.86**	
Total cost				**$735.71**	
Net return				**$1.29**	

[1] Fertilizer and fuel prices as of December 2009. All costs are subject to change.

[2] Herbicide programs are highly variable. Cost assumes managing Palmer amaranth for glyphosate resistance. Hand weeding may be necessary.

Labor savings are a result of a decrease in preharvest activities. Labor savings include reductions in operator labor for machinery and reductions in labor for other farming activities such as maintenance of equipment. Labor savings may allow farmers to increase the amount of land being farmed, further increasing farm profits and viability. Assuming a 1,000-acre cotton farm and the availability of suitable rental land for $25 per acre, a farmer who converted to conservation tillage would save enough to increase the number of acres farmed by 10 percent without increasing production costs above those of a conventional tillage system [6].

Impact on Net Returns from Crop Production

Studies comparing conventional and conservation tillage systems have found mixed results when analyzing crop yields. In a number of cases, conservation tillage systems resulted in reduced yields but compensated for the reduction with cost savings [30]. In many cases, these studies did not use cover crops in the conservation tillage systems. With a cover crop, many studies show that conservation tillage systems can outperform conventional tillage systems with respect to crop yield and potential net returns. Activities such as winter grazing provide farms with additional sources of income and help reduce risk [2]. Combining livestock grazing with a conservation tillage system is discussed in depth in Chapter 8.

Bergtold et al. [6] examined the profitability of alternative mixtures of high-residue cover crops in conservation tillage systems. They found that net returns to cotton in a conservation tillage system with a rye/black oat cover crop mixture increased 10–37 percent per acre over a conventional tillage system. The net returns to corn production in a conservation tillage system with a lupin/fodder radish/crimson clover cover crop were lower when compared to the conventional tillage system. This was due to the prohibitive cost of the cover crop mixture. The study points

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TABLE 15.4. Comparison of corn, cotton and peanut enterprise budgets for conventional and conservation tillage systems based on 2011 University of Georgia Crop Enterprise Budgets in $ per acre, 2011 [36]

	Corn		Cotton		Peanuts	
	Conv. Till (base)	Strip Till (change in cost)[1]	Conv. Till (base)	Strip Till (change in cost)	Conv. Till (base)	Strip Till (change in cost)
Variable expenses						
Seed	53		77.79	7.77	97.50	
Cover crop seed		24.75		39.36	0	24.75
Fertilizer	116		103.19		52.38	
Herbicide	31.60	5	42.75	4.80	54.45	14.65
Insecticide	0		30.23		54.50	
Fungicide	0		0		41.92	
Adjuvants/inoculants	0		0		7	
Defoliants	0		13		0	
Growth regulators	0		1.38		0	
Drying/ginning[2]	41.48		18.03		45.60	
Service fees						
Crop insurance	18.50		22		34.50	
Other fees			0.92		12.45	
Labor	11.18	-2.04	25.48	-3.20	34.23	-5.35
Machinery[3]						
Fuel	20.24	-3.72	34.71	-4.83	60.60	-11.47
Repairs/maintenance	14.57	-2.29	22.52	-2.13	42.02	-6.41
Interest on operating capital[4]	8.62	0.70	12.15	1.36	15.57	0.53
Total variable expenses	$315.19	$22.40	$404.14	$43.13	$552.72	$16.69
Fixed expenses[5]						
Machinery	50.06	-6.66	99.31	-11.75	127.50	-20.17
Overhead/mgmt.	31.52	2.24	40.41	4.31	55.28	1.66
Total fixed expenses	$81.58	-$4.42	$139.72	-$7.44	$182.78	-18.51
Total cost of operations	**$396.76**	**$17.98**	**$543.86**	**$35.69**	**$735.50**	**-$1.82**

[1] Negative changes are decreases in the costs of production by converting to strip-till.

[2] Includes cleaning for peanuts and storage/warehousing and promotion/boards/classing for cotton. For cotton, cottonseed is subtracted from the ginning/warehousing costs. Assume yields of 135 bushels per acre for corn, 700 pounds per acre of lint for cotton, and 1.9 tons per acre for peanuts to calculate drying/cleaning/ginning and hauling costs.

[3] All machinery costs except fuel are represented in repair and maintenance costs.

[4] Interest on operating capital is the opportunity cost of investing the money spent on production into an interest-bearing account earning 6.5 percent interest for the growing season (6 months).

out that financial incentives from government programs can help offset the cost of converting to a conservation tillage system or planting a winter cover crop. These programs are discussed later in this chapter.

COVER CROP ECONOMICS

This section provides an economic perspective on planting and managing cover crops. Production costs, equipment, management requirements, cover crop choices, termination practices and termination timing are discussed. In addition, the observed and perceived benefits of cover crops to yield and cost saving for the following cash crop are examined.

Production Costs

Production costs for cover crops vary based on the cover crop variety and the management approach. The costs are farm specific, as is their impact on farm profitability. Table 15.5 provides production costs for four alternative cover crop options. Hairy vetch and crimson clover are legumes that fix nitrogen, so fertilizer is not applied. Rye and oats are cereal grains that can produce more aboveground biomass than legumes [37].

Seed Costs

Seed cost to establish a cover crop is highly variable depending on the cover crop chosen and the seeding rate used. Year-to-year variability of seed costs necessitates careful annual evaluation of cover crop selection. Thus, while one type of cover crop may prove to be more beneficial in terms of biomass production, nitrogen fixing or erosion control, the profitability of the practice will be impacted by seed cost, cover crop management and income-generating uses for the cover crop. For example, winter peas and hairy vetch both provide high levels of nitrogen, but winter peas are preferred by many producers because they are easier to kill and offer grazing opportunities [10].

Planting Costs

Cover crop planting requires the same basic equipment as a no-till cropping system, with minor additions. High-residue planting environments may require row cleaners, additional

TABLE 15.5. An example of variable costs (per acre) of managing and planting four cover crop varieties in cropping systems using no-till

Variable Costs	Hairy Vetch	Crimson Clover	Rye	Oats
Seed	\$50[1]	\$34[2]	\$21[3]	\$14[4]
Planting[5]	\$8	\$8	\$8	\$8
Fertilizer[6]	---	---	\$27–\$47	\$27–\$47
Application[5]	---	---	\$7–\$14	\$7–\$14
Termination[7]	----	----	(\$7)–\$0	(\$7)–\$0
Total Variable Cost	**\$58**	**\$42**	**\$56–\$90**	**\$49–\$83**

[1] Seeding rate at 20 pounds per acre. Seed cost at \$2.50 per pound.

[2] Seeding rate at 20 pounds per acre. Seed cost at \$1.68 per pound.

[3] Seeding rate at 90 pounds per acre. Seed cost at \$0.23 per pound.

[4] Seeding rate at 90 pounds per acre. Seed cost at \$0.15 per pound.

[5] Custom rate [22].

[6] Assume zero pounds of fertilizer applied to legumes to allow nitrogen fixation to begin as early as possible. The lower cost for the grains assumes a single liquid application of 15 pounds of N per acre. The higher cost assumes two liquid applications of 15 pounds of N per acre utilizing 28-0-0 liquid fertilizer [Personal communication, Jeris McMullen, Ag Valley Co-op, Norton, KS. July 18, 2008].

[7] In no-till, chemical termination of cover crop is done with the same pass that would be done pre-plant. Therefore, no additional cost is assumed. Lower cost (\$7) is combination of mechanical termination (roller/crimper) and ½ rate of herbicide pass.). Roller/crimper costs and savings are taken from Mississippi State University crop enterprise budget information (http://www.agecon.msstate.edu/whatwedo/budgets.asp) and are adjusted for inflation and energy costs. Herbicide treatment was assumed to be 22 oz. glyphosate, 10 oz. 2,4-D, + surfactant. (Ag Valley Co-Op Agronomist, Norton, KS, July 18, 2008).

down pressure springs and/or spike closing wheels. These add-ons are used to penetrate thick residue, ensure proper seed-to-soil contact and minimize hair-pinning [37]. Costs of these investments can range $350–$700 per row [4]. The total add-on cost is based on the number of rows the equipment plants in one pass.

Other planting options include broadcast or aerial seeding. With broadcast seeding, germination and stands are inferior to planting or drilling. As a result, seeding rates are increased by 25–50 percent over the rates for planting or drilling [31, 34]. This impacts the profitability. Another broadcast seeding method, aerial seeding, is the only large-scale method to inter-seed cover crops into standing cash crops without damaging the cash crop [20]. The process can be done with a spinner-spreader attached to a tractor and driven through the field, or with an airplane. The drawback is that the germination rate is low and depends heavily on receiving late-summer rains. As a result, substantially higher seeding rates are required for aerial seeding as compared to planting or drilling [20].

Fertilization Costs

Fertilizer is used with non-legume cover crops to improve biomass production. Maximizing grain and small-grain cover crop biomass, such as with cereal rye, may provide benefits to the following cash crop [24, 32]. A one-time or split application of fertilizer is used to establish the cover crop and improve the likelihood it will suppress weeds [5].

Termination Costs

Cover crops are terminated prior to planting the cash crop. There are two primary methods for termination: spraying herbicides and using a roller/crimper. Winter-kill is a possibility with less-hardy cover crops in harsher environments [20], but this is not likely in the Southeast. For a no-till operator, the pass to terminate a cover crop is unlikely to require an additional pass since one pass is normally done to kill weeds anyway [5]. Mechanical termination involves the use of a roller/crimper, which does not disturb the soil and can be used alone or in conjunction with reduced rates of non-selective herbicides [16]. A roller/crimper uses blunt blades attached to a rolling drum to crack the cover crop stems, killing the plant and preventing regrowth. It leaves a residue mat on the soil surface [3]. The purchase cost of a roller/crimper is much less than that of a sprayer, and the roller/crimper requires less energy than termination by tillage, lowering fuel costs [9]. Mechanical termination can be the least expensive alternative when compared to herbicides or tillage. It can also be the most labor and time intensive, as roller/crimpers are usually operated at speeds from 2–10 mph, slower than the operating speed of a sprayer [16]. Roller/crimpers and cover crop termination are discussed in depth in Chapter 9.

Opportunity Costs of Cover Crop Adoption

The opportunity costs of cover crop adoption represent the foregone opportunities that producers could have invested their time and money into rather than a cover crop.

Foregone Cash Crop

Most producers find the idea of planting, fertilizing and paying to terminate a cover crop counterintuitive since potential revenue is left in the field. Some cover crops may be managed as a cash crop, with the grain being harvested and sold. Wheat is an example. Another alternative may be utilizing cover crop residues as a cellulosic biofuel feedstock for ethanol production. Rye and wheat straw can be used in this way [1]. In certain circumstances it may be more profitable to treat a cover crop as a cash crop enterprise. However, leaving residue in the field can provide important conservation benefits that may also lead to an economic return.

Foregone Forage Opportunities

Grazing land is a valuable asset, and the need for forage requires some producers to winter-graze their herds. Many cover crops are highly palatable to livestock, and it is tempting to either graze or bale the cover crop. For example, oats are not only a popular cover crop but also a common and valuable feed crop [15]. While grazing or baling does not negate all cover crop benefits, repeated removal of biomass can substantially decrease the cash crop yield benefits that result from leaving the residue in the field [32]. Another issue to consider is the compaction caused by cattle. The force exerted per square inch by a mature cow is equivalent to that of a heavy tractor [7]. Chapter 8 discusses the aspects of including livestock grazing in a conservation tillage rotation.

Potential Cost Savings to the Cash Crop

While cover crops come with their own production cost, some or all of that cost can be offset by savings they generate in the form of reduced cash crop production costs.

Herbicide Savings

High-residue cover crops leave behind a “residue mat” that provides a significant benefit. Teasdale and Mohler [35] found that increasing levels of biomass exponentially decrease weed emergence rates. Residue mats are responsible for nearly complete light blockage that plays a large part in eliminating weed emergence. A potential savings to the following cash crop is the elimination of one or more herbicide passes due to weed suppression provided by the cover crop’s residue mat [19]. Reddy [28] found that a rye cover crop in Mississippi reduced total weed density by 9–27 percent and total weed biomass by 19–38 percent across different tillage systems. This decrease may not eliminate the need for an herbicide application but could result in production input savings through reduced application rates. Herbicide savings will depend on the type of cover crop, the type of cash crop following it and how the cover crop’s biomass is managed.

Fertilizer Savings from Legumes

Legume cover crops fix atmospheric nitrogen that may be available for the following crop. The range of available nitrogen in the soil from legumes varies [19]. Some legume cover crops, such as sunn hemp, can fix more than 100 pounds of nitrogen per acre, with up to 50 percent being available to the following cash crop [21]. However, studies have shown that legume cover crops may be too costly to use as a replacement for all applied commercial fertilizer. Legume cover crops become noticeably more profitable when commercial fertilizer prices are high [26, 33]. The fertilizer application rate is reduced in accordance with available legume-fixed nitrogen. If not, the fertilizer benefit of the legume is wasted [12, 17]. Simply stated, if a producer does not “credit” fixed nitrogen to the total amount available for the cash crop, then no fertilizer savings are realized.

Cash Crop Yield Benefits, Returns and Risk

A potential benefit from the use of cover crops over time is improvement in soil productivity. This can improve cash crop yields and increase crop revenue. Using average yearly spot prices from 2001–2003 for crops in Alabama, Bergtold et al. [6] found net returns from cotton production using conservation tillage with a high-residue and high-cost cover crop mixture exceeded those of conventional tillage with no cover crop by $45–$70 per acre. This analysis takes into account a $40 per acre government cost share for maintaining 50 percent or greater soil coverage for a three-year period through the Environmental Quality Incentives Program (EQIP). Cotton yields were 5–25 percent higher in the conservation tillage system. In the same study, net returns for corn under the conservation system only exceeded the conventional system during a drought year, 2002. Without the EQIP payment, the 2002 results would have favored the conventional cropping system by nearly $22 per acre. Without EQIP payments, beneficial but costly cover crops may not provide a yield boost sufficient to cover production costs, even when cost savings for the cash crop are considered [19].

A study in Tennessee found that no-till corn yields over five nitrogen fertilizer application rates, from 0–200 pounds per acre, were higher with a hairy vetch cover crop as opposed to no cover at each application level [17]. Average yield increases were as much as 45 bushels per acre at 0 pounds of applied nitrogen and as small as 9 bushels per acre at 150 pounds of applied nitrogen [17]. These results primarily stem from the use of legume cover crops, which are among the most profitable cover crops [19, 33]. Additionally, cover crops have been shown to stabilize yields over time, which is a benefit to risk-wary producers [6, 33].

There is nothing more vital to success in farming than managing risk. A study of cotton production systems with various cover crops and tillage practices in western Tennessee found that a legume cover crop, such as hairy vetch or crimson clover, was less risky than a small-grain cover crop [11]. No cover was observed to be the riskiest option. Corn production systems in western Tennessee that incorporated legume cover crops in no-till systems tended to be the least risky when compared to a small-grain cover crop.

On-Farm Economics of Cover Crops

Evaluate the economics when considering whether or not to adopt a cover crop variety. The economics include the direct costs of planting and managing the cover crop, such as seed cost, planting costs, fertilization costs and termination costs; any potential cost savings for the cash crop; opportunity costs; expected future cash crop yield benefits; and government program support. Partial budgeting can be a useful tool when estimating the potential economic return from adopting a cover crop, but keep in mind that partial budgeting does not include the social, environmental and soil costs and benefits that may not be quantifiable. That is, it is difficult to place a dollar value on all the benefits provided, but they need to be considered.

GOVERNMENT PROGRAMS

There are government programs that provide financial incentives to install conservation practices on agricultural land. The programs are authorized through the conservation title in the Agricultural Act of 2014, also known as the 2014 U.S. Farm Bill. To become familiar with the opportunities to participate in federal government programs, review this section and visit the website mentioned in it. State agencies also have programs available for producers. Since they vary by state, only federal programs will be covered in this section. Your local Natural Resources Conservation Service (NRCS) representative can direct you to the appropriate state agency for more information.

Administration and General Eligibility

The majority of federal conservation programs are administered through NRCS. NRCS has service centers located in almost every county in the country. Visit http://offices.sc.egov.usda.gov/locator/app to find your local NRCS office. The NRCS representative can describe conservation program availability and timeframes, and can make recommendations that are compatible with your conservation goals and agricultural operation. So, a good relationship with your NRCS representative is helpful.

Qualifications are different for different federal conservation programs. For example, to be eligible to receive payments through EQIP, you must:

- be an agricultural producer
- have an average adjusted gross income (AGI) not more than $900,000
- control or own eligible land
- be in compliance with highly erodible land and wetland conservation requirements
- develop needed conservation plans for the program of interest

For the Conservation Stewardship Program (CSP), qualifications vary by state.

Types of Programs

Conservation programs within the Farm Bill can be classified into three categories: land-retirement programs, land-preservation programs and working-lands programs. Land-retirement programs, such as the Conservation Reserve Program, provide incentive payments to producers for taking land out of agricultural production and planting it back to native plant or tree species. Land-preservation programs enable the placement of easements on land for conservation purposes or for maintaining agricultural practices. An example of a land-preservation program is the Farm and Ranch Lands Protection Program that allows a producer to place an easement on agricultural land to keep it in agricultural production for perpetuity, usually 30 years. Working-lands programs provide incentive payments including cost-share payments to encourage the maintenance and adoption of conservation practices on land that is under agricultural production. Because working-lands programs have more impact on producers engaged in agricultural production and conservation, the following sections will describe two working-lands programs administered through NRCS, EQIP and CSP.

Environmental Quality Incentives Program (EQIP)

EQIP allows a producer to enter into a one- to multiple-year contract to receive technical and financial assistance to install and maintain conservation practices. The 2018 farm bill introduced five- and 10-year contracts. Eligible practices are those that sustain agricultural production; enhance air, soil and water quality; or conserve energy. Eligible agricultural land includes cropland, pasture, rangeland, and non-industrial, private forest land. Producers engaged in livestock and/or crop production are eligible to participate in EQIP.

In order to receive payments a producer must enter into a contract with NRCS based on a plan to implement and maintain conservation practices on their agricultural land. Once entered into a contract, a producer will receive incentive payments or cost-share funds based upon the conservation practices that will be implemented on the farm. For a producer, total payments from all EQIP contracts between 2014 and 2018 cannot exceed $450,000.

Conservation practices eligible for incentive payments vary depending on the type of operation and the state. Some examples of conservation practices that may be eligible include animal waste management facilities, terraces, filter strips, tree planting, permanent wildlife habitat, residue management, upland wildlife habitat management, grazing land management, no-till farming, strip-till farming, cover crops and cross-fencing pastures to allow for rotational grazing. Producers can receive payments for conservation practices related to organic production and the transition to organic production. More information on EQIP can be found online. Local NRCS representatives have information concerning the conservation practices that are eligible for payments in their designated area.

Conservation Stewardship Program (CSP)

The CSP allows an eligible producer to receive technical and financial assistance to enhance conservation efforts on their farming operation. The program is designed to assist farmers already doing conservation by helping them to enhance their existing conservation efforts and to further address soil, water and other resource concerns. This means undertaking additional conservation activities and improving, maintaining and managing existing conservation activities. For example, a farmer who has already adopted no-till and manages residues on crop fields to reduce soil erosion could apply for the program to assist with adding cover crops to provide further protection for the soil. The producer enters into a five-year contract and has the option to renew the contract for one additional five-year period. More information about CSP can be found online.

Eligible land includes cropland, pastureland, rangeland, grassland, prairie land, and non-industrial, private forest land. To be eligible, a landowner or producer must meet the stewardship threshold for at least two resource concerns and must meet or exceed the stewardship threshold for at least one additional priority resource concern by the end of the contract. The stewardship thresholds for priority resource concerns are determined for each state or for particular geographic areas within a state. Some examples of priority resource concerns include air quality, soil erosion, soil quality, water quantity, water quality, energy, plant life and animal life.

In order to receive payments, a producer must apply to enter into a CSP contract with NRCS. The producer must enroll all agricultural land in their operation under the contract. The approved contract enables the producer to receive existing activity payments to maintain current conservation efforts that address identified resource concerns at $350 per resource concern addressed per year plus a per-acre payment that varies by land use. The national payment rate is $7.50 for cropland and the farmstead. Payments are made for maintaining and managing existing conservation activities already in place on the land. Additional activity payments are earned for addressing or exceeding one additional resource concern on the operation. These payments will vary by practice and state. There is also a supplemental payment for implementing a resource-conserving crop rotation. A resource-conserving crop rotation is defined as a rotation that provides natural resource conservation benefits and production benefits. Additional CSP payment information can be found online.

There are numerous conservation activities that are eligible under CSP. Some examples include extension of riparian forest buffers or filter strips; grazing management to improve wildlife habitat; continuous no-till with high residue; intensive management of rotational grazing; use of cover crop mixes; forest stand improvement; precision application technology; use of non-chemical methods to kill cover crops; irrigation system automation; and seasonal residue management. Producers may initiate organic certification and transition to organic production while participating in a CSP contract. Local NRCS representatives have more information on eligible conservation activities.

General Tips

Most conservation programs are competitive, and producers must apply to participate. A good working relationship with local NRCS representatives is imperative. This will help the producer be aware of program timelines and requirements. Additionally, the strong working relationship will aid the NRCS representative in understanding the conservation objectives and goals of the producer. Good records of conservation activities and efforts ease the application process and aid in verifying contract compliance.

SUMMARY

Transitioning from a conventional cropping system to a conservation system that uses both reduced tillage and cover crops will change the economics of your farm operation. Partial budgeting and enterprise budgets are two tools described in this chapter that can help estimate how changes in management practices might affect the bottom line. Partial budgeting isolates a proposed change in the farm operation, such as a new management practice or new technology, and assesses the change in revenue and costs associated with it. An enterprise budget looks at the revenues, costs and returns associated with a single crop or livestock enterprise on the farm. Conservation systems can lead to lower costs for labor, fuel, herbicides and fertilizers, and can improve the long-term productivity of the soil, but they can also create added costs due to increased pest pressures, new capital investments and new management activities such as the termination of winter cover crops. Studies that compare crop yields in conventional and conservation systems have showed mixed results, and while cover crops come with their own costs, they tend to pay for themselves through savings in other areas. To help farmers pay for the adoption of conservation systems, a number of financial support programs are available, in particular those available through NRCS. Overall, conservation tillage systems that incorporate cover crops have the potential to improve farm profitability through a combination of lower costs and higher productivity. To realize this potential, it is necessary to carefully analyze the economics of switching to a conservation system as relates to the specifics of your operation.

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CHAPTER 16

Biofuel Feedstock Production: Crop Residues and Dedicated Bioenergy Crops

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Editor's note: All tables appear at the end of the chapter.

Today's economy is primarily based on the use of fossil fuel, but the potential of renewable alternatives, such as bioenergy, is being evaluated. The rationale for this interest centers on climate change, national security and rural development. The United States has increased its production capacity of ethanol, a bioenergy alternative to gasoline, from 1.7 billion gallons in 2000 to 15.5 billion gallons at the beginning of 2017 [70]. Current legislation requires production to increase into the future, and this ethanol will mostly be produced from cellulose [67]. Thus, the use of crop residues for bioenergy and the use of dedicated bioenergy crops are likely to play an important role in the management of conservation tillage systems in the Southeast.

An analysis by English et al. [19] found that 100 million acres of dedicated energy crops would be needed to replace 25 percent of the nation's energy by 2025. While production is projected to occur throughout the United States, the mid-southern states (Kentucky, Tennessee, Alabama, Mississippi, Georgia and the Carolinas) would produce the bulk of these feedstocks. While dedicated energy crops are one source of cellulose, crop residues may play a role as an energy feedstock as well. In a joint study by the USDA and Department of Energy (DOE) on potential biomass feedstocks, annual production of 75 million dry tons of corn stover and 11 million dry tons of wheat straw were identified as a possible bioenergy feedstock [53].

This chapter examines the potential role of harvesting crop residues and producing dedicated bioenergy crops in conservation tillage systems. When crop residues such as corn stover are left on the soil surface, they provide a number of benefits such as reduced erosion, increased soil organic carbon, improved soil tilth, improved water retention and the recycling of nutrients back to the soil [32]. The benefits of conservation tillage systems are in part based on residues on the soil surface, and removal of the residues would reduce these benefits. Harvesting crop residues could provide another income stream for farmers, but it must be done sustainably and should be weighed against any loss in soil conservation benefits. The other option, planting a dedicated bioenergy crop, may enhance conservation tillage systems. Switchgrass, a perennial bioenergy crop, is well-suited from an agronomic and economic perspective to being planted on marginal cropland. Switchgrass can help reduce erosion, increase soil organic carbon, reduce nutrient leaching and restore soil health. When evaluating switchgrass as a bioenergy feedstock, consider the costs and constraints it may impose on the current cropping system. The remainder of this chapter provides insight on the removal of crop residues and conservation concerns, and includes an in-depth discussion of growing switchgrass as a dedicated bioenergy crop.

CROP RESIDUES AS A BIOENERGY FEEDSTOCK

Much has been written about using crop residues as a bioenergy feedstock. In the mid- to late-1970s, energy prices soared, which led to discussion about using crop residues for energy [1, 18]. In 2003, the DOE shifted interest from dedicated energy crops to crop residues such as corn stover and wheat straw [70]. Kim and Dale [30] estimated that harvesting crop residues worldwide could replace 32 percent of worldwide gasoline consumption if E85 ethanol is used in midsize vehicles. E85 is 85 percent ethanol and 15 percent gasoline.

Corn stover gets the most attention as a potential feedstock for biofuel production in the United States. Corn stover includes the stalks, cobs and leaves left in the field after grain harvest. Some believe that corn stover is the largest untapped source of agricultural biomass in the United States [53]. About 5 percent of corn stover is currently used for animal bedding and feed, and less than 1 percent is used for industrial processing. This leaves more than 90 percent of corn stover in the field. According to Petrolia [55] the most abundant agricultural biomass source in the United States is corn stover, followed by manure.

Karlan et al. [28] examined harvest strategies for corn stover to evaluate the impact its removal has on the soil. After five years of study, they found that the phosphorus and potassium available to the next crop were low following stover removal. This reduced soybean yields the next year. Following the five-year analysis, it was concluded that “with good crop management practices, including routine soil testing, adequate fertilization, maintenance of soil organic matter, sustained soil structure, and prevention of wind, water or tillage erosion, a portion of the corn stover being produced in central Iowa USA can be harvested in a sustainable manner” [28].

In 2008, R. Lal [34] discussed the interactions between crop residue and soil. Crop residues provide food and energy for soil organisms, resulting in enhanced species diversity. Residues increase soil-nutrient levels by decreasing nutrient runoff and by returning nutrients to the soil as they decompose. Crop residues can also increase available water in the root zone, increase water infiltration rates and decrease erosion. However, the question still remains if it is wise or economically viable to harvest residues for bioenergy. Many agronomists and economists argue that only a few crop residues are practical as bioenergy feedstocks. They include corn, small grains, sorghum, rice and sugarcane. Crops such as cotton and soybeans leave too little residue behind or their residues decompose too quickly for harvesting [32].

Studies have shown that removing crop residues will result in decreased yields the following year [78]. Crop residues are directly related to soil organic carbon (SOC): The more residues, the greater the SOC [39]. In turn, greater SOC increases both soil quality and yields [33]. Lal stated that the long-term benefits of leaving crop residues in the field outweigh the financial gain from selling the residue to a biorefinery [34]. He goes on to say that residue removal is not a sustainable option for biofuel production. More research is needed to determine if some residue can be removed while leaving enough to prevent soil deterioration and decreased yields [27, 53].

Another problem with harvesting crop residues is the short harvest window: one to three months depending on the crop. Enough biomass has to be harvested and stored during the harvest window to supply the biorefinery year round. Storage can be a significant cost. More research is needed before crop residues can be considered a commercially viable feedstock for ethanol production.

Estimates of the costs to harvest, collect, store and transport corn stover to a biorefinery [8, 17, 23, 37, 40, 55] range from \$29–\$116 per dry ton (Table 16.1) [46, 47, 48]. It is difficult to estimate the costs since efficient residue-harvesting technology has yet to be developed. Current research focuses on developing equipment that can harvest both corn stover and corn grain at the same time.

DEDICATED ENERGY CROP PRODUCTION SYSTEMS

The potential for dedicated energy crops to further energy security and environmental sustainability goals depends on their ability to generate farm income. Despite the best intentions of policymakers, realization of these broader goals will fall short without market incentives that make energy crop plantings economically competitive with alternative farm enterprises.

There are a number of crops suggested as feedstocks for bioenergy production, and selection will be determined by the location, sustainability criteria and biorefinery type. The crops are typically divided into herbaceous crops and short-rotation woody crops. Herbaceous crops are further divided into annual and perennial crops. Annual crops including sweet sorghum (*Sorghum bicolor (L.) Moench*) and forage sorghum (*Sorghum vulgare* Pers.) are frequently mentioned candidates for the Southeast, as are perennial grasses such as switchgrass (*Panicum virgatum*) and miscanthus (*Miscanthus giganteus*). Short-rotation woody crops that have been suggested for the Southeast include poplars, sweetgum (*Liquidambar styraciflua* L.), sycamore (*Platanus occidentalis* L.), black locust (*Robinia psuedoacacia* L.) and eucalyptus (*Eucalyptus* spp.) [58].

After extensive research funded by the DOE, switchgrass was selected as a model biomass feedstock [22, 41, 80]. This was based in part on high biomass yields and low input requirements. Switchgrass also provides ecosystem services such as soil conservation through decreased erosion and climate regulation through carbon sequestration. However, whether these attributes are sufficient to earn switchgrass a place among current farm enterprises across the nation remains uncertain.

SWITCHGRASS PRODUCTION SYSTEMS

In this section, an economic framework is presented for deciding whether to plant switchgrass as a dedicated energy crop. Emerging issues in the establishment, production, harvest and handling of switchgrass are also discussed. Finally, an overview of policy incentives designed to encourage switchgrass plantings on private landholdings is presented.

Farm managers are faced with four fundamental economic questions when determining what enterprises to pursue on their farms:

- What products to produce?
- What production methods to use?
- With what resources?
- For what markets?

For a dedicated energy crop to be considered a profitable enterprise, the net return must be high enough to bid away land from competing enterprises. Key factors in the decision-making process include biomass yield, price paid for the biomass, government incentives, production and delivery costs, and resource availability such as labor, money, land and other necessary resources.

A simple decision framework based on net returns highlights multiple channels through which switchgrass could fit into a profitable enterprise mix. For instance, net returns may increase through increased yields, increased biomass prices, decreased input costs or by using resources when they are normally dormant. Other opportunities may include developing markets for co-products such as the seed or hunting habitat, or technological efficiency gains, meaning producing the same amount at a lower cost.

Because markets for biomass are currently absent in much of the United States, most economic analyses of switchgrass production have reported findings on a unit cost basis. For example, findings are reported on a cost per ton or “breakeven price” rather than on net return or profitability [29, 45, 54, 56]. Rather than ask, “Does switchgrass currently bid land away from competing enterprises, and, if so, how much?” these studies answer the question, “What price would producers need to receive for switchgrass to start bidding land away from competing enterprises?”

An important issue in cost-of-production and breakeven-analysis studies is the assumed productive lifespan of a switchgrass stand. The production of perennial, dedicated energy crops results in annual yields and production costs. Switchgrass yields typically reach full potential during the third year of production [51]. Costs are typically higher and yields lower during the establishment phase, which is the first two years of production.

The assumed economic lifespan is important as it reflects the period over which investments may be recovered. Many studies assume a 10-year stand lifespan, which represents the suggested productive lifespan from an agronomic and economic perspective. However, the period might be shorter as a result of contracts or technology development. Under a three- or five-year production contract, a producer will want to recover all of their production costs within that contract period. The shorter the contract period, the higher the breakeven price. Genetic improvements to switchgrass will also occur over time. Each year, the economic impact of adopting a new variety needs to be assessed. If a new variety is adopted, the existing stand will likely be destroyed, reducing the stand life.

Contracting

Contracting is important when developing a feedstock for biofuel production. Contracts help outline the price paid to the farmer for biomass and helps set quality control standards and quantity expectations. Several studies have considered the best type, length and price for a contract between producers and a biorefinery. A study by Larson et al. evaluated four types of contracts that could be used to encourage biomass production [37]. The study included a spot-market contract, a standard marketing contract, an acreage contract and a gross-revenue contract. In a spot-market contract, the price received for the biomass is based on the equivalent cost of gasoline at the time the biomass is delivered. The standard marketing contract has a set price for a certain amount of feedstock, with penalties for underages. Excess biomass is sold at the spot-market price. An acreage contract has a guaranteed annual price for the biomass produced each year on the contracted acreage. The gross-revenue contract provides a guaranteed amount of money per acre based on expected yields over the life of the contract. Larson et al. found that a contract price above the spot-market price would be needed to entice farmers to produce biomass [37]. Gross-revenue contracts induced the greatest amount of biomass production when compared to the other contract types. It was also found that a provision to help offset establishment costs was effective in enticing farmers to produce large amounts of biomass at lower contract prices.

Clark et al. [10] hosted a competitive bidding auction for middle Tennessee farmers as part of a larger project to determine willingness and ability of Tennessee farmers to grow switchgrass. Farmers were instructed to bid a minimum and maximum acreage allotment for switchgrass production. They were also asked for a base bid in dollars per acre plus an incentive payment in dollars per dry ton of switchgrass produced, assuming an average yield of 5.5 tons per acre. Eleven bids were received and five were accepted. Base bids did not differ much, with most being in the \$200–\$250 per acre range. Seven of the 11 incentive bids were in the \$20–\$30 per ton range. The minimum and maximum acres bid were eight and 100 acres, respectively. The switchgrass was planted, harvested and transported to Gadsten, Ala., for generating renewable electricity. Following this experiment, another was done in East Tennessee.

Contract length is negotiated between the biorefinery and the farmer. A survey performed by Menard et al. of 7,000 farmers in the Southeast yielded 1,300 responses [44]. They discovered that farmers preferred an average contract length of 6.5 years to produce switchgrass. The most frequent response given by farmers was for a five-year contract followed by 10 years and three years [44]. Most biorefineries are going to want long-term contracts to help guarantee that they have a sufficient supply of biomass year round and in the future. Contract length is likely to be affected by other factors, including a farmer's lease and rental arrangement with the landowner. The average productive stand life, estimated to be around 10 years, will also affect the contract length but could be shortened due to stand obsolescence resulting from improved varieties. Most contracts will likely fall into the five- to seven-year range [5], which seems to be an adequate length for both the farmer and the biorefinery.

The University of Tennessee (UT) and Genera Energy have contracted more than 5,000 acres of switchgrass in East Tennessee. Two different three-year contracts were used. The first contract paid producers a flat price of $450 per acre each year. The contract currently used by UT and Genera Energy offers a flat price per acre for the first year of production. Each year thereafter, farmers are paid a sliding percentage of a flat fee and a per ton price as the switchgrass reaches its yield potential. The prices received by the farmer under this contract are [9]:

Year one: $450 per acre plus $0 per ton
Year two: $250 per acre plus $40 per ton
Year three: $150 per acre plus $50 per ton

UT and Genera Energy also provide the farmer with seed and professional expertise.

Emerging Issues in Switchgrass Production

Establishment

Switchgrass establishment costs typically include land preparation, seed, planting, weed control and fertilizer application. Seed costs have increased in recent years due to increased demand. They are likely to remain high as seed production becomes commercialized and improved varieties are introduced.

Previous research has suggested that switchgrass yields are unresponsive to increased seeding rates [45, 61, 73]. This finding is likely explained by increased root growth or above-ground growth in stands with low initial plant densities, such that the potential yield is realized. The combination of high seed costs and limited yield response to increased seeding rates will likely result in producers reducing seeding rates below the 6–10 pounds per acre of pure live seed currently recommended in university enterprise budgets. In Mooney et al. [45], using data from a Milan, Tenn., experiment, a maximum cumulative yield over three years of 14.2 dry tons per acre was achieved at a seeding rate of 5.7 pounds per acre of pure live seed with an associated net return of $478 per acre. However, a reduction in the seeding rate from 5.7–3.8 pounds per acre decreased yields by 0.3 dry tons per acre but increased net returns by $23 per acre. The amount of seed to plant when establishing switchgrass is open for debate. In the experiment described above, reducing the seeding rate decreased cost while sacrificing little yield. However, establishment of the stand is critical and there is little information on the probability of stand failure as the seeding rate decreases.

If a switchgrass stand needs to be re-established in the second year of production due to stand failure, production costs increase and the revenue stream is delayed. Little data exists on stand failure rates from large plantings on multiple fields. In establishing 92 acres of switchgrass in middle Tennessee in 2005, 12 percent of the acres required replanting. The stand failure resulted from several factors including weed competition, seed planting depth and chemical application on adjacent fields. Additional experience in Tennessee has been gained through the Tennessee Biofuels Initiative, where planting 720 acres in a drought year required approximately 25 percent of acres to be reseeded. From an economic perspective, this may become an issue for three- to five-year contracts where the period for cost recovery is shorter [43].

Weeds are primarily a factor during the establishment phase. In the first year following planting, most switchgrass growth occurs in the root structure. Stands generally look poor and weed infestations may appear high. Annual grass weeds are potentially more problematic than broadleaf weeds because they more easily canopy the emerging switchgrass seedlings and because recommended chemical controls may damage the switchgrass. However, the economics of weed control in switchgrass are poorly understood. In multiple field experiments conducted by the University of Tennessee Switchgrass Project, strong stands emerged by the third year even where severe weed infestations occurred during the first two years and weed control was absent [43]. It is yet to be determined whether yield losses avoided with chemical weed control during establishment are sufficient to cover the expense of herbicide applications.

Annual Maintenance

The annual maintenance of switchgrass stands typically includes fertilizer application, chemical weed control during years one and two, and harvest costs. Fertilizer applications are an important cost and environmental consideration in switchgrass production. Nitrogen fertilizer is the primary nutrient needed for switchgrass [51]. The dynamics of switchgrass yield response to nitrogen are poorly understood. In a report summarizing 10 years of fertility research, it was observed that switchgrass plots harvested once a year and receiving high nitrogen rates had lower stand densities when compared to single-harvested plots with lower nitrogen rates [52]. The report concludes that the "application of nitrogen to achieve maximum short-term yields may greatly reduce long-term yields . . . and recommend around 45 pounds of nitrogen per acre to achieve good stands with long-term yield potential." Based on this observation, it is possible that economically optimal nitrogen application rates may change depending on the length of the production contract.

Current recommended phosphorus and potassium application rates differ widely. In Tennessee, recommendations are based on data contained in Parrish et al. [52] where phosphorus and potassium applications are not recommended unless soil levels are low. Even when no phosphorus or potassium is applied, it may be appropriate to include an opportunity cost for the phosphorus and potassium removed in the harvested biomass. Possible approaches include an annual cost based on removal rates or an amortized annual cost representing maintenance applications every few years. Another option is to include no costs during production but charge a fixed cost in the final year of production for building fertility levels back to initial levels.

Harvest

Harvest typically represents the largest cost for switchgrass produced as a bioenergy crop. Recommended harvest procedures for maximum biomass production include one harvest following fall senescence to allow for translocation of nutrients to the roots. This minimizes the nutrients removed and maximizes the amount of lignocelluloses. Decreasing the nutrients in harvested material results in a decreased need for fertilization, a springtime bloom of switchgrass prior to weed growth and a reduction in minerals that might interfere with the conversion of harvested materials to ethanol. Harvest costs will vary by yield and harvest method, for example round bales versus rectangular bales. In this chapter, round bales are 5 feet in diameter and 4 feet long. Rectangular bales are 8 feet by 4 feet by 4 feet [76].

While switchgrass can be harvested with conventional hay equipment, the coarse and fibrous nature of switchgrass plus the large yields may impact equipment repair and maintenance costs. Equipment performance in terms of throughput and field speed may also be reduced. For these reasons, reliance on average engineering performance standards developed for crops with other characteristics and/or much lower yields may significantly misrepresent the actual costs of harvesting switchgrass. Large rectangular balers will generally result in the lowest per-dry-ton harvest costs but are more expensive and require a larger tractor than round balers. Round balers are better adapted to the marginal landscapes, such as small/irregular fields and sloping hillsides, where switchgrass is likely to be grown.

Technological Constraints

While enterprise budgets and cost analyses are useful for on-farm decision making, they do not provide insight into the optimal design of biomass production systems as production scales up. For example, harvest costs will vary by the type of baler used, and this may impact costs of other supply chain elements such as handling, storage and pre-processing on the way to or at the biorefinery. This suggests a need to evaluate different harvest methods within the context of the entire system. Precipitation and weathering may also result in quality losses and dry-matter losses in bales delivered to the plant [37, 60, 79]. Higher precipitation in the fall and winter may limit field access, increase harvest times and increase biomass losses relative to other harvest times [25]. Previous harvest and storage cost analyses have focused on various aspects of integrating harvest, storage and transportation systems [7, 13, 14, 16, 64, 65].

A study in Milan, Tenn., compared round bales and large rectangular bales. The study looked at individual bales rather than bales in the large stacks necessary for commercial operation. The large rectangular bales reduced harvest and transportation costs, but dry-matter losses due to weathering were higher when compared to the round-bale system [75]. When harvest and transportation costs are included with dry-matter losses, a mixture of harvest and storage solutions becomes optimal. Wang [75] reports that if bales are processed immediately after harvest, costs are lowest for rectangular bales. For bales stored without protection and processed within three months of harvest, round bales have the lower cost. And, if bales are stored with protection for more than three months, round bales again have the lowest cost. Protection refers to storing the bales on a pallet covered with a tarp.

Given this, a proposed harvest, storage and transportation system might be described as follows. Harvest is initiated after the first frost and continues until initial greening in the spring. The material that is harvested and transported to the plant for immediate use would be harvested using the large-rectangular-bale system. Any bales that are not to be used during this window would be harvested using a round-bale system. Bales to be stored for fewer than 90 days would not require protection. Bales harvested and stored for more than 90 days would require protection. It is possible that the handling of two different types of bales could increase costs to the biorefinery. The system to handle large rectangular bales may differ from that which handles the large round bales. However, the additional costs that would result from having a dual handling system were not incorporated in the analysis.

Policy Incentives

Typically, switchgrass reaches its full yield potential in the third year after planting [74]. In an experiment in Milan, Tenn., Mooney et al. [45] reported that first- and second-year switchgrass yields across several landscapes and soil types averaged 14 and 60 percent of third-year yields, respectively. Harvest can be conducted in the first two years after planting, though some experts recommend not harvesting the crop in the first year to allow more root growth [74]. Farmers may be reluctant to grow perennial switchgrass as a dedicated energy crop because of the upfront costs to establish the stand and the delay in revenue from selling biomass [35]. This section explores potential incentives that may encourage the adoption of switchgrass.

The government may have a role in creating incentives to establish a commercial-sized biorefinery feedstock supply chain to provide a steady supply of biomass. Suggested methods include a carbon credit market, state-run producer incentive programs and the Bioenergy Crop Assistance Program (BCAP). The 2008 Food, Conservation and Energy Act [68] and the subsequent rule-making process established guidelines for BCAP-eligible feedstocks [69]. In summary, crops known as Title I crops are not eligible to receive benefits from the program. Title I crops include corn, soybeans, sorghum and wheat. Dedicated energy crops such as switchgrass, miscanthus and other grasses are eligible for BCAP. Short-rotation woody crops planted for energy purposes are also eligible. Crop and forest residues such as straw and stover may also be eligible feedstocks. Perennial crops and short-rotation woody crops are eligible for establishment, collection, storage, transportation and logistics payments. Feedstocks produced from agricultural and forest residues are only eligible for collection, storage, transportation and logistics payments.

With BCAP, producers of switchgrass could contract with the USDA to receive payments of up to 75 percent of establishment costs during the first year. Subsequent annual payments then offset the so-called “lost opportunity costs” until the dedicated energy crop is fully established and begins to provide producers with revenue. In addition, the BCAP provides for cost-share payments up to $45 per dry ton for the harvest, storage and transportation of biomass crops to a biorefinery. Eligible participants for BCAP include producers located within a "project area" defined as an area at an economically viable distance from a biorefinery. Contracts with the BCAP program will run for 5–10 years depending on the type of biomass crop grown. Producers will also be required to contract with a biorefinery to receive payments.

Switchgrass Production Cost Case Study

Table 16.2 summarizes several switchgrass production cost scenarios based on a five-year planning horizon and a 10-year planning horizon. The baseline scenarios look at the cost of production without replanting costs, storage costs, transportation costs and BCAP incentives. Then, these other cost components and incentives are included to determine their impact on the cost per dry ton of switchgrass. The remainder of this section reviews the methods used to simulate the yields and costs that resulted in Table 16.2. Tables 16.3 through 16.14 include detailed information about those costs.

The cost of producing switchgrass, a perennial grass, includes the expenses to establish the stand at the beginning of the first year of production. However, experience with the Tennessee Biofuels Initiative suggests that stand failure may occur after the initial planting due to improper management, weather, pests or other growing environment events [43]. Therefore, a farmer may incur additional expenses for replanting the stand in the second production year. Once the stand is established, the recurring annual costs include land rental rate (dollars per acre); expenses for nutrients and weed control (dollars per acre); expenses for mowing, raking and baling of switchgrass (dollars per acre); expenses for moving the switchgrass from the field to storage (dollars per acre); expenses for storing switchgrass (dollars per acre); and expenses for transporting the switchgrass from storage to the biorefinery (dollars per acre). Harvesting, handling, storage and transportation costs are dependent on yields and are adjusted for dry-matter losses (dry tons per acre).

Switchgrass Stand Life

The life of the stand determines the time over which start-up costs and maintenance costs must be recovered. [54]. Switchgrass has a potential stand life of 10 or more years from an agronomic and economic perspective [74]. However, several factors may dictate a shorter planning horizon in a developing switchgrass feedstock market [35]. First, improved varieties may be developed that result in a stand being killed before its potential life span. Improved varieties may have higher yields or traits geared toward producing more ethanol, such as maximizing the production of desired sugars. The potential for stand obsolescence may be a factor in determining contract length. Second, the length of the contract may be limited by land rental or lease arrangement. Finally, the anticipated capital requirement for a first-generation biorefinery is expected to be substantially greater than for an equivalent capacity corn ethanol plant [57]. Given the substantial startup costs of a biorefinery, investors will want long-term contracts in place that assure stability of feedstock supply. Feedstock represents about half of the anticipated operating expenses of the plant [5]. However, the length of the contract will likely be shorter and in the range of five to seven years [5]. Expectations about yields, costs and net returns are based on the length of the contract rather than potential stand life.

Simulating Yields

Given that the production costs vary with yields, stand life and contract length, yields and production costs were simulated for different stand lifespans on a common agricultural soil in East Tennessee. The soil, Dandridge, is shallow and excessively drained, and is frequently found on upland slopes that are not conducive to row cropping. Agricultural uses for this land include pasture and hay for beef cow-calf production.

ALMANAC, a crop simulation program [31], was used to simulate random switchgrass yields in a Dandridge soil. The model was adapted to Tennessee growing conditions using switchgrass yields during establishment and mature yields from a field experiment [45], and the knowledge and expertise of a soil scientist [66] and a crop simulation modeler [6]. Production inputs and machinery operations used in the crop simulation were from University of Tennessee enterprise budgets [24]. Historical rainfall and temperature averages for Knoxville, Tenn., from the National Oceanic and Atmospheric Administration were used to calibrate the model to east Tennessee weather conditions. Two scenarios were simulated: a five-year planning horizon and a 10-year planning horizon. The average switchgrass yields for each year of the two scenarios are presented in Figure 16.1.

Budgeting Production Costs

Annual land rental costs were assumed to be $22 per acre for hay and pastureland [2]. This is an opportunity cost for growing switchgrass. The operations schedule and the labor, materials, machinery operating and machinery ownership expenses for establishment, maintenance, harvest, handling, storage and transportation activities were estimated using budget parameters produced by The University of Tennessee Department of Agricultural and Resource Economics [24, 20, 36, 37, 45, 42]. The cost of labor was charged at 1.25 times the machine time for each equipment operation using a wage rate of $9.75 per hour, and diesel fuel for all equipment operations was expensed at a rate of $2.35 per gallon [42]. The capital recovery method was used to estimate depreciation and interest on equipment using a 3 percent real rate of interest [3]. A nominal interest rate of 6 percent was used to charge six-months interest on expendable materials and supplies used annually in the production process [42].

The simulated costs for switchgrass establishment are detailed in tables 16.3 through 16.6. The operations to establish the switchgrass in May at the beginning of year one of the simulation include one to two herbicide sprays to kill weeds before planting, sowing the switchgrass using a no-till drill, fertilizer application (only if soil is rated poor in phosphorus and potassium), three post-emergence sprays to control weeds and a pass with a rotary mower to clip weeds taller than the fledgling switchgrass stand.

The simulated annual maintenance costs for switchgrass are detailed in tables 16.7 through 16.10. Annual nitrogen fertilization was at the University of Tennessee Extension recommend-

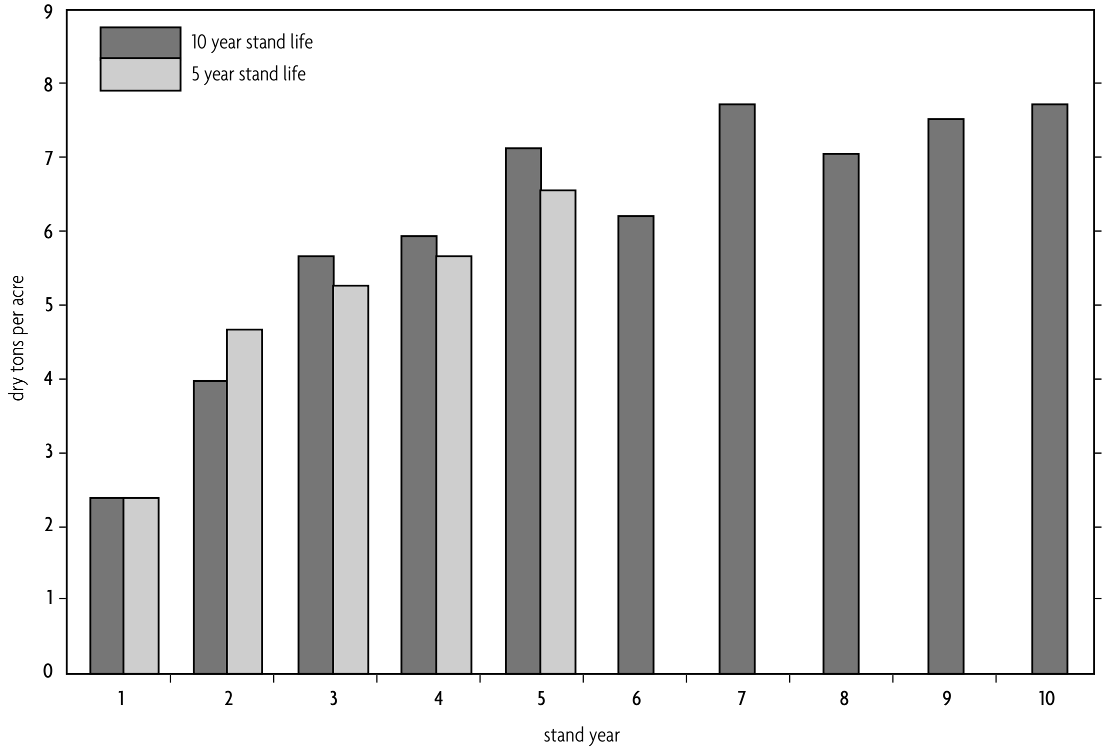

FIGURE 16.1. Simulated average switchgrass yields on a Dandridge soil in east Tennessee.

ed rate of 60 pounds per acre [24] with a cost of $0.48 per pound [42]. University of Tennessee Extension does not recommend phosphorus or potassium fertilization if soil tests indicate medium or high levels of phosphorus and potassium. [24]. However, to account for the potential removal of these nutrients, it was assumed that phosphorous pentoxide (P_2O_5) and potassium oxide (K_2O) were applied at University of Tennessee Extension recommended rates of 40 and 80 pounds per acre, respectively, in each year of the simulation. In addition, two spray operations to control weeds were assumed in year two of the simulation but not in subsequent years of the simulation.

The simulated costs for harvest, hauling and storage are detailed in tables 16.11 and 16.12. Tables 16.13 and 16.14 provide the annualized costs for operating, ownership and labor expenses associated with harvest based on five- and 10-year planning horizons. The operations schedule for harvest from November through February of each year of the simulation includes mowing, raking and baling; the movement of the bales from the field to the storage location; and the placement of bales into storage. Mowing and raking costs were assumed to remain constant on a per-acre basis for all yield levels in the simulation [45]. Machine, labor and twine for the baling and handling operations were assumed to be a function of switchgrass yield. To accomplish this, the capacity of the large-round baler was assumed to be 5.5 dry tons per hour, meaning one hour of machine time will result in a 5.5 dry-ton yield [45]. The rate at which bales are moved to the edge of the field for storage or transport to another storage location was assumed to be 8 dry tons per hour using a front-end loader with two bale spears to move two round bales per trip [45].

For this analysis, bales were assumed to be stored outdoors at the edge of the field. Because of abundant precipitation in the Southeast, it may be difficult at times to field-dry biomass below 20 percent moisture content [15]. Storing round bales outdoors in a single layer stack will facilitate further drying after harvest [15]. However, the cost of storing bales under protection is more expensive in a single-layer stack than in a multi-layer stack [26]. A storage stack in a 3-2-1 pyramid design with three bales in the bottom row, two in the middle row and one in the top row, and covered by a protective tarp has also been recommended as a method to protect against dry-matter losses in the Southeast [11]. Thus, the cost of a 25-bale, single-row stack where round bales are placed end-to-end and the cost of a 72-bale, 3-2-1 pyramid stack of round bales were simulated to evaluate the effects of storage method on production costs. It was assumed that bales were placed on wooden pallets and covered with reinforced plastic tarps for both storage options.

Annualized costs for materials, labor and equipment to build the stack were estimated using assumptions reported in English et al. [20] and were $14.64 and $8.79 per dry ton going into storage, respectively, for the single-row and 3-2-1 pyramid stacks. An average weight of 816 pounds of dry matter for a 5-foot-by-4-foot round bale going into storage was used to calculate tonnage and the cost per dry ton for each storage option [20]. Materials used to build the stack were amortized over an expected five-year useful life with zero salvage value. Tractor and labor time to haul 8 dry tons per hour to the edge of the field [45] was increased by an extra 10 percent to account for additional tractor and operator time to place the pallets as the stacks are being built. Storage dry-matter losses for large round bales stored under a reinforced plastic tarp were estimated using the dry-matter loss as a function of days in storage relationship estimated by Larson et al. [38]. Transportation costs for moving the feedstock from storage to the biorefinery was assumed to be $11.95 per dry ton with a 2 percent dry-matter loss during trucking [38].

Five-Year and 10-Year Cost of Production Scenarios

Table 16.2 shows the simulated production costs and yields for five- and 10-year planning horizons. The prices of all production inputs were assumed to be constant in the five- and 10-year simulations. Annual cash flows were discounted to present value using a 10 percent discount rate [54]. The baseline scenario in Table 16.2 is the simulation of the costs of establishment, maintenance, harvest and handling of switchgrass before being placed into storage at the edge of the field. The simulated impact of replanting on this cost is the second scenario in Table 16.2. A 20 percent probability of replanting was used for estimating the impacts on the cost of production [24].

Given that the biorefinery will be a startup operation that will require a steady supply of biomass once operational, the third scenario assumes that switchgrass is planted four years before the biorefinery starts processing biomass. Planting four years in advance of the plant opening allows the switchgrass stand to reach full-yield potential and builds an inventory of biomass to ensure a steady supply for the biorefinery. Thus, it was assumed that biomass was delivered to the biorefinery starting in the fourth year. Switchgrass from the first, second and third years of production were assumed to be stored an average of 3.5 years (1,277 days), 2.5 years (913 days) and 1.5 years (548 days), respectively. Starting in year four, the biomass was assumed to be stored an average of six months (183 days) before delivery to the biorefinery.

Biomass yields were adjusted for dry-matter losses in storage using 5 percent for bales stored for up to six months and 14 percent for bales stored between six months and 1.5 years [36]. The 14 percent dry-matter loss for bales stored for extended periods was the plateau value estimated by Larson et al. [36]. This assumes that dry-matter losses due to precipitation and weathering increase at a decreasing rate as the number of days in storage increases. Dry-matter losses reach a maximum level when organic matter is exhausted.

Two BCAP incentive-payment scenarios are included in Table 16.2. For the first scenario, the establishment incentive was included. Total budgeted machinery, materials and labor costs for establishment were reduced by 75 percent. For the second scenario, both the establishment and harvest incentive payments were included. The estimated on-farm harvest, handling and storage costs were reduced by a maximum of $45 per dry ton in the simulation. If harvest, handling, storage and transportation costs were less than $45 per dry ton, the lower cost was used to calculate the amount of the cost reduction with the incentive.

Cost of Production Results and Analysis

Several important findings can be drawn from Table 16.2. First, the baseline cost of biomass before replanting, storage and transportation costs was lower by 18 percent ($12 per dry ton) under the 10-year planning horizon than under the five-year planning horizon. The annualized cost of production was $66 per dry ton under the shorter planning horizon and $54 per dry ton under the longer planning horizon. Spreading the costs of establishment and maintenance over more total biomass tonnage was the key factor influencing lower per-unit costs with the longer planning horizon.

Second, the effects of replanting on the cost of production were less under the longer planning horizon. Replanting increased annualized production costs by 4 percent ($2 per dry ton) under the 10-year planning horizon and 6 percent ($4 per dry ton) under the five-year planning horizon. Notwithstanding the difference in annualized costs of replanting with a longer planning horizon, results indicate that the risk of replanting does not have a large influence on the present value of switchgrass unit costs.

Third, the costs of feedstock delivered to the biorefinery that considers storage and transportation expenses under the biorefinery startup scenario were about 1.6–1.8 times greater than the costs of storage-bound feedstock placed at the edge of the field. The average cost of feedstock stored in a single-row stack and delivered to the biorefinery was $124 per dry ton under the five-year planning horizon and $100 per dry ton under the 10-year planning horizon. By comparison, storing feedstock in a 3-2-1 pyramid reduced those delivered costs by 10 percent ($13 per dry ton) for the five-year horizon and 10 percent ($10 per dry ton) for the ten-year horizon. Contributing to the high delivered costs were the average holding times of inventory of 1.5–3.5 years during the startup phase. In addition, biomass inventory stored before delivery in year four of the simulation incurred an average 14 percent storage matter loss. By comparison, biomass stored for an average of six months in years four through 10 incurred a storage dry matter loss of 5 percent. These two factors explained the large increase in production costs from the time the feedstock went into storage to the time it was delivered to the biorefinery.

Results indicate that the costs of storage for switchgrass produced using traditional hay harvesting and storage methods may be a major barrier for establishing the feedstock production base in a biorefinery startup. It also should be noted that the estimated costs of storage and transportation of feedstock to the biorefinery in this analysis do not include insurance on the feedstock for fire or other perils, or an explicit charge for the land area used for storage.

Finally, BCAP planting and harvest payments in this analysis have the potential to offset the increased costs of storage with a traditional large-bale harvesting and storage system, under a delayed biorefinery-startup schedule. Assuming that the producer received both the BCAP planting and harvest payments, the delivered cost of feedstock at the plant gate for the single-row storage configuration averaged $68 and $66 per dry ton, respectively, for the five- and 10-year planning horizons. For the 3-2-1 pyramid storage option, the delivered cost of feedstock averaged $55 and $57 per dry ton, respectively, for the five- and 10-year planning horizons. The reduction in production costs with the BCAP payments were the largest under the five-year planning horizon, dropping by $56 per dry ton when compared to the no-BCAP-payment scenario. Thus, the BCAP has the potential to reduce the risk associated with establishing a feedstock production base under a biorefinery startup scenario.

SUMMARY

Today, agriculture is at a crossroads. It is receiving increased attention as the nation is concerned about its ability to meet food, feed and fiber demands along with increasing fuel demands. This chapter examines the use of crop residues in a conservation tillage system as a source of cellulosic fuel, as well as the economic potential of growing a dedicated energy crop to meet the demand for cellulosic feedstocks.

There are economic and conservation trade-offs to consider when thinking about harvesting a crop residue such as corn stover for use as a feedstock. Crop residue left on the soil surface provides important agronomic benefits that influence yield, including reduced erosion, improved water retention, the recycling of nutrients and improved soil health. Studies have shown that removing residue from fields negatively affects crop yields and can outweigh the financial gains from harvesting residue for bioenergy. If crop residue removal is to become a sustainable strategy for supplying energy feedstock, more research is needed on acceptable levels of residue removal.

Growing dedicated energy crops on marginal agricultural land offers a potentially viable option, particularly in the Southeast. An example crop is switchgrass, an herbaceous perennial. This chapter analyzes the economic feasibility of growing switchgrass in various scenarios that take into account emerging issues in establishment, production, harvest and handling. Stand establishment and lifespan are critical variables when evaluating the economics of switchgrass, as are the availability of a buyer and the costs associated with long-term storage and transportation. The chapter also discusses the role policy incentives play in the financial feasibility of switchgrass production, particularly the Bioenergy Crop Assistance Program (BCAP).

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TABLE 16.1. A comparison of studies on the estimated delivered cost of corn stover to ethanol plants[1]

AUTHOR	Year Published	DOLLARS PER DRY TON Low Estimate	High Estimate	Low Estimate	High Estimate
		$, in year published		$, adjusted to 2015	
Gallagher [23]	2003	15	32	29	61
Petrolia [55]	2008[2]	40	-[3]	67	-
Lazarus [40]	2008	50	-	63	-
Brechbill and Tyner [8]	2008	37	49	46	60
Eidman et al. [17]	2009	74	87	99	116
Larson et al. [37]	2008	35	80	44	100

[1] These studies contain different cost components.
[2] Published in 2008 but submitted in 2006
[3] “-” indicates that data is not available.

TABLE 16.2. Switchgrass production costs and yields for alternative planning horizons, storage options and Biomass Crop Assistance Program (BCAP) payments

SCENARIO	NET PRESENT Value Costs ($/acre)	ANNUALIZED NET PRESENT VALUE Cost ($/acre)	Yield (dry ton/acre)	Cost/Dry Ton ($/dry ton)
5 Year Planning Horizon				
Baseline[1]	1,174	310	4.72	66
Replanting[2]	1,216	321	4.56	70
Storage and Transportation[3]				
25 Bale Single-Row Stack	1,892	499	4.02	124
72 Bale 3-2-1 Stack	1,694	447	4.02	111
BCAP Planting[4]				
25 Bale Single-Row Stack	1,654	436	4.02	109
72 Bale 3-2-1 Stack	1,456	384	4.02	96
BCAP Planting and Harvest[5]				
25 Bale Single-Row Stack	1,035	273	4.02	68
72 Bale 3-2-1 Stack	837	221	4.02	55

TABLE 16.2 continues on the next page.

TABLE 16.2. continued

	NET PRESENT	ANNUALIZED NET PRESENT VALUE		
SCENARIO	Value Costs ($/acre)	Cost ($/acre)	Yield (dry ton/acre)	Cost/Dry Ton ($/dry ton)
10 Year Planning Horizon				
Baseline	1,900	309	5.73	54
Replanting	1,942	316	5.63	56
Storage and Transportation				
25 Bale Single-Row Stack	3,127	509	5.10	100
72 Bale 3-2-1 Stack	2,831	461	5.10	90
BCAP Planting[4]				
25 Bale Single-Row Stack	2,888	470	5.10	92
72 Bale 3-2-1 Stack	2,593	422	5.10	83
BCAP Planting and Harvest[4, 5]				
25 Bale Single-Row Stack	2,079	338	5.10	66
72 Bale 3-2-1 Stack	1,783	290	5.10	57

[1] Costs of production without replanting, storage, and transportation costs and BCAP subsidies.

[2] Assumes 20 percent probability of replanting the stand after the initial planting [24].

[3] Assumes switchgrass was planted four years before the biorefinery is operational in year four. Thus, biomass produced in years one, two and three was assumed to be delivered in years four and five, respectively. Feedstock harvested in years four through 10 was assumed to be stored an average of 0.5 years before delivery. Biomass in years one, two and three was assumed to be stored an average of 3.5 years, 2.5 years and 1.5 years, respectively. Biomass yields were adjusted for storage dry-matter losses using 5 percent for bales stored for up to six months and 14 percent for bales stored between six months and 1.5 years [36]. Annualized storage costs of $14.64 and $8.79 per dry ton going into storage were used for the single-row and 3-2-1 stacks. Transportation to the biorefinery assumed 2 percent dry-matter losses and trucking costs of $11.95 per dry ton [38].

[4] BCAP planting incentive payment of 75 percent of initial establishment costs.

[5] BCAP harvest incentive payment of $45 per dry ton for biomass sold in years four and five.

TABLE 16.3. Switchgrass establishment operations schedule [24]

Month	Operation	Equipment	Machine hours	Labor hours
August	Fall burn down	Sprayer, 60-foot boom	0.03	0.0375
May	Spring burn down	Sprayer, 60-foot boom	0.03	0.0375
	Plant	No-till drill	0.24	0.30
	Spread fertilizer	Tractor	0.07	0.0875
July	Post-emerge spray	Sprayer, 60-foot boom	0.03	0.0375
July	Post-emerge spray	Sprayer, 60-foot boom	0.03	0.0375
August	Post-emerge spray	Sprayer, 60-foot boom	0.03	0.0375
July	Bush hogging	Rotary mower, 15 foot	0.10	0.1250

TABLE 16.4. Switchgrass establishment materials costs per acre

Cost Item	Description	Units	Quantity	Price	Cost
Seed	Pure live seed	Pound	8[1]	$20[2]	$160
Fertilizer					
	P_2O_5	Pound	40[1]	$0.52[3]	$20.80
	K_2O	Pound	80[1]	$0.44[3]	$35.20
Weed control					
Fall burn down	Glyphosate	Quart	1[1]	$8.76[3]	$8.76
Spring burn down	Glyphosate	Quart	1.5[1]	$8.76[3]	$13.14
Post-emerge	Broadleaf herbicide	Pint	2[1]	$2.50[1]	$5
Post-emerge	Grass herbicide	Acre	1[1]	$8[1]	$8
Post-emerge	Grass herbicide	Acre	1[1]	$8[1]	$8
Total materials cost—seed, fertilizer and chemicals ($ per acre)					**$258.90**

[1] From [24]
[2] From [45]
[3] From [42]

TABLE 16.5. Switchgrass establishment machinery costs per acre

Cost Item	Sprayer	Drill	Rotary mower	Tractor	Total
	$ per acre				
Diesel fuel[1]				$12.39	$12.39
Lubrication[2]				$1.86	$1.86
Repair and maintenance[3]	$0.69	$5.65	$1.37	$5.30	$13
Operating costs	$0.69	$5.65	$1.37	$19.55	$27.25
Capital recovery[4]	$0.74	$5.99	$0.99	$7.74	$15.47
Taxes, insurance and housing[5]	$0.19	$1.92	$0.44	$2.82	$5.37
Ownership costs	$0.93	$7.91	$1.44	$10.56	$20.84
Total cost	**$1.62**	**$13.56**	**$2.81**	**$30.11**	**$48.09**

[1] A fuel price of $2.35 per gallon [42], a fuel consumption rate of 6.57 gallons per hour for a 150 HP tractor [4], and the machine time per acre for each equipment operation [24] were used to calculate fuel costs.
[2] Lubrication costs were estimated using 15 percent of diesel fuel costs [4].
[3] Repair and maintenance costs were estimated using the formula and coefficients for each equipment type from the ASABE Standards [4].
[4] Depreciation and interest on equipment were calculated using the capital recovery method [3], a real interest rate of 3 percent [3], and the remaining (salvage) value formula and coefficients for each equipment type from the ASABE Standards [4].
[5] Taxes, insurance and housing annual expenses were calculated as 2 percent of the purchase price of equipment [4].

TABLE 16.6. Switchgrass establishment cost summary

Cost Item	Amount	
	$ per acre	
Total materials cost—seed, fertilizer, chemicals		$258.90
Seed	$160	
Fertilizer	$56	
Chemicals	$36.02	
Total machinery costs		$48.09
Operating costs	$27.25	
Ownership costs	$20.84	
Labor cost at $9.75 per hour[1]		$6.83
Operating capital—six months at 6 percent[1]	$286.10[2]	$8.58
Total cost of establishment		**$322.40**

[1] From [42]

[2] Operating capital is the total materials cost plus the total machinery operating cost.

TABLE 16.7. Switchgrass annual maintenance operations schedule [24]

Month	Operation	Equipment	Machine hours	Labor hours
May	Herbicide application[1]	Tractor and sprayer, 60-foot boom	0.03	0.0375
	Herbicide application[1]	Tractor and sprayer, 60-foot boom	0.03	0.0375
	Spread fertilizer	Tractor	0.07	0.0875

[1] Herbicide applications only occur in year two if needed.

TABLE 16.8. Switchgrass annual maintenance materials costs

Cost Item	Description	Units	Quantity	Price	Cost
Fertilizer					
	N	Pound	6[1]	$0.48[2]	$28.80
	P_2O_5	Pound	40[1]	$0.52[2]	$20.80
	K_2O	Pound	80[1]	$0.44[2]	$35.20
Weed control					
Post-emerge	Grass herbicide	Acre	1	$8[1]	$8
Post-emerge	Grass herbicide	Acre	1	$8[1]	$8
Total materials costs ($ per acre)					**$100.80**

[1] Quantities are University of Tennessee (UT) Extension's recommended fertilization rates for switchgrass. UT Extension does not recommend P2O5 and K2O on medium- and high-test soils [24].

[2] From [42].

TABLE 16.9. Switchgrass annual maintenance machinery costs

Cost Item	Sprayer	Tractor	Total
		$ per acre	
Diesel fuel[1]		$2.88	$2.88
Lubrication[2]		$0.43	$0.43
Repair and maintenance[3]	$0.27	$1.23	$1.50
Operating costs	**$0.27**	**$4.54**	**$4.81**
Capital recovery[4]	$0.29	$1.80	$2.09
Taxes, insurance and housing[5]	$0.08	$0.65	$0.73
Ownership costs	**$0.37**	**$2.45**	**$2.82**
Total cost	**$0.65**	**$6.99**	**$7.64**

[1] A fuel price of $2.35 per gallon [42], a fuel consumption rate of 6.57 gallons per hour for a 150 HP tractor [4], and the machine time per acre for each equipment operation [24] were used to calculate fuel diesel costs.

[2] Lubrication costs were estimated using 15 percent of diesel fuel costs [4].

[3] Repair and maintenance costs were estimated using the formula and coefficients for each equipment type from the ASABE Standards [4].

[4] Depreciation and interest on equipment were calculated using the capital recovery method [3], a real interest rate of 3 percent [3], and the remaining (salvage) value formula and coefficients for each equipment type from the ASABE Standards [4].

[5] Taxes, insurance and housing annual expenses were calculated as 2 percent of the purchase price of equipment [4].

TABLE 16.10. Switchgrass annual maintenance cost summary

Item	Amount	
	$ per acre	
Total materials cost—fertilizer, chemicals		$100.80
Fertilizer	$84.80	
Chemicals[1]	$16	
Total machinery cost		$7.64
Operating costs	$4.81	
Ownership costs	$2.82	
Labor cost at $9.75 per hour[2]		$1.58
Operating capital—six months at 6 percent[2]	$105.61[3]	$3.17
Total annual cost of maintenance		**$113.19**

[1] Chemical cost occurs only in the second year.

[2] From [42]

[3] Includes material cost plus operating costs

TABLE 16.11. Switchgrass harvest, hauling and storage operations schedule

Month	Operation	Equipment	Machine time/rate	Labor Hours
November–February	Mow (hours per acre)	Mower	0.38[1]	0.48[1]
	Rake (hours per acre)	Rake	0.25[1]	0.31[1]
	Bale (tons per acre)	Large round baler	5.5[2]	
	Haul to stack (dry tons per hour)	Front end loader	8[2]	
	Haul pallets and tarp (hours per 20 pallets)	Pickup	0.5[3]	1
	Affix tarp to stack (hours per 72-bale stack)			0.5
	Affix tarp to stack (hours per 25-bale stack)			0.25

[1] From [24]

[2] Tractor and labor time to haul 8 dry tons of bales per hour (2 bales per trip) to the edge of the field to the stack [45] was increased by an extra 10 percent to account for additional tractor and operator time to place the pallets as the stack is being built.

[3] Assumes 0.5 hours of operating and ownership costs for a pickup truck to haul a load of 20 pallets to the site of the stack and one hour of labor time to drive the pickup and load and unload pallets.

TABLE 16.12. Switchgrass harvest, hauling and storage materials costs

Item	Description	Units	Quantity	Price	Cost
Twine	Twine per dry ton	Bale	1	$2.92[1]	$2.92
				Total	**$2.92**
Single-row stack	Pallet	Pallet	25	$6. 50[2]	$162.50
25 bales	1,000 square foot tarp	Tarp	1	$115[3]	$115
	Tie-down kit	Kit	1	$60[3]	$60
				Total	**$337.50**
3×2×1 stack	Pallet	Pallet	36	$6.50[2]	$234
72 bales	1,620 square foot tarp	Tarp	1	$25[4]	$251
	Tie-down kit	Kit	1	$68[5]	$68
				Total	**$553**

[1] From [24]

[2] Cost per 40-inch-by-48-inch pallet is the average from a survey of providers by the authors.

[3] Slip Ons/Bale Bonnet Company, Cynthiana, Ohio: http://roundbalecovers.com/info.htm.

[4] Assumes 22.5 square feet of reinforced plastic tarp per 5-foot-by-4-foot bale in a 3-2-1 pyramid stack housing 72 bales [26]. Reinforced plastic tarp cost of $0.16 per square foot was the average from a survey of providers by the authors.

[5] Average cost from a survey of providers by the authors.

TABLE 16.13. Switchgrass annual operating, ownership and labor expenses for harvest assuming a five-year planning horizon[1]

Stand Year	Fuel and Lubrication	Twine and Repairs	Capital Recovery	Taxes Insurance and Housing	Labor	Operating Interest	Total
	$ per acre						
1	22.15	26.56	23.07	2.43	15.20	1.46	90.86
2	36.46	50.35	40.34	4.28	25.03	2.60	159.07
3	40.46	57	45.16	4.80	27.77	2.92	178.12
4	43.19	61.54	48.45	5.15	29.65	3.14	191.13
5	48.54	70.41	54.90	5.84	33.32	3.57	216.57

[1] Annual expenses for mowing, raking, baling and handling of biomass before being placed into storage.

TABLE 16.14. Switchgrass annual operating, ownership and labor expenses for harvest assuming a 10-year planning horizon[1]

Stand Year	Fuel and Lubrication	Twine and Repairs	Capital Recovery	Taxes Insurance and Housing	Labor	Operating Interest	Total
	$ per acre						
1	22.83	27.56	23.97	2.53	15.67	1.51	94.08
2	34.01	46	37.53	3.99	23.34	2.40	147.27
3	45.06	64.22	50.92	5.44	30.93	3.28	199.84
4	46.79	67.08	53.02	5.66	32.12	3.42	208.08
5	54.34	79.54	62.18	6.65	37.30	4.02	244.02
6	48.72	70.27	55.37	5.92	33.44	3.57	217.29
7	57.31	84.44	65.78	7.04	39.34	4.25	258.17
8	53.75	78.57	61.47	6.57	36.90	3.97	241.23
9	55.84	82.02	64	6.85	38.33	4.14	251.18
10	57.17	84.21	65.61	7.02	39.24	4.24	257.50

[1] Annual expenses for mowing, raking, baling and handling of biomass before being placed into storage.

PART 3

Regional Management Considerations for Conservation Tillage Systems

CHAPTER 17

Tennessee Valley and Sandstone Plateau Region Case Studies

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The Tennessee Valley and Sandstone Plateau region of northern Alabama is part of two major land resource areas (MLRA) as defined by USDA Natural Resources Conservation Service (NRCS): MLRA 128 (Southern Appalachian Ridges and Valleys) and MLRA 129 (Sand Mountain) (Figure 17.1). MLRA 128 is located in Tennessee (36 percent), Alabama (27 percent), Virginia (25 percent) and Georgia (12 percent). MLRA 129 is located mostly in Alabama (96 percent) with small parts in Georgia (3 percent) and Tennessee (1 percent). MLRA 128 has a land area of 21,095 square miles (13,500,800 acres). This area of the Southern Appalachian Mountains is highly diversified with many parallel ridges, narrow valleys and large areas of low, irregular hills. Elevations range from 630–2,300 feet. The Tennessee Valley is one of the broader valleys in the region and was formed primarily from eroded limestone. The ridges and plateaus are capped with sandstone and shale. The climate of the region is moderate, with annual frost-free periods near 245 days. Rainfall is relatively abundant, with annual precipitation averaging 41–55 inches. Annual rainfall in the region is evenly distributed throughout the year. [5, 13]

The limestone valley soils tend to be deeper, with more silt and clay than soils formed from sandstone and shale on the plateaus. Locally, farmers refer to the more arable limestone valley soils as “red land,” in reference to their red color. An example is the Decatur soil series. The soils of the Tennessee Valley may have more than 20 feet of unconsolidated material over the limestone bedrock. On eroded knolls, cherty limestone outcroppings may be found, and in some fields there are depressions and sinkholes that resulted from dissolving limestone underneath.

The Tennessee Valley was a center of plantation-style cotton production in the antebellum period. Sharecropping dominated the post-Civil-War era until World War II. Throughout the 19th and 20th centuries, traditional cultivation practices included fall moldboard plowing, winter fallow, spring disking or chisel plowing (post World War II), harrowing and planting followed by several mechanical cultivations for weed control. Erosion, sometimes severe, was an accepted sacrifice for row crop production. Even after terracing and contour farming practices were introduced in the 1930s, erosion continued and perhaps increased with larger equipment in the 1960s, 1970s and 1980s. Locals seemed to accept that the Tennessee River and its tributaries flowed red with late-winter and early-spring rains.

In spite of almost 200 years of continuous cultivation and some severe erosion, these valley soils remain relatively productive. The USDA estimates that about 6 percent of the Tennessee Valley and Sandstone Plateau region is in cropland, but the Tennessee Valley and Coosa River valley of northern Alabama are intensively cultivated. In 2012, 549,507 acres of row crops were planted in the nine Alabama counties contiguous to the Tennessee River [12]. The sandier sandstone plateau soils on the sandstone ridges and plateaus have not fared as well. They are often acidic and infertile, with the depth to the sandstone bedrock anywhere from a few inches to several feet. A history of soil erosion has forced some of these soils out of cultivation entirely. The soils were not extensively cultivated until the late 19th and 20th centuries, when the use of fertilizers and ground

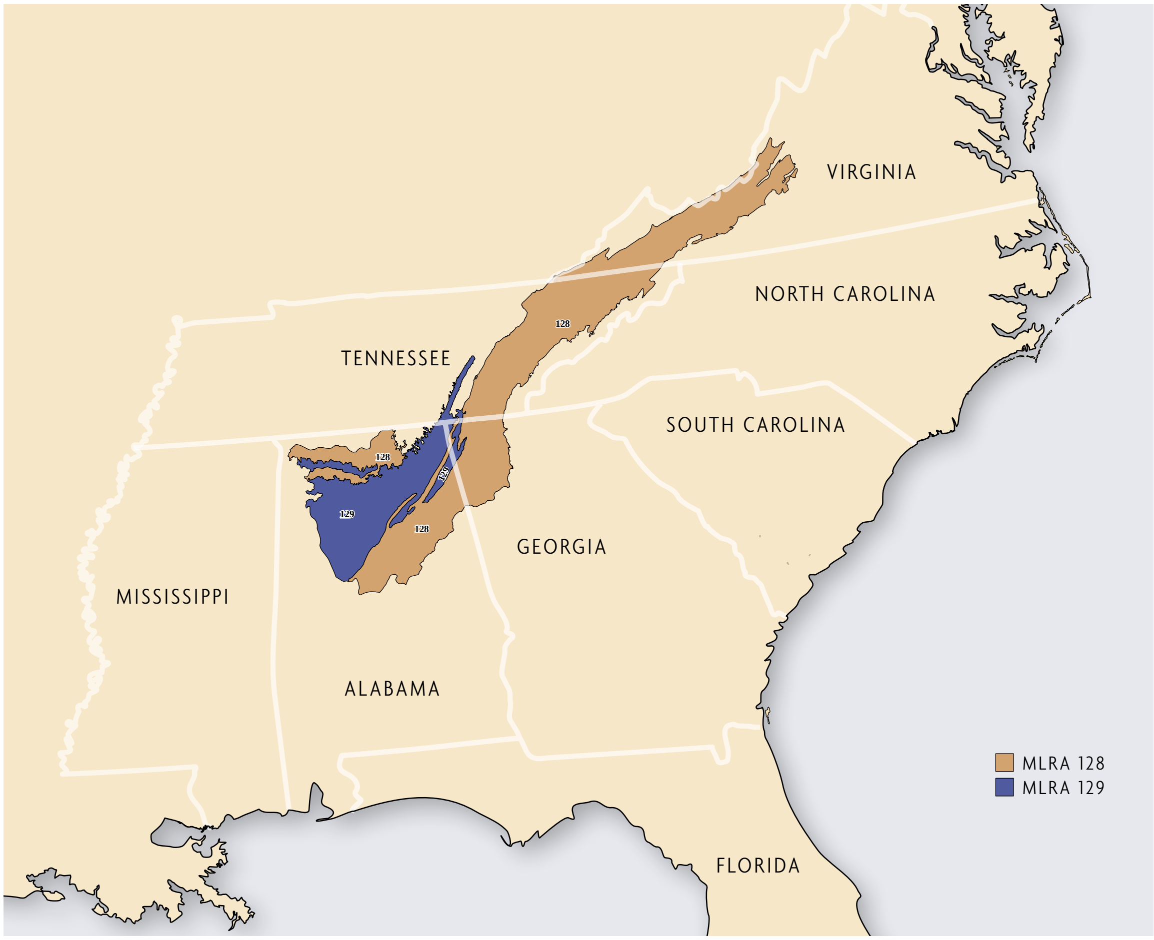

FIGURE 17.1. MLRA 128 (Southern Appalachian Ridges and Valleys) and MLRA 129 (Sand Mountain) [13].

limestone greatly enhanced their productivity.

MLRA 129, Sand Mountain, is located primarily in northeastern Alabama, includes 8,030 square miles (5,139,200 acres) and is one of the broader ridges in the region. Fields on the plateaus are typically much smaller than those in the valleys and are more dissected by terraces and contours. Most of Cullman, Blount, Marshall and Dekalb counties in Alabama are on the sandstone plateaus. These counties had 55,984 acres of row crops and 118,378 acres of hay land in 2012 [12]. The steeper terrain and shallow soils of the Sand Mountain region make poultry broiler production more economically viable than row-crop farming. Poultry production increased rapidly in this region in the 1970s and 1980s. Land was converted from row crops to pastures and hayfields where broiler litter could easily be applied at any time of the year. Most of the Sand Mountain region is now industrialized, with a large percentage of the rural population earning a non-farm-related income.

CROP SELECTIONS AND CROP ROTATIONS

The primary cash crops grown in the ridges and valley are cotton, corn, soybeans and wheat. Prior to the 1980s, some specialty crops were grown on the Sand Mountain soils, including white potatoes, sweet potatoes, pimento peppers, tomatoes and small patches of other vegetables. But, the total acreage of these crops was small compared to cotton, corn and soybeans. Very little cotton is grown on sandstone plateau soils today, comprising less than 4 percent of total row-crop acreage [12].

Traditionally, crop rotations were determined by commodity price and government programs. Growing cotton every year on the same fields with no cover crop was common until the 1990s. A cotton-soybean rotation was adopted when the price of soybeans justified it. Wheat for grain double-cropped with soybeans is riskier than it is in the Coastal Plain farther south due to climate, but some growers in the region use double-cropping. Adoption of conservation tillage makes these rotations and double-cropping more feasible due to potentially higher yields, improvements in soil organic matter and reductions in compaction [4]. Corn for grain fits well into a three-year rotation but is planted only when the profit margin is competitive with cotton.

SPECIFIC MANAGEMENT CONSIDERATIONS

In the mid-1980s, growers in the region realized the need to adopt conservation practices on highly erodible cropland. However, techniques such as high-residue management, in-row subsoiling and strip tillage, which work well on the sandier Coastal Plain soils of southern Alabama and southern Georgia, did not do as well as conventional tillage with cotton in the "red lands" of the Tennessee Valley. Strict no-till as used in the loessial soils of western Tennessee and Kentucky did not do as well as conventional tillage with cotton on the red lands. Conservation tillage worked much better on the sandier soils of the Sandstone Plateau/Sand Mountain region. The silt loams and clay loams of the valleys apparently did not respond to in-row subsoiling because they rarely develop traffic pans as do the sandier Coastal Plain soils [11]. A traffic pan is a 2- to 4-inch thick layer of compacted soil that results from the downward pressure of tillage equipment [6]. Deep spring tillage on red-land soils often brings up wet, clayey soil that can result in severe clodding when it dries. This limits deep tillage on these soils to the late fall and winter months when winter freezes can break up the soil. High residue tends to keep valley soils cooler and wetter in the spring, and this is not desirable for cotton production because growing degree days are limited in the region.

Tillage

Conservation tillage in the Tennessee Valley proceeded in small steps before a complete system could be developed. Cotton farmers in the Tennessee Valley who tried no-till in the late 1980s and early 1990s reported 8–15 percent yield reductions compared with conventional tillage [2, 3, 8]. Most farmers were planting cotton into old cotton stubble using no-till techniques and reporting reduced cotton stalk growth after a few years. Research at the time supported either a lack of cotton-yield response to no-till or a yield reduction when no-till practices followed conventional tillage on these highly eroded soils low in organic matter [9, 11]. While in-row subsoiling showed positive corn and cotton yield responses in the Coastal Plain soils of South Alabama, in-row subsoiling on a Decatur silt loam in the Tennessee Valley actually reduced cotton yields [11]. Valley cotton farmers began using small-grain cover crops more intensely in the mid-1990s. Research showed that a surface compaction layer was limiting cotton growth and yields. Planting wheat or rye after cotton harvest breaks up the compacted layer and improves growth and yields [3, 7].

The recommended conservation tillage system finally developed for the valleys consisted of non-inversion deep tillage such as paratilling under the row in the fall coupled with a high-residue rye cover crop [10]. Fall tillage allows these heavier soils to "mellow" over the winter, which reduces the number of clods and surface roughness. A fall cover crop with fall tillage helps control erosion and provides a surface cover to conserve soil moisture. Research over a seven-year period showed that cotton, no-till planted into wheat cover crop residue, out yielded conventional-tillage cotton by over 16 percent [4]. On the sandstone plateaus, soybean and grain producers can be successful with no-till, strip till and high-residue management systems that are common on the sandy Coastal Plain soils.

Cover Crops

Traditionally, cover crops were never popular on the large fields of the Tennessee Valley. They kept soils cooler and wetter in the spring when early cotton planting is critical. However, gradually declining soil organic matter with conventional tillage, continued soil erosion and stagnant yields led many growers to reconsider the use of cover crops. Cover crops, typically wheat or rye, with no deep tillage can produce yields similar to deep tillage on these silty and clayey textured soils [5, 8]. Irrigation coupled with cover crops has been shown to improve cotton yields and fiber characteristics [1]. Wheat and cereal rye are by far the most popular winter cover crops for this region. They are easier to kill with glyphosate in the early spring than winter legumes, and they produce dry matter earlier than most legumes.

CASE STUDY

Glenn Acres Farm, Hillsboro, Alabama

Editor's note: This case study was written in 2009 and updated in 2018.

"It was the worst farm in the Valley in the fall of 1995," Don Glenn says to describe his farm when he and his brother, Brian, took it over. There were gullies big enough to bury a tractor and creeks that were silted in from decades of conventional tillage and abuse. One farm had 238 acres of cotton but the eroded hilltops were not planted. Today, that same farm has 385 acres of no-till corn, wheat and soybeans. Ultimate plans are to produce five crops in three years and to continue to improve soil quality. The farm has not seen a plow since the Glenns took over.

The Glenns are fourth-generation farmers in northwestern Lawrence County near the Tennessee River. Their father, Eugene, raised alfalfa and sold hay. The family had been in the dairy business, the cattle business and the poultry business until they sold their last farm for a City of Decatur industrial park. Today a huge steel mill sits on the former farm. Brian notes that when they gave up commercial hay production, they could no longer afford to have cattle. Today, it is all grain. The Glenns never were traditional Tennessee Valley cotton farmers, a fact that probably contributed to their ability to implement no-till practices. Today, the farm consists of about 2,000 acres of grain crops, primarily corn followed by double-cropped wheat and soybeans. They have had canola in the rotation but currently are not growing it due to the loss of their market for it. Both brothers emphasize that they take a systems approach to farming and look for crops that fit into their system. They stick with the system regardless of commodity prices. The brothers do most of the work with some help from their families. There is only one hired laborer.

The following are questions about Glenn Acres Farm asked directly to Brian and Don Glenn. The answers to the questions are direct quotations and combined responses from both brothers.

Why do you use conservation tillage?

To stay in business. We wouldn't be farming today if it were not for no-till. Economics and labor costs cannot justify the time it takes to till the land. When we first began, our plans were to no-till for three or four years and then come back and deep rip the land. As we saw our bean (soybeans) and corn yields go up with no-till, we decided not to till in spite of research that showed you needed to deep-till wheat. We thought we'd just give up some yield on wheat and make up for it with increased corn and bean yields. Soon we saw that our wheat yields were going up because of soil improvements from no-till, better drainage and more root channels left in place. Roots do a better job of tilling than a subsoiler.

What conservation tillage practices work best for you?

We're 100 percent no-till into the previous crop residue. We've never been cotton farmers because it's easier to make grain work with no-till than cotton. We saw so many neighbors no-till grain and maybe one cotton crop and then complain because of soil compaction. They'd get out the moldboard plow to correct the situation and they were back where they started. We've found that the more residue we have, the easier it is to get back in the field. Every crop is rotated. We're working toward a rotation of year one, corn followed by canola in the fall; year two, soybeans planted after canola harvest with wheat in the fall; and year three, soybeans following wheat harvest.

What is the biggest advantage of conservation tillage on these soils?

The residue. Residue is as important as the crop itself. We have seen yields go up as organic matter increases in the surface soils. We attribute this to increased water infiltration and increased soil water-holding capacity. We used to sell wheat straw when we were in the hay business. When we stopped selling the straw, our fertilizer bill went down. The residue is our friend. We just have to learn to manage it better. Because of the residue, we can plant our entire crop in four to five days and harvest in 10 days without hired labor. We can have a crop planted using no-till while you would still be waiting on the soil to dry out for conventional tillage.

What are some of the challenges you've faced?

Initially, all this land was severely eroded. In addition, our soils are highly variable. In one 50-acre field, there are 16 soil-mapping units that we have to treat differently. This is one reason we went with precision agriculture along with no-till. High crop residues have caused some problems, but these are the kind of problems we can manage. For example, the toughest challenge is drilling soybeans into wheat residue behind a conventional combine. We bought a stripper head for our combine to harvest the wheat because it left the wheat standing so we could drill soybeans the same day we harvest the wheat. We did have a difficult time planting soybeans after our 100 bushels per acre wheat yields.

Do you use or have you tried any in-row subsoiling like they do in the sandy Coastal Plain soils?

Subsoiling pulls up clods in these soils. We use absolutely no tillage and we let the plant roots do the subsoiling. We're always looking for deep-rooted crops to include in the system.

Do you use cover crops?

No. We never could find a cover crop that fit into our system other than another grain. Residue from our crops is our cover crop. The only winter when our soil has no crop is the winter before planting corn. We harvest soybeans so late in the fall that no cover crop would be able to make significant growth before corn planting in late March. Because of the residue it leaves, wheat was the first crop we planted when transitioning to a conservation tillage system. Get a good stand of the wheat and from then on it is easy.

Any final comments?

It's all about organic matter, organic matter and organic matter, and residue, residue and residue. When we first started farming this land and tried to take grid samples, we could not get a soil sampling tube into the ground. However, we noticed that where there was a clump of crop residue, we could scrape off the residue and the tube went easily into the soil. The soil beneath the residue was moist, not dried out like the bare soil. Now, we have no problem sampling every acre whenever we need to. We were inspired by the early no-till research and the field days at Milan, Tenn. Then, a 1999 trip to Brazil convinced us that we could be just as successful as the Brazilians at no-till farming.

CASE STUDY

Jimmy Miller and Pat Whitley, Sandstone Plateau

Editor's note: This case study was written in 2009.

Jimmy Miller farms with his nephew, Lance Miller, in northern Blount County, Ala., near the community of Snead. Most of his acreage is on Wynnville fine sandy loams on the southwestern end of the Sand Mountain plateau. Jimmy is a fifth-generation farmer in this area and notes that his great, great grandfather, who served in the Civil War, is buried near the family farm. Jimmy started farming in 1964 but, like most farmers in the area, did not try conservation tillage until the mid-1980s when he planted his first no-till corn. He planted his first no-till cotton in 1997 when Roundup Ready cotton was introduced. He has been using high-residue, no-till on his

FIGURE 17.2. Panoramic view of a portion of Glenn Acres Farm in the Tennessee Valley of northern Alabama.

corn, soybeans and cotton ever since. He tries to strip-till one-third of his cotton each year so that every three years, all of the acres have been strip-tilled. In 2009, Jimmy and Lance planted around 400 acres of cotton, 100 acres of soybeans and 36 acres of corn using conservation tillage. For the first time since 1985, Jimmy planted 110 acres of peanuts in 2009. He was advised to use conventional tillage on his peanuts this year but he is already making plans to plant them into rye residue following cotton in 2010. Jimmy and Lance also own four broiler houses. Lance's wife, Stephanie, works in them. Jimmy points out that in 2008, one 44-acre field of cotton planted in rye cover crop residue had the highest yield, over 1,300 pounds lint per acre. It still lost some bolls to an early freeze. Their overall farm average was 1,076 pounds lint per acre. All of the 2009 cotton was no-till. They usually try to plant behind a strip-till into the rye residue, but the planting window was narrowed due to a wet spring, and they did not have time to strip-till. They attribute the high cotton yields to soil improvements from conservation tillage. Jimmy serves on the Alabama Cotton Commission and is chairman of the Alabama State Cotton Committee.

Pat Whitley started farming in 1980. He lives down the road from the Millers and they farm similar land and work closely together. Both Jimmy Miller and Pat Whitley are part owners of the nearby Rainbow Gin Company, Inc. Pat looks at Jimmy and is quick to exclaim, "That's my teacher!" They use very similar techniques on their farms and farm the same type of rolling, terraced fields typical of the Sandstone Plateau region. Pat has one field on a Decatur silty-clay loam (red land) in one of the narrow valleys in Blount County. He has about 850 acres of cotton, 200 acres of corn, 140 acres of soybeans and 140 acres of peanuts. In addition, he also owns six broiler houses that are managed by his wife, Kathy. The Whitleys have some cattle on pasture too. Pat admits that you can't get more diversified than this and it does keep them busy.

The following are some questions about Jimmy Miller's and Pat Whitley's farming operations. The answers to the questions represent combined responses from both producers.

Why did you switch to conservation tillage?

Pat was quick to answer that the number one reason they went with conservation tillage was to save on labor. Jimmy and Lance do all the work themselves. Pat has one full-time farm employee. With conservation tillage, there are fewer trips across the field, which requires less equipment and fewer operators. A related reason was fuel savings. A third reason was ease of planting in the spring. In this region, cotton is truly a full-season crop. These sandy soils do not warm up as rapidly as the red soils of the valley and because of a slightly higher altitude, they can get an earlier frost than the Tennessee Valley region just north of here. They need to take advantage of every opportunity to get cotton in as early as possible. Later, the men pointed out that they have few weed problems since they no longer disturb the soil. They pointed to their conventionally tilled peanuts and said they had more weed problems since they tilled this land for peanuts than they ever had when it was in conservation tillage for corn, soybeans or cotton.

When did you switch?

Jimmy planted his first no-till corn crop in the mid-1980s because he could control weeds with atrazine and other herbicides. Cotton weed control was still very difficult and expensive even with conventional tillage and cultivation. When Roundup Ready varieties became available in 1997, he started planting no-till or strip-tilled cotton. All their fields are relatively small compared to Tennessee Valley fields and all are on highly erodible land. Conservation tillage is the only way to farm these soils.

What winter cover crops do you use?

Rye is their only cover crop. Jimmy quoted his friend, Tom Ingram, who has been no-till farming in the South Alabama Coastal Plain region longer than any other grower in Alabama. He says, “Rye is the poor man’s irrigation!” This quote is testimony to rye’s ability to increase soil organic matter on the surface, thus increasing soil infiltration and water-holding capacity. They also claim that rye is a natural subsoiler, putting down deep roots and opening channels in compacted soils. The straw also suppresses weed growth. Rye is seeded in the fall after crop harvest at a rate of about 60 pounds per acre. They use light disking to cover the seed. Pat noted that it would be best if they had a no-till drill to use in planting the rye, but most of the no-till drills, they claim, were too small and too slow for their purpose. The rye is terminated with herbicides as soon as it begins to head, or about 30 days before planting cotton. Cotton or corn is planted directly into the rye residue without using a roller/crimper.

What are your biggest problems with conservation tillage?

Getting the rye seeded early enough to get some good fall growth has been a problem. Then, if rye is planted too thickly and it gets too big in the spring to lay down [meaning rye biomass is flattened using a roller/crimper] we can get “wrapping” on the trash wheels of the planter. This is a big problem! We can’t plant until the dew has completely dried or the wrapping is worse.

Do you in-row subsoil like they do in similar sandy Coastal Plain soils?

Jimmy bought a four-shank paratill a few years back, tried it and then put it away. In order for it to work well, he has to pull it too deeply in these shallow, sandstone plateau soils. That uses a lot of fuel, which defeats one of our purposes for using conservation tillage. Most of the soils that Jimmy and Pat farm are Wynnville fine sandy loams and these have a natural fragipan about 2 feet deep. Tillage will not help with this naturally occurring, dense soil layer. Pulling the paratill shallow only pulled up clods. Unlike most Coastal Plain soils, they have found that most of the traffic compaction from the cotton picker is shallow, less than 6 inches. Strip tilling about 6–8 inches deep at planting with their Remlinger no-till rig seems to work just fine. Jimmy notes, “The ground is not as hard as it used to be. Rye roots do more than all the plowing you can do. We now have more earthworms to do the tilling than we ever had with conventional tillage.”

Do you use winter legumes as cover crops?

No. They have found that in this region, they would have to wait until May to kill the clover in order to get maximum benefit from the fixed nitrogen. This is just too late to plant for their region.

Final comments?

Both producers have built dry-stack facilities for temporary storage of broiler litter, which is the main source of nutrients used on their cotton and corn. As a result, most fields test very high in phosphorus and high in potassium. Today, the broiler litter is mainly used as a source of nitrogen. Jimmy has found that 2–3 tons per acre at planting is enough in most years to produce a crop of non-irrigated cotton or corn. A ton of boiler litter will contain about 60-60-40 pounds N-P-K. One of the reasons they wanted to grow peanuts, a legume, was to take advantage of the very high fertility levels without having to apply additional broiler litter for the nitrogen as in cotton and corn.

SUMMARY

Jimmy Miller, Pat Whitley and Lance Miller are three of only a few row-crop farmers remaining in the Sandstone Plateau region of the Southern Appalachians. However, they are quick to let you know that without the savings and soil improvements that they have realized from conservation tillage practices with high-residue management, they probably would not be farming today.

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CHAPTER 18

Southern Coastal Plain and Atlantic Coast Flatwoods Case Studies

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The Southern Coastal Plain and the Atlantic Coast Flatwoods major land resource areas (MLRAs) extend along the southeast coast of the United States from Virginia to Mississippi and to the eastern tip of Louisiana, excluding the Tidewater regions of Virginia and North Carolina as well as the Florida peninsula (Figure 18.1). MLRA 133A, the Southern Coastal Plain, has a land area of 106,485 square miles (68,150,400 acres). MLRA 153A, the Atlantic Coast Flatwoods, has a land area of 28,720 square miles (18,380,800 acres).

Land use in the Southern Coastal Plain and the Atlantic Coast Flatwoods is similar, with both predominantly forested: 64 percent of total area for the Southern Coastal Plain and 67 percent for the Atlantic Coast Flatwoods. Crops are produced on 11,585,600 acres in the Southern Coastal Plain (17 percent of the total area) and on 2,757,100 acres of the Atlantic Coast Flatwoods (15 percent of the total area) [16].

As their names imply, the two MLRAs have relatively flat topography. The elevation in the Atlantic Coast Flatwoods ranges from 25–80 feet, while the elevation in the Southern Coastal Plain ranges from 80–650 feet. Although the potential for water erosion exists, especially on the Southern Coastal Plain soils, most of the topography is relatively flat. Thus, adoption of conservation tillage for erosion control has been slower than on the steeper slopes of the Southern Piedmont (MLRA 136) and other regions of the Southeast. The climate in both MLRAs is mild with a long growing season. Annual frost-free periods range from 200 days in northern areas to 305 days in southern areas. Rainfall is abundant, with annual precipitation of 44–57 inches in the Atlantic Coast Flatwoods and of 41–60 inches in most of the Southern Coastal Plain. An important feature of the annual rainfall distribution is that it occurs in a bimodal fashion, meaning that annually there are two rainy periods. Peak rainfall occurs in the summer, with frequent thunderstorms and occasionally tropical storms. The highest average annual rainfall occurs during late summer. A second, smaller rainfall peak occurs in early spring.

Though rainfall is plentiful, the seasonal pattern of precipitation leads to periods of plant water-deficit stress in most years for summer-grown crops. A considerable amount of the total summer rainfall comes from heavy thunderstorms, and there are often long periods between rainfall events. Rain-free periods of 21 days occur in most years during the growing season [12].

Potential evapotranspiration is a calculated estimate of the amount of water plants use plus water that evaporates. During the months of April, May, June and July, the evapotranspiration, on average, exceeds rainfall. For the period from 1985–2003, the cumulative difference between evapotranspiration and accumulated rainfall for those four months was approximately 10 inches, or 0.53 inches each year [2]. On average for those years, rainfall was about the same as evapotranspiration during August, September, October,

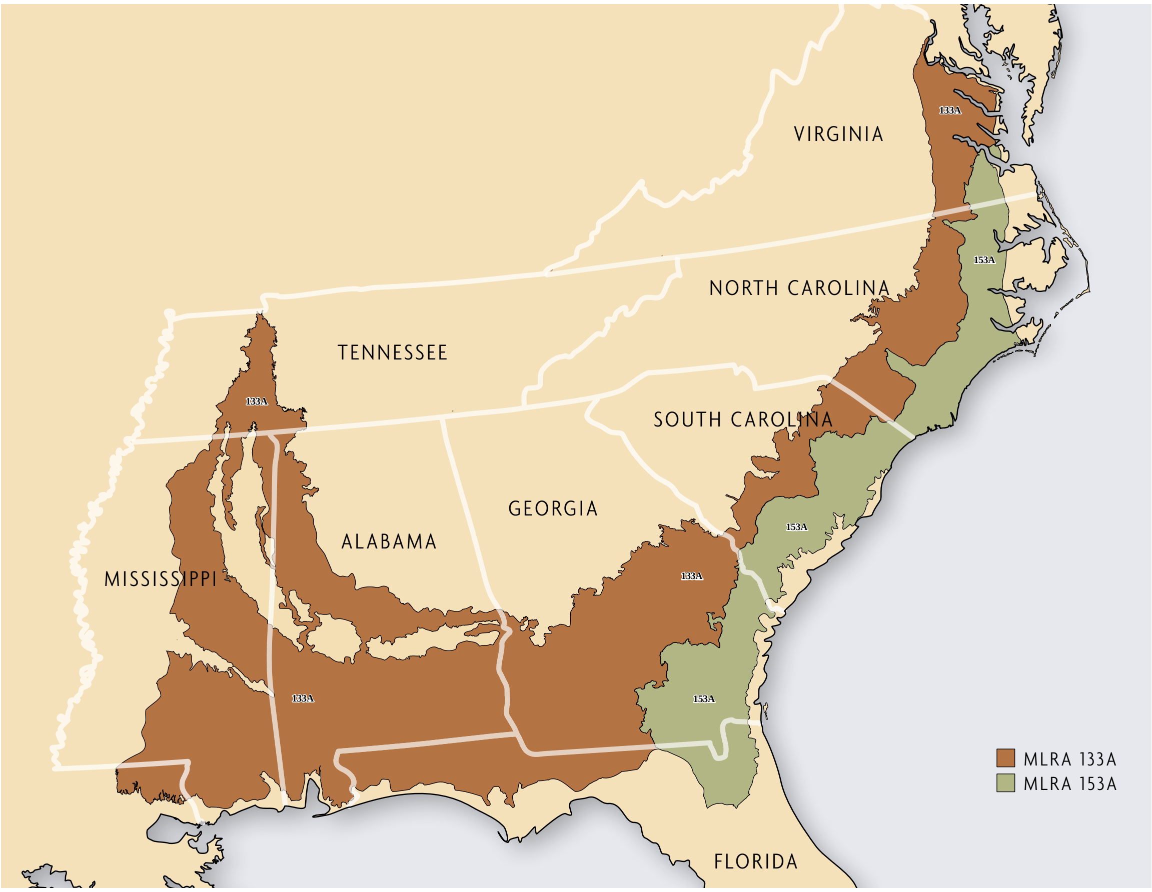

FIGURE 18.1. MLRA 133A (Southern Coastal Plain) and MLRA 153A (Atlantic Coast Flatwoods) [16].

November and March, while rainfall exceeded evapotranspiration during December, January and February.

Compounding the problem of summer precipitation deficits, most soils in the region are sandy in texture with low organic matter and low water-holding capacity. These soils were formed in marine sediments. The Tifton and Norfolk soil series are found throughout the Southern Coastal Plain. The sandy-soil surface layer, the A horizon, typically has a highly leached layer, the E horizon, below it that can form dense hardpans (Figure 18.2). The E horizon is a mineral horizon made up of sand and silt particles that are coarser than the A horizon. For many crops, it needs to be fractured for optimal production. The sands in the A and E horizons tend to be many different sizes and will compact due to rainfall even without tillage or traffic. Below the E horizon is the B horizon, which generally has a sandy-clay loam texture that gives it more water-holding capacity than either the A or E horizons. However, these subsoils are often acidic, which reduces rooting depths and the volume of soil plant roots can explore for water and nutrients [13].

On the other hand, many of the soils are poorly drained, especially in the Atlantic Coast Flatwoods. Seasonal high water tables and surface ponding can significantly reduce crop yields. Subsurface tile drains are used on approximately 800,000 acres in North Carolina (25 percent of cropland), 175,000 acres in South Carolina (25 percent of cropland) and 230,000 acres in Georgia (8 percent of cropland) [15].

CASH CROP SELECTION AND CROP ROTATIONS

Agronomic crops dominate the row crop acreage in the two MLRAs. The primary agronomic cash crops grown are corn, small grains (primarily winter wheat), soybeans, peanuts, cotton and tobacco. Sweet potatoes and many types of fruits and vegetables including onions, cucumbers, watermelons, pumpkins and strawberries are also grown on smaller acreages. Cash crop selection depends on a number of factors, including growing-season climate, availability of a market, a contract to grow, local infrastructure, government programs and availability of labor. For individual fields, cash crop selection depends on soil type, irrigation capacity and the species of weeds, soil-borne diseases and nematodes in the field. Crop price, production cost and potential net income are primary considerations in crop selection.

Even though most of the soils in the southern Coastal Plain have a low water-holding capacity, farmers in this region widely grow cotton, peanuts and soybeans without irrigation. These crops, along with tobacco, produce yield over a longer time, as compared to corn. This makes them a lower risk for substantial yield loss due to short-term drought. The region's climate is also favorable, because a greater percentage of the yield is produced during August and September, when evapotranspiration is lower and rainfall more closely matches evapotranspiration.

Many different crop rotations are used in these MLRAs. Because of the long growing season, growing two crops in the same year (double-cropping) is common. For example, about half of the soybean acreage in South Carolina is planted immediately after winter-wheat harvest. When winter cash crops are not grown, cover crops are often planted for soil protection and improvement.

Rotations are often used for pest management. To control pod disease in peanuts, maintain a minimum three-year rotation, with non-legume crops grown in two of the years. Rotations with

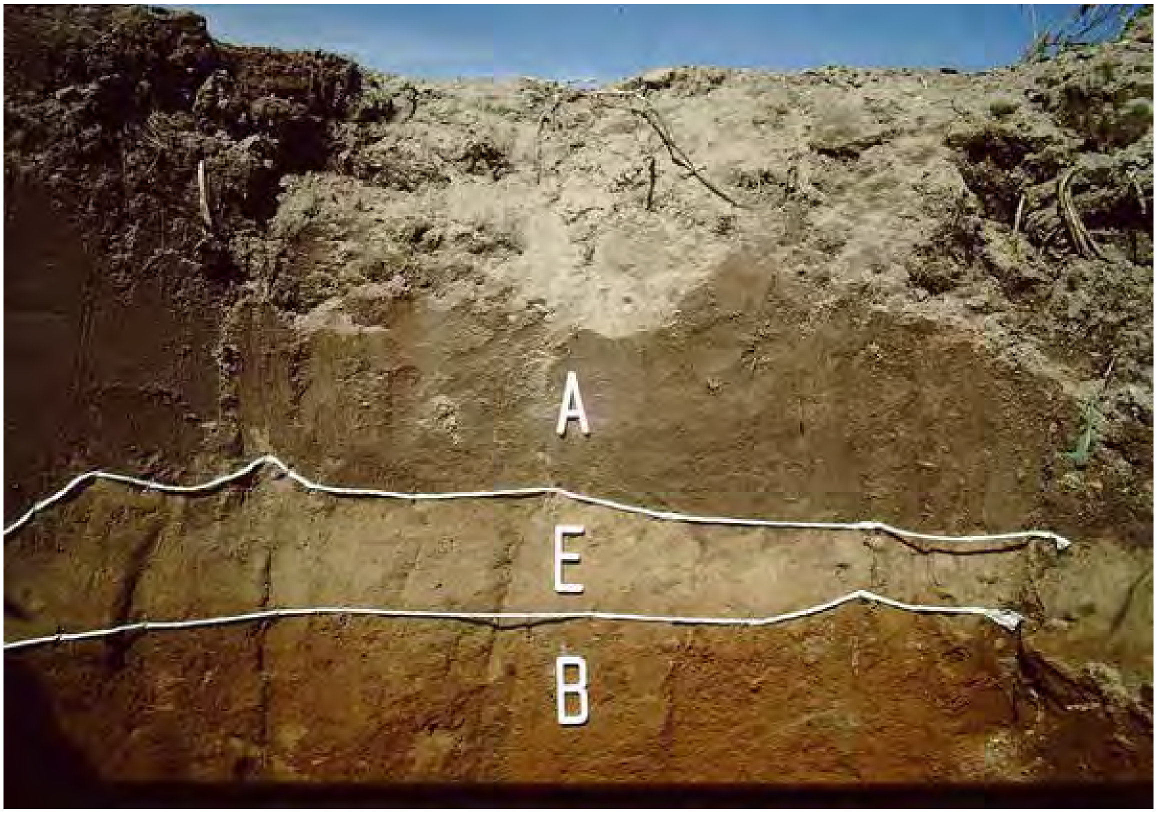

FIGURE 18.2. Profile of a Southern Coastal Plain soil showing the sandy A horizon, the leached E horizon, and the higher clay B horizon. The E horizon can become very dense and inhibit rooting. *Photo courtesy of Warren Busscher, USDA ARS.*

cotton and corn are common in a peanut crop rotation. Several species of nematodes infest the soils of the Southern Coastal Plain and Atlantic Coast Flatwoods. Rotations that include non-susceptible crops can be an economically effective management option (Chapter 12).

SPECIFIC MANAGEMENT CONSIDERATIONS

In general, conservation tillage practices in these regions are similar to conservation tillage practices in other regions. On Southern Coastal Plain and Atlantic Coast Flatwoods soils, keys to successful crop production with conservation tillage include:

- adequate residue cover and residue management
- good seed/transplant placement and crop establishment
- timely and aggressive weed control strategies
- management of soil compaction

Adequate Residue Cover

Adequate residue cover is needed in conservation tillage systems not only to reduce erosion but also to restore soil biology and enhance crop productivity. In addition to reducing erosion, a good residue cover:

- decreases raindrop impact and the potential for surface-soil crusting
- increases rainfall and irrigation infiltration into the soil
- decreases soil-water evaporation
- decreases soil temperature

A very high-residue cover can also aid in weed management. There are two proven methods for producing adequate surface residues. The first is rotating cash crops such as corn and small grains that leave a large amount of stalks that slowly decompose on the soil surface. Examples of common rotations that include high-residue crops are a one-year wheat>soybean rotation and a two-year corn>wheat>soybean rotation.

The second proven way to produce residues is to use cover crops. Common species of winter cover crops include small grains such as rye, wheat and oats; and legumes such as clovers, peas and vetches. Summer cover crops are also grown, primarily in rotations with vegetables or other short-duration rotations. Cowpeas, millet and sorghum-sudan grass are used for summer cover crops.

For a winter cover crop, rye is often used because it is more cold tolerant than the other small grains. Because of this, it can produce more biomass in the spring before it is killed. Small-grain cover crops may need a small amount of nitrogen fertilizer to produce adequate residue cover. Nitrogen fertilizer is not applied when cover crops follow legumes, such as soybeans or peanuts. Similarly, nitrogen is not applied to a cover crop that follows a non-legume cash crop that had low yield due to drought. The cover crop will use the nitrogen left in the soil after the cash-crop harvest.

Legume cover crops are planted to produce nitrogen for the subsequent crop. For best results when choosing a winter legume, match the cover crop species to the field's plant hardiness zone. Growers can expect legumes to provide 50–100 pounds of nitrogen per acre to the subsequent crop under most growing conditions.

Crop Establishment

Higher crop yields and easier crop maintenance generally result when stands are uniform and seedlings grow vigorously. Successful conservation tillage planting or transplanting really begins at the harvest of the previous crop. Harvesting when the soil is too wet is avoided because it can result in ruts. Evenly distributed residues yield the best results. Planters have difficulty accurately placing seed into the soil when residues are not evenly distributed and there are residue mats.

Careful management of vegetation between crops is also important because the coarse-textured soils in these MLRAS do not store much water, only about 1 inch of water in the top 12 inches. The vegetation between crops is managed so the seedbed soil water is not depleted before the next crop is planted. Most recommendations call for cover crops or weeds to be killed two to four weeks prior to planting the cash crop. If conditions are dry and long-range weather forecasts indicate only a small chance of rain, then vegetation is killed earlier to reduce the depletion of soil water. This is especially critical in fields that are not irrigated. On the other hand, if precipitation is abundant and soil conditions are wet, letting the vegetation grow longer will help dry out the fields and will allow planting equipment to get in the fields sooner.

Planting or transplanting is done with equipment designed for conservation tillage systems. Settings are adjustable to match soil-water conditions and the composition and thickness of residue in the field. Drills and planters must:

- cut through the crop residue and soil
- place seed at a uniform spacing and depth
- completely cover or close the seed slot
- firm the soil around the seed

For planters, row cleaners can be used to move residues out of the row. This facilitates planting and allows for the soil around the seed to warm faster. If row cleaners are not used or when planting crops with drills, it is best to wait until the residue is dry to plant seeds. When residue is wet, coulters can push the residue into the seed slot rather than cutting through the residue as they are designed to do. This is called hairpinning. Hairpinning keeps seed from reaching the proper depth, inhibits closing of the slot and prevents good seed-soil contact. This is a common cause of poor stands in conservation tillage systems.

Crops established as seedlings are common in the Southern Coastal Plain and Atlantic Coast Flatwoods MLRAs. Researchers at Virginia Tech have developed a transplanter that can be used with high-residue, allowing for conservation tillage to be used for tobacco and other transplanted crops [8]. Named the Subsurface Tiller Transplanter (SST-T), the implement allows for more efficient and effective planting than previous transplant systems, provides higher capacity to set plants in heavy residues, and reduces the disturbance of surface residues [8].

Weed Management

Weed management in the Southern Coastal Plain and Atlantic Coast Flatwoods is similar to other MLRAs. However, all interviewed producers identified herbicide-resistant weeds as the most important challenge in the future. After years of successful no-till production, one of the interviewed producers, Kirk Brock, stated that herbicide-resistant weeds could be the reason to return to conventional tillage.

Herbicides are the main tool for managing weeds in most conservation tillage systems. Repeated use of the same herbicides has resulted in herbicide-resistant weeds such as Palmer amaranth. Management of herbicide-resistant weeds in conservation tillage fields is difficult. Multiple applications of herbicides with different modes of action are needed, including residual pre-emergent chemicals. High-biomass cover crops such as wheat or rye cover the soil surface and aid in weed suppression. During the growing season, fields are routinely scouted and if small pockets of potentially herbicide-resistant weeds are found they are removed. For example, if Palmer amaranth stands are found that are close to mature and suspected of being glyphosate resistant, the plants are removed from the field to eliminate the chance of reseeding.

Glyphosate-resistant Palmer amaranth is not the only herbicide-resistant weed species found in the Southern Coastal Plain and Atlantic Coast Flatwoods. Other weeds in the region that have been found to be herbicide resistant include goosegrass, common cocklebur, Italian ryegrass, prickly sida, smooth pigweed, lambsquarters and horseweed. These weeds and associated herbicide modes of action are identified in Table 11.2. Information on herbicide-resistant weeds and herbicide resistance can also be found at weedscience.org, a website documenting herbicide resistance internationally [4].

Use the following management guidelines [7] to help delay herbicide resistance in weeds:

- Rotate classes of herbicides used to control the same weeds.
- Tank mix a combination of herbicides that

have different modes of action.

- Use Integrated Pest Management (IPM), including scouting, crop rotations and other cultural or biological control practices.
- Monitor fields for weeds that have not been successfully controlled by prior herbicide applications, and control them before they set seed.
- Clean harvesting and other equipment to prevent moving resistant weed seeds between fields.

For more information on weed management, see Chapter 11.

Soil Compaction Management

Many of the soils in the Southern Coastal Plain and Atlantic Coast Flatwoods are coarse textured, highly weathered and inherently low in fertility. These soil properties, combined with hot summers and years of tillage, have resulted in soils that are low in organic matter. This makes the surface soils prone to compaction from machinery, trucks and rainfall. Also, the soils often have a subsurface hardpan, the E horizon, that limits root growth to the upper 12 inches. Surface traffic, especially when soils are wet, can increase subsoil compaction.

To alleviate subsurface compaction, subsoiling implements are often used. One such implement is an in-row subsoiler that consists of a shank that penetrates 10–16 inches into the soil. Since 1970, Extension specialists throughout the Southeast have recommended subsoiling for row crops grown on soils with a hardpan layer [11]. Because of compaction, conservation tillage equipment developed for other parts of the nation did not work well in the Southern Coastal Plain and the Atlantic Coast Flatwoods. Some researchers [14] have attributed the slower adoption of conservation tillage in these two MLRAs to problems associated with root penetration through the eluviated hard pan. Conservation tillage equipment capable of planting in these soils finally became available in the late 1970s. That is when the “No-Till Plus” implement was introduced by Harden et al [3]. This implement combined in-row subsoiling with no-till planting for a one-pass subsoiling-planting operation. The implement consisted of a no-till coulter, a subsoiler shank, a wheel to close the slit behind the shank, a double disc opener that places seed directly over the slit and a packing wheel to firm the soil around the seed [3].

Since the introduction of the No-Till Plus planter, many variations of planting and subsoiling equipment have been used. There are many planting and compaction management strategies:

- No-till planting is a viable option for soils without compaction problems. This is usually accomplished with just a coulter in front of the planter to open the seed furrow.
- In-row strip tillage is similar to the No-Till Plus system and is often called a version of strip tillage. In this system, a coulter is followed by a narrow shank called a ripper. The ripper tills to a depth of 10–16 inches and leaves a slit in the soil that is closed by packing wheels or other equipment. Often, planters are attached for a one-pass planting operation.
- Strip-tillage is widely used for row-crop planting. Strip-tillage rigs consist of coulters, rolling baskets, spider gangs, firming wheels and other devices. The tilled zone is 6–12 inches wide and 6–8 inches deep.
- Fall or winter ripping, followed by no-till planting in the spring, is also widely used. In this practice, compacted layers are loosened with straight-shank subsoilers or bent-legged subsoilers, such as the paratill.
- For drilled crops like winter small grains, bent-legged subsoilers can be used before the crop is planted to disrupt more of the soil profile than straight-shank implements. If used prior to planting the preceding summer crop, running the implement again may not be necessary in the fall unless the small grain is being managed for high yield.

Subsoiling is expensive, especially since tractor horsepower requirements are generally over 25 horsepower per shank, depending on the implement. Thus, it is critical that their use be optimized. Subsoilers are run so that the E horizon is disrupted, but no deeper. Generally, this is just at the top of the B horizon. Deeper tillage requires more energy and probably will not result in increased crop yields. If the tillage is too shallow, root growth will be limited. Checking soil compaction levels before tillage with a penetrometer can determine the depth of tillage necessary. Penetrometers can also tell whether subsoiling is needed. For example, if employing controlled traffic and planting near the row subsoiled the previous season, the penetrometer can determine if subsoiling is needed in the row again.

Another way to reduce subsoil compaction is to include deep-rooted annuals and perennials in the crop rotation. The roots provide channels for root development through the restrictive layer by subsequent crops.

Enterprise Budgets

Most universities with agricultural programs provide crop enterprise budgets to help determine which production systems and practices are most economical for a farm. Budgets take into consideration both fixed and variable costs and provide projected incomes at different yield levels and prices. For example, Clemson University provides crop enterprise budgets for the major row crops grown in South Carolina, with more options for crops that have the most acreage in the state. There are five budget options for corn through which farmers can calculate net economic returns at different yields, with or without irrigation, with conventional or conservation tillage, and with or without using new genetic technologies. There are nine budgets for cotton that differ in similar variables. In contrast, only one or two budget options are available for crops like tobacco, oats and barley. The comparison between conservation tillage and conventional tillage is available for all major crops grown in South Carolina except tobacco, oats and barley. In conservation tillage, the following variable costs are different than the costs in conventional tillage: land preparation, herbicides, machinery and labor. Fixed costs for tractors and machinery are also different in the two systems.

Other Considerations Specific to the Region

The adoption of conservation tillage practices by growers in the two MLRAs was slower than in other MLRAs. In addition to the compaction problems, there was little environmental incentive to adopt the technology because the soils are generally flat and water erosion is less than in other MLRAs. Rotations with crops that are dug are common in the two regions. Peanuts are widely grown throughout the two MLRAs, and sweet potatoes occupy a significant acreage, especially in North Carolina. There were two concerns about using conservation tillage for these crops. One was the ability of crops to properly grow in fields with high residues. For example, pegging in peanuts can be inhibited by surface residues. The second concern was digging- and harvesting-equipment operating properly.

Another reason for slower adoption of conservation tillage was that research found small differences in yield between conservation and conventional tillage systems. This is contrary to research results from other MLRAs, especially the Southern Piedmont. For example, North Carolina studies in the 1980s conducted in the Southern Coastal Plain found that corn grown with conservation tillage had higher yield than conventional tillage in only one of five years. There was no yield difference between conventional and conservation tillage in any of the five years for soybeans [17]. Another study in South Carolina on the Southern Coastal Plain [6] reported lower yield of wheat when conservation tillage was used than when moldboard plowing or chisel plowing was used. Researchers attributed part of the lower no-till yield to the inability to get uniform stands with the drill they used in that study. With this experience, agricultural advisors in the region were less aggressive in promoting conservation tillage than advisors in other regions.

Long-term experiments in the region are providing evidence that using conservation tillage slowly improves soil characteristics. In Florence, S.C., organic matter in the top 2 inches of soil in conservation tillage was 76 percent higher than soil in conventional tillage. This is based on a study of soil properties after 25 years of conventional and conservation tillage. The soil organic carbon under conventional tillage was 0.95 percent and was 1.67 percent under conservation tillage [1]. In this experiment, high-residue crops were grown in every year of the study. It included a two-year rotation of small grains double-cropped with soybeans followed by corn in the second year (small grains>soybeans>corn). Cotton replaced soybeans in five years of the study. Contrary to what has been found in other regions, analysis of the trend over 25 years showed that soil organic matter levels were continuing to increase in the top 2 inches of the soil in those plots [10]. This analysis indicates the need for continuous conservation tillage on these soils for maximum soil improvements.

Building soil organic matter in these soils improves the biological and chemical properties of the soil. Low soil organic matter makes the soil prone to compaction, and as compaction increases, bulk density increases. A long-term study (1996–2003) in Goldsboro, N.C., found that conservation tillage increased organic matter and decreased soil bulk density in the surface 2 inches of soil compared to conventional tillage. It also found a strong inverse correlation between soil organic matter and bulk density [9]. However, the soils managed with conservation tillage had lower soil organic matter at the 2- to 5-inch depth and higher bulk density in that layer if the soils had low silt content. In coarse-textured soils, 2.16 percent soil organic matter (1.25 percent organic carbon) is needed to keep bulk density at levels where root activity is not inhibited in the 2- to 5-inch depth range.

Sod-based rotations also increase soil quality in conservation tillage systems. The University of Florida has developed a new crop rotation scheme for irrigated production that has higher economic viability than conventional production. In this four-year rotation, two years of bahiagrass are followed by one year of cotton and one year of peanuts. Cover crops are grown during the winter following cotton and peanuts. The bahiagrass is either grazed or baled for hay. Although this is not a “permanent” conservation tillage rotation because the peanuts must be dug, the system does provide long-term soil improvements. In experiments, the soil organic matter in the top 6 inches of soil increased 0.1 percent per year [18]. See Chapter 8 for more information about sod-based rotations with grazing.

CASE STUDY FARMS

Editor’s note: These case studies are based on interviews from November 2008–March 2009. The case studies on the Davis and Brock farms were updated in 2018.

The case study farms were chosen by Natural Resources Conservation Service (NRCS) field staff based on the producers’ conservation tillage experiences and their willingness to contribute their time. The income sources on these farms range from substantial off-farm income to exclusively on-farm income. Some farms work very closely with university Extension and participate in university research and demonstrations. Others only use Extension publications, websites and/or enterprise budgets and do not participate in research or demonstrations.

Conservation tillage is commonly used in the interviewed producers’ communities. In some cases, estimates of local acreage in conservation tillage were 90 percent or greater. Other than herbicide-resistant weeds, the interviewed producers did not see significant barriers to the adoption and use of conservation tillage. The seven case study farms are described below.

The Davis Farm, Paul and Boogie Davis, New Kent, Virginia

Paul Davis works as an agricultural Extension agent, and along with his father, Boogie, he operates a grain and specialty crop farm in eastern Virginia. The 250-acre field crop and specialty crop farm is located in the upper portion of the Southern Coastal Plain. Most of the farm, 235 acres, is in a two-year corn and double-cropped wheat and soybean rotation, corn>wheat>soybeans. Pumpkins are grown on an additional 15 acres. The pumpkins are rotated with other crops and are not always grown on the same field.

The Davises began using a no-till system to plant corn and soybeans in the mid-1970s but continued to till before planting wheat and specialty crops. In 1999, they started a continuous no-till system that includes no-till small grains and pumpkins. The only tillage on the Davis Farm is the occasional smoothing of areas rutted during harvest. Cover crops were added in 2005. A cover crop or a small grain for harvest is grown on every acre during the winter.

The soil types are Bojac and Pamunky sandy loam or loamy sands with slopes of 2–4 percent. Soil pH is typically 6.5 or higher. They have used biosolids from wastewater treatment facilities and plan to continue to do so. However, they do not use lime-adjusted biosolids because that would increase the pH too much and would tie up micronutrients, especially manganese. They do not use animal manures. The Davises started using the Green Seeker variable rate nitrogen-fertilizer application technology to more accurately apply nitrogen fertilizer to their small grains. They have been involved with a Conservation Innovation Grant, a SARE grant, and other research and demonstration projects.

The Brock Farm, Kirk Brock and Gene Brock, Monticello, Florida

The Brock Farm is located in the southern range of the Southern Coastal Plain. The Brocks own approximately 450 acres and rent 500 acres. There are approximately 75 fields ranging in size from 1–100 acres. Most fields are 5–15 acres. The farm stopped animal operations in 2001 and all open land is currently used for field crop production. Usually four crops are grown: peanuts, corn, soybeans and cotton. However, cotton is not planted in some years. The acreage planted to each crop is more or less evenly distributed. When there is a four-crop rotation, approximately 25 percent of the fields are in each crop. When there is a three-crop rotation, approximately one third of the fields are in each crop. Rye is planted each fall on all acreage as a cover crop (Figure 18.3). Brock is experimenting with other cover crops, including crimson clover alone or in a blend with cereal rye or ryegrass, or with both.

The more common soils are Dothan, Fuguay and Orangeburg, with Pellam and Rains in the low spots. Slopes are typically 0–7 percent. The natural pH is 4.5–5.8, but the pH of cropland on the farm is maintained at 6.5–6.8 through liming.

FIGURE 18.3. Planting corn into a rolled/crimped rye cover crop on the Brock Farm. *Photo courtesy Drew Demott, USDA NRCS.*

Organic matter ranges from 0.6–0.9 percent on most fields and from 1.5–2 percent on the old pastureland that is now used for crops.

Bottom (moldboard) plowing was abandoned in 1976 for corn, soybeans and cotton but was used for peanut production up to the early 1990s. The transition to strip-till/no-till on the Brock Farm began in 2001. The Brocks sample their soil every third year. During the interview, the Brocks cited literature references they used to plan their no-till and cover crop activities.

Triple J Farm, Dalzell, South Carolina

William, Whit and Hastings James own and operate a farm located in the Southern Coastal Plain region in South Carolina. Their farm has four major enterprises: cash crops, a peanut-buying station, a cotton gin and a granary. The cash crops are:

- corn and soybeans, planted in 30-inch rows using true no-till and supplemental irrigation
- cotton and peanuts, planted in 38-inch rows using strip-till and supplemental irrigation
- wheat, planted using conventional tillage with no irrigation

Soybeans follow wheat in a double-crop system when wheat is planted in the fall. The crop rotation is generally corn>cotton>peanuts>soybeans. Wheat is grown on a field once every 6–10 years. Disking before wheat is seen as a necessity in order to level out tractor and irrigation wheel track ruts accumulated during the previous years. Although ruts occur, the fields do not have erosion rills or gullies. Irrigation water does gather in the equipment ruts. The farm does not use cover crops, although the Jameses have considered it.

Cotton requires warmer soil for seed germination than the other crops. No-till keeps the ground cool longer into the growing season, which presents a concern for cotton-seed germination and stand establishment. So, the farm uses strip-tillage when growing cotton. Strips 11–14 inches wide are tilled in order to allow the seedbed to warm. Seed placement for cotton and peanuts is more critical than other crops, and planting into a tilled strip allows more-accurate seed placement.

The cash crops are grown on approximately 1,800 acres, most of which are rented annually. When the James brothers want to install irrigation, they sign a 10-year lease for the cropland. Annual land rentals are very stable in this area. A renter is fairly sure they will be able to rent the same land for several years, so the James brothers are more inclined to improve soil health on rented land, because they are likely to see the benefits in future years. The common soil types are Norfolk and Orangeburg loamy sands. Soil pH is typically 5.5 or higher, and organic matter ranges from 0.5–1.5 percent on most fields.

The farm often uses NRCS and Clemson University Cooperative Extension Service (CES) for assistance. Triple J Farm also participates in CES research. The farm is currently providing peanut production records to CES.

The Rawlins Farm, Rebecca, Georgia

Bob Rawlins farms approximately 450 irrigated and dryland acres in the central Southern Coastal Plain region of Georgia. The farm also has a cow-calf operation with approximately 200 cows. Additionally, Rawlins has a tree planting business that takes up a considerable amount of his time during the winter months.

Some fields with steep slopes were terraced when conventional tillage was used, and the terraces are still there. Some of the cover crop acreage close to the pastures is grazed to provide winter forage. The irrigated acreage is approximately evenly split between silage corn, peanuts and cotton. Watermelons are double-cropped with silage corn for a three-year watermelon>silage corn>peanut>cotton rotation. Rawlins uses herbicide-resistant varieties of cotton and corn, and Bt corn. Bt corn includes a gene that produces a protein that kills the European corn borer. The crop rotation takes disease potential into account by keeping peanuts and watermelons separated by corn or cotton. It is recommended that there be three to four years between peanut crops to help minimize disease pressure and pest pressure, especially nematode pressure [5]. However, the typical two-year rotation on the dryland fields is cotton>peanuts.

Most of the cropland on the Rawlins farm is Tifton loamy sand on slopes of 2–10 percent. Rawlins has been reading *No-Till Farmer* magazine for a long time.

The Dargan Farm, Darlington, South Carolina

This farm is located in Darlington County, which has land in both the Southern Coastal Plain and Atlantic Coast Flatwoods. The farm has two enterprises: turf grown on approximately 300 acres and cash crops grown on approximately 1,700 acres. Cash crops include wheat, soybeans, corn and cotton. Approximately 60 percent of the cash crop acreage is rented. Tobacco had been a major crop on this farm for many years, but they stopped production two years ago. This change in operation has allowed the Dargan Farm to implement continuous no-till on a greater amount of acreage. This farm has broadcast-planted rye cover crops for a number of years.

Edwin Dargan and his son work closely with the scientists at the Coastal Plains Research Station operated by the Agricultural Research Service (ARS), specialists at CES and consultants with Southern States Cooperative. The Dargan Farm has implemented newer technologies such as variable-rate irrigation and variable-rate nutrient application.

The Winslow Farm, Scotland Neck, North Carolina

The Winslow Farm, operated by Jack and Herb Winslow, is located in the upper portion of the Southern Coastal Plain, has always produced row crops and previously had a 2,000-sow operation. Currently, 2,200 acres are in row crops and the farm has maintained 400 acres of sod production since 1996. In 1986, Jack Winslow received the national Conservationist of the Year award from the National Association of Conservation Districts (NACD). At one time this farm had the largest subsurface irrigation system in the United States. For the remainder of the chapter, all comments about the Winslow farm were made by Herb Winslow.

The farm had been in no-till for about 20 years. Then, in 2006 the Winslow Farm became certified organic. Initially they attempted to use no-till in the organic system but experienced challenges for which technology was not yet available. The challenges were primarily weeds, but they also included residue accumulation that could limit the effectiveness of planting and harvesting equipment, and excessively cool soil temperatures at planting. The farm has returned to conventional tillage to maintain their organic certification. Now the farm is experiencing the downsides of conventional tillage, especially a degradation of soil biota that is addressed by applying compost extract.

The organic corn and soybeans go to Braswell Milling for organic chicken feed. The organic wheat goes to a Charlotte bakery. The manure from Braswell Milling's organic chicken operation (layers) is used on the Winslow Farm as a fertilizer. The Winslow Farm conducts test plots for organic corn demonstrations and continually samples soil and plant tissue for liming and nutrient needs. The Winslow brothers designed and built their own compost extraction process.

The Harris Farm, Littleton, North Carolina

The Harris Farm includes cropland in the Southern Piedmont and in the upper portion of the Southern Coastal Plain. Tom Harris's comments were in consideration of both regions. This farm has 75–80 Black Angus brood cows. The primary rotation has wheat double-cropped with soybeans for a three-year rotation of wheat>soybeans>corn>peanuts. However, Harris often deviates from this rotation as commodity prices and feed needs of the farm change. At times, pastures are rotated with crops in a sod-based rotation system.

Harris began conservation tillage in 1993 using strip-tillage. He subsoils, strip-tills a 6-inch wide strip and plants in the strip. He relies heavily on cover crops, compost, manure, crop residues and sod rotations. This has allowed him to achieve high yields of quality products using little commercial fertilizer.

PRODUCER EXPERIENCES

The interviewed producers had various experiences. No-till did not look the same on every farm. For example, some found that residue amount and height were concerns, but Triple J Farm did not experience this. Some found they needed additional nitrogen during the first years of conservation tillage, but others did not.

There were common experiences. Producers from all seven farms experienced labor and fuel savings, and enhanced soil quality. They have all become concerned about herbicide-resistant weeds. Most producers learned at least some facts about no-till from *No-Till Farmer* magazine, no-till production symposiums and experiences of other producers.

Producer experiences are described below. First, their perspectives on two no-till myths are discussed. Then the experiences concerning the transition to no-till, changes to the farms' natural resources, changes in agricultural production and specialty crops are reviewed. The producers give their perspective on why they changed to no-till production and discuss their vision for the future of no-till.

Myth No. 1: No-till is more difficult and requires more equipment adjustments than conventional tillage.

The Brocks, when comparing conventional tillage to no-till, listed the adjustments they had to make with conventional tillage. After listing the adjustments, they concluded that no-till did not require more adjustments, just different adjustments. They readily recalled about a dozen conventional tillage adjustments they had to make. Six are listed below:

- adjustments in tillage methods for different soil conditions, weather and crops
- adjustments to move dry dirt out of the way of the planter
- adjustments to manage crusting of the clean-tilled soil
- adjustments to the closing wheels on the planters
- adjustments to ensure that the seed-to-soil contact was sufficient and that the seeds were covered
- adjustments to reduce soil compaction

Myth No. 2: "No-till, No Yield."

More recently, this myth has come to mean "no-till, no yield in the first years." But, no producer interviewed reported significant yield losses even during the first years. The Davises and Brocks have observed that when the producer studies no-till before trying it, yield will not decline because of no-till. In fact, Triple J Farm experienced some modest gains in the first years, and no losses. Producers learn about no-till by talking with local no-till farmers and their advisors, and by reading *No-Till Farmer* magazine and other publications. In addition to learning about no-till before starting, producers had additional suggestions for preventing yield losses as described in the following sections.

Field Preparation and Planting

Prepare the field for proper seed placement and check the planting depth during planting. Paul Davis says that in Virginia, shallow seed placement of wheat could result in a 50 percent yield loss due to freezing. To prevent this, he smooths out field rills and ruts to make seed placement more uniform. If needed, he performs a last tillage incorporating lime and other soil amendments before the field is smoothed. Dargan and other producers state that when the soil is too rough, they do not get a good crop stand.

Check the residue for proper seed placement. Make sure the residue is uniformly distributed over the field after the field is smoothed. The Davises find that uniform residue depth keeps the seed-placement depth constant and thus removes one reason for yield loss. Kirk Brock rolls some residues to achieve a uniform depth. If residue builds excessively, producers either bush-hog or flail mow the field. Rawlins agrees that uniform distribution of residues is a key to good seed placement. Dargan and others say that cotton-seed placement is more critical than seed placement for other crops. Thus, residue-depth uniformity is very important for cotton planting.

Triple J Farm does not have any problems with residue management since solving the concerns about residue flow around the subsoil shafts in their first year of no-till.

Scout the Field Often

Frequently check the no-till field for seed emergence. If seed emergence is too low and it is detected early, replant to reduce yield loss.

Scout for weeds early in the season. Consider using herbicide-resistant crops to make chemical actions more effective. Remember that over dependence on a specific herbicide can lead to herbicide resistance in weeds.

Check the crops frequently. All of the producers spent more time than usual in the field during the first year to monitor crop progress. It was a new system and they did not know how it would perform.

Equipment

Buy or rent good equipment and use it correctly. The Davises suggest purchasing equipment that adjusts easily and maintains the adjustments as it moves over the field. Good equipment, adjusted properly, results in seed placement at a uniform depth.

Rawlins points out that equipment that might be good for the Midwest may not be appropriate for the Southeast. For example, the rototiller used in the Midwest for strip-till did nothing to break up Georgia clay. Rawlins purchased a used Brown-Harden Super Seeder planter with in-row subsoilers for his strip-till operations.

Feed the Soil Ecosystem

To feed the soil ecosystem, some producers apply nitrogen, some plant high-residue crops, some plant cover crops and one uses a compost extract. During the first years, the increased amount of residue ties up nitrogen because there are too few soil organisms to process the residue. The Davises applied additional nitrogen fertilizer in the first years. Applying nitrogen and/or inoculating with compost extract hastens the growth and diversity of soil organisms. This transforms soil organic matter and releases nutrients.

Find a Mentor

Find a mentor with no-till experience. The mentor can be an agricultural Extension agent or a successful no-till producer. Talk with your mentor whenever there is a doubt or a question. “Don’t make the same mistakes that have already been made,” says Kirk Brock. According to William James, another reason to find a mentor is, “Nothing ever goes as smoothly as you hear.”

Transition to No-Till

The producer recommendations with regard to myth No. 2 are important parts of a successful transition from conventional tillage to no-till. However, there are other aspects of the transition that are important. The steep part of the learning curve occurs during the first three to five years. Most interviewed producers, however, state that they are still learning and are really still in transition. This is because they are working with a dynamic biological soil system and continue to learn what that means. The following three observations concern getting through the steep part of the learning curve.

Determination

Interviewed producers state that the most important requirement for a successful transition was determination: a commitment to make it work. “You have to want no-till to work,” says Kirk Brock. “Determination to make no-till work is a key,” says Bob Rawlins. Determination means monitoring the fields, looking for seed placement problems early enough to make adjustments, monitoring to catch weeds early and seeking advice at the first sign of trouble.

Although it was 30 years ago, William James from Triple J Farm readily remembers his first year of no-till. “The subsoilers on the planting rig pulled up large clods of clay and the wheat straw balled up on the subsoiler shanks,” he says. “The dry weather that year made the problem worse.” It was such a mess that James thought they might not do no-till again. However, James experimented and minimized these problems by putting a piece of black plastic pipe over each of the subsoiler shanks. This aided the flow of the straw to the sides of the subsoiler shaft and prevented the clods of clay from being pulled to the surface.

Triple J Farm suggests that the key is to “get the first stand.” If determination can get the producer to the first successful stand, then the transition will appear feasible.

NRCS field observations indicate that farmers who start with only a small portion of their acreage in no-till often fail. Starting small means that most of the farm, still in conventional tillage, receives most of the attention because it produces most of the revenue. The small “test” plot of no-till tends to be ignored, which tends to result in failure.

Mindset

To be successful, producers must change their mindset about production. Paul Davis explains one mindset change concerning soil. Soil is more than a substance that physically keeps plants erect. Soil is an ecosystem that works with the plants to use nature’s resources in agricultural production. New instincts about farming develop. However, if the mindset is to return to conventional tillage at the first problem, then the transition will be unsuccessful. No-till requires perpetual fine-tuning as the soil ecosystem changes. Eventually the producer becomes more comfortable with less soil contact and less soil disturbance.

The Brocks, Rawlins and others point out that the no-till mindset requires patience and a longer planning time horizon. With a 20-year planning horizon for conventional tillage, the major variables are weather and prices (input and output prices). The dead soil from years of conventional tillage is rather stable and requires approximately the same inputs from one year to the next. However, a 20-year plan for no-till has three major variables: weather, prices and soil biology. The living soil changes over time in terms of biological diversity and population. No-till production works with, and needs to be mindful of, changes in soil biology. For example, during the transition, the need for fertilizer diminishes as the soil biology builds and provides a larger pool of nutrients for the next crop. Also, the symbiotic relationship of some soil fungi with plant roots enhances the ability of the plant to take up the available nutrients.

Cover Crop

Some of the producers have observed that a winter cover crop results in a faster transition to a healthy soil. When considering no-till, check if local conditions indicate that a cover crop would be part of a successful transition. The Brocks state that cover crops are key to the success of no-till on their soils. They now observe rye cover crop roots 60 inches deep, which enhances permeability.

Changes in Natural Resources

Interviewed producers have observed changes to their farms’ natural resources. This section includes their comments on these changes.

Soil Quality and Quantity

After three to four years of continuous no-till, the Davis Farm fields softened. There was no crusting and the plant residues were soft. When the soil is softer, there are more soil pores for water movement, increasing water infiltration.

“The soil does not leave the farm anymore,” says Rawlins, adding that it also does not crust over and it has fewer clay clods. Triple J Farm saw soil health noticeably improve in a few years. Dargan reports that his fields are smoother with less ponding, less dust, fewer rills and cooler soil temperature.

The Davises noticed fewer rills within the first three years. There are no field repairs to make and fewer drainage ditches to maintain. Equipment damage from field ruts and rills has been eliminated.

Reduced Flooding and Ponding

The increased soil softness reduces incidence of flooding and ponding, and increases water infiltration. Continuous no-till has practically eliminated runoff on the Davis Farm. On the Brock Farm, with conventional tillage, even a quarter-inch storm produced runoff. With no-till, a 6-inch rain produces very limited runoff. With more soil organisms and more healthy plant roots, there are more soil pores, especially macro-pores, through which water moves. When there is runoff, it is clear. Within the first three years, there were fewer rills in the field.

Increased Earthworms

Poking into the soil of the Davis Farm will typically reveal at least one earthworm and usually reveals several. Paul Davis reports this was a significant change.

Groundwater Quality

When the runoff is clear, the question is: Are the nutrients leaching into the groundwater? The Davis Farm, working with Virginia Tech and the local soil and water conservation district (SWCD), installed 12 lysimeters on the farm to measure nitrogen leaching through the soil to the groundwater. For four years, samples were taken after significant rainfall events. So far, no difference has been measured in nitrogen leaching between the tilled and the continuously no-tilled fields. That is, reducing runoff did not increase nitrogen leaching to the groundwater.

Air Quality

All producers interviewed have noticed a reduction of dust.

Changes in Agricultural Production

Changing from conventional tillage to no-till results in several changes in the crop production system. In this section, the producers' observations concerning these changes are reviewed.

Decreased Fuel Consumption

Fuel consumption is less with no-till even though more fuel is used applying herbicides to kill weeds. Spraying uses less fuel than plowing or disking, says Paul Davis. The increased soil softness reduces the soil's resistance to planting, thereby reducing the amount of fuel needed to plant.

Increased Flexibility

The reduced incidence of ponding enables producers to get into the field more frequently. As Paul Davis says, the producer is "not handcuffed to muddy soils." For the Brock Farm, no-till builds firmer soils with less bogging, smoother fields and less bouncing of the equipment. Thus, no-till increases the flexibility in timing for both planting and harvesting operations.

Seed Germination

The residue from no-till keeps soils cooler longer. Some crops, such as cotton, need warmer soils to germinate. The softer soil from no-till makes seed germination rates higher, according to Rawlins.

Improved Plant Health

No-till soil holds more moisture than conventionally tilled soil. Increased soil moisture is especially beneficial during periods of drought.

The Davises, experiencing a significant drought in the past two years (2007–2008), observed that the neighbor's conventionally tilled corn wilted seven days sooner than theirs. The Davis Farm yielded 25 percent more corn and 5–10 percent more soybeans in a dry year when compared with conventionally tilled fields.

Rawlins states that there is less disease because less soil and spores are splashed onto the plants. Winslow states that pests and diseases do not bother them anymore because the healthy soil biology has produced healthier crops. "Healthy plants resist bugs and disease," he says. He also suggests that other organic producers have problems with bugs and disease because "they are organic by neglect." He means that some organic producers removed the chemicals but have not actively managed the soil ecosystem.

The Brock Farm has not had a corn crop failure since moving to no-till. With conventional tillage, the Brock Farm experienced more variability in corn yield when compared with no-till and a cover crop. During years when corn yields are low, the no-till system has higher yields and is more profitable than the conventional system.

Improved Product Quality

Conservation tillage has improved the quality of the pumpkins grown on the Davis Farm and the watermelons grown on the Rawlins Farm. The pumpkins and watermelons are lying on straw instead of dirt. They have fewer "belly rot" spots as a result. Also, the fruit color is more uniform and the surface of the fruit is free of soil material.

Equipment

The Davis Farm made a few equipment changes. They traded the conventional grain drill for a Great Plains 10-foot No-Till Drill. "Ten foot" refers to the width of the implement. They attached a "chaff spreader" on the back of the combine to prevent residue piles from forming and to spread the residue evenly over the field.

The Brocks and other producers found that they use smaller tractors with conservation tillage. Conventional tillage requires more horsepower and diesel to break up the crusts and clods. The Brock Farm fabricated its own roller/crimper for killing cover crops because none meeting their specifications were available at that time.

All interviewed producers state that there is less equipment in use. The following characteristics reduce maintenance and operating costs. The tractors are used less frequently and can be smaller. The equipment stays cleaner because there is less dust and mud. Since there are fewer rills in the field, there is less equipment damage due to rills and ruts. Fuel costs decline because there are fewer field passes.

However, some maintenance costs increase. At the Davis Farm, no-till residue increases tire damage because the equipment operator cannot readily see deer antlers or other debris when it is covered by residue. Last year the Davis Farm experienced four flat tires. Previously, with bare soil, the operator saw the debris and picked it up.

Field Operations Costs

There are fewer maintenance costs for drainage ditches and waterways. The Rawlins Farm has terraces and the strip-till operations have significantly reduced terrace maintenance.

Pesticide Use

This includes herbicides, insecticides and fungicides. The residues tie up some of the pesticides by absorbing them, and they may harbor volunteer small-grain crops that need to be killed. The Davises suggest that very young volunteer plants may harbor insects that could pass to the next cash crop. Thus, pesticide use has increased on the Davis Farm. However, the producers in general did not experience an increase in plant pests. Grasshoppers were noted as a potential crop pest. However, belly rot on Rawlins' watermelons and tomato spotted virus in Triple J Farm's peanuts were reduced with no-till without an increase in the amount of pesticide applied. The Davis Farm did not experience an increase in wireworms or slugs, which have been a problem for no-till corn seedlings in cooler climates.

Labor

Most producers have observed reduced labor costs when comparing no-till with conventional tillage. In fact, labor savings was the major reason some of the producers changed to no-till. Labor savings are not just wages. Hiring labor requires transactional costs, meaning the costs of hiring and then managing the labor. For example, in the eastern part of Virginia, agricultural labor is mostly people who have retired from other careers. They need training and their mistakes must be corrected. Hired labor requires paperwork for citizenship and taxes. Lastly, labor is a management burden. Thus, having to hire fewer people means lower transaction costs as well as lower wage costs.

"Paying for helpers is like paying for a house," says Rawlins. With no-till, Rawlins can significantly reduce his seasonal labor and accomplish more on the farm with existing, permanent labor. Because of the time saved with no-till, Rawlins operates a tree planting service, harvests more watermelons and spends less money on farm labor.

Paul Davis is able to work as a full-time county agricultural agent and still farm with his father without hiring temporary labor for the field crops. With no-till, the Davis Farm can use its hired labor budget for planting and harvesting higher-value crops such as pumpkins.

Triple J Farm says that no-till planting is slower than planting in conventional tillage: 4 miles per hour compared to 5–6 miles per hour. However, no-till still requires less time than conventional tillage overall. No-till has brought more flexibility to the whole farm because labor can move from one enterprise to another as needs change. On a multi-enterprise farm such as Triple J, no-till flexibility brings benefits to the whole farm operation.

The labor requirement has not changed on the Brock Farm, which always uses cover crops in its no-till operations.

Lime

Before no-till, the Davis Farm applied lime every three years. They now apply lime every four to five years.

Planting Dates

No-till on its own does not change planting dates. However, no-till with cover crops can result in a change in planting dates. The Davis Farm in Virginia must plant the cover crop soon enough before winter to get effective cover. Cover crop planting can force the producer to harvest the cash crop sooner. The use of cover crops and Bt corn varieties has allowed the Brock Farm to shift the planting date of corn later into the summer, which takes advantage of early summer rainfall. With a cover crop, more soil moisture is retained for the corn.

Mindset, Again

Because the producers have observed soil quality improvements, some are constantly looking for additional ways to improve soil quality. The mindset has changed from seeing soil as a medium that keeps plants erect and holds the applied fertilizers and amendments to seeing soil as an ecosystem that can automatically produce nutrients, water and minerals for plants. The changed mindset encourages producers to think of different production options. For example, the Brock Farm follows a controlled traffic pattern and does not run grain carts in the field. This minimizes soil compaction and supports a healthy soil ecosystem.

Specialty Crops

Paul Davis is growing pumpkins with no-till, as seen in Figure 18.4. Following a no-till rye cover crop, Rawlins is growing strip-till watermelons on plastic. There is less soil-laden splashing on leaves and stems. There is less contact be-

FIGURE 18.4. No-till pumpkins on the Davis Farm. *Photo courtesy of Paul Davis.*

tween the fruit and the soil. Both of these reduce disease. Reducing disease increases production quantity and quality. Both Davis and Rawlins receive higher prices for their higher-quality produce.

Rawlins compares the steps in producing watermelons with conventional tillage versus with no-till. With conventional tillage, the March winds bent and sandblasted the young plants; six trips were made across the field; and sheet and rill erosion due to watermelon production was significant. With no-till, the March winds had little effect because the straw took the brunt of the wind; there was only one trip across the field; soil erosion no longer created major problems; and there was less disease and fruit rot. Rawlins also successfully grew no-till snap beans. He discontinued snap beans only because of the unfavorable market price.

Why Change to No-Till?

The producers were asked why they made the transition to no-till. There were three major reasons: fewer trips across the field, the soil and future market opportunities. Table 18.1 captures the perspective of one interviewed farmer, Rawlins, on the various challenges associated with both conventional tillage and no-till.

Fewer Trips Across the Field

Fewer trips across the field mean less fuel, less equipment maintenance and less labor. These cost savings allow for investment in other enterprises on the farm. And, labor previously used to plow the fields is now available for other farm enterprises.

On the Davis Farm, it takes two days to plant 75 acres of wheat using one tractor and one no-till drill. Previously, with conventional tillage, it took seven days to plant the same 75 acres using moldboard plowing, heavy offset disking and planting.

Time was the major reason for Triple J Farm to start no-till. Labor previously used for field operations is now available to repair equipment in the cotton gin or to work in the granary.

Dargan says fuel consumption is reduced by 50 percent, and he saves the labor cost of three trips across the field.

Soil

The soil ecosystem and soil erosion were concerns for all of the producers regardless of their production system and rotation.

Rawlins started no-till more than 40 years ago because he wanted to keep his soil on the farm. “What could be more important to a farmer than soil erosion and soil quality? High-quality soil is a business asset,” he says. He knew he had to do something when a 1.1-inch rain resulted in extensive erosion and sediment deposition. His conventionally tilled snap bean seedlings were uprooted and were carried into row furrows and terrace channels by runoff. Snap beans had to be replanted. As Rawlins still sees it today, he cannot farm if he does not have high-quality soil.

The Brocks saw that their soil quality was deteriorating and the very dry years of 1998 and 2000 made the deterioration obvious when they experienced “corn disasters.” Before the switch to no-till, the Brocks worked each winter to address drainage and erosion problems.

Soil moisture was the second reason that Triple J Farm changed to no-till. Dargan estimates that no-till, in addition to saving soil moisture, also saves two to three tons of good soil per acre because of reduced erosion.

Future Market Opportunities

For the Davis Farm, the second reason to adopt no-till was “futuristic.” Because no-till increases soil organic matter, the Davises believe they have the potential to participate in future carbon and/or nutrient trading markets.

Supporting Technologies and Practices

The interviewed producers use supporting technologies and practices. Some are designing new technologies and practices, especially when striving to use no-till and to become certified organic. Table 18.2 is a summary of the supporting technologies and practices used on the case study farms.

TABLE 18.1. The challenges associated with conventional tillage and no-till, according to Georgia farmer Bob Rawlins

CHALLENGES WITH CONVENTIONAL TILLAGE
The soil is leaving the farm via erosion.
Gullies and rills from erosion increase the wear and tear on equipment.
During rainstorms in the growing season, soil may splash onto the crops, increasing disease.
During spring winds, wind erosion damages watermelons through sandblasting and by whipping on the young, tender seedlings.
On bare soil, watermelon stems have nothing to anchor onto and flop more in the wind, incurring more damage.
Soils dry out more quickly following rainfall events, and plants show stress quicker during periods of drought.
Soils crust and water runs off and does not infiltrate into the soil. Water puddles on the surface.
Equipment costs are greater because more equipment is required for multiple passes over the field. This also requires more fuel, labor and maintenance.
A lot of time in the field is spent harrowing and plowing. Thus, there are lost opportunities for additional agricultural enterprises with the same labor force.
There is a bigger reliance on seasonal labor.
CHALLENGES WITH NO-TILL
Weeds are a different problem because the option to cultivate is removed.
During the first few years of no-till, there is a yield lag in peanuts. The crusty, cloddy soil thwarts peanut germination until increases in organic matter have improved the soil tilth.
Recreational plowing (or plowing when it is not needed) is eliminated.
The field surface may be rougher and can slow down sprayer operations.
Variable residue depth creates seed placement problems. Residue must be uniformly distributed.
Different crops leave different types and amounts of residue, which necessitates adjustments in residue management. Cotton residue in the spring is more woody and sparse than corn.
No-till grain drills are more expensive than conventional grain drills.
If a cover crop is used in the winter, it must be watched in the spring to make sure it does not get out of hand. That is, it could deplete soil moisture or attain so much mass that available equipment will not be able to plant into the residue.
If a cover crop is used, it is difficult to find roller/crimper equipment in the market.
With no-till, one must consciously decide to go to the field to monitor plant health. In contrast, with conventional tillage, one is out in the field more often and can incidentally assess plant health.

The Future

The interviewed producers are experimenting with new ideas for more-profitable farming. Some continue to modify their operations to improve their systems. They are still in transition.

There are several remaining challenges in the near future. Because the Brocks use a cover crop in their no-till operation, the timing of crop harvest, cover crop planting, cover crop termination and crop planting is very important and is a challenge. Davis must plant his cover crops before winter sets in and sometimes harvests the cash crop a little early in order to meet the winter deadline. The Brocks are looking for ways to increase the conversion of carbon to stable humus.

The sections below describe the producers' thoughts about the future of conservation tillage.

TABLE 18.2. Supporting technologies and practices used by case study farms

Supporting and specialized technology or practice	Producer(s) using the technology
Cover crops	Davis, Brock, Rawlins, Harris, Dargan, Winslow
Roller/crimper	Davis, Brock, Rawlins
Grid sampling and variable rate application of nutrients	Dargan
Variable rate (precision) irrigation	Dargan, Triple J Farm
Green Seeker technology	Davis
Sod-based rotation	Harris
Compost extract	Winslow
No-till specialty crops	Davis, Rawlins
Auto steer or other GPS applications	Brock, Triple J Farm, Dargan
Organic production	Winslow

No-Till Will Evolve

As more producers work with no-till and try no-till on different types of crops, it may evolve into a type of a blend, or a "middle ground," between strict no-till and conventional tillage, suggests Winslow. Kirk Brock thinks that no-till works differently for different crops. Cotton requires warm soils earlier than no-till allows and cotton seeds need to be planted uniformly at 3/4 inches deep, which is difficult with no-till. However, peanuts bloom and peg better under the cooler conditions. Winslow has observed that after many years of no-till, the soil condition reaches a plateau and begins to compact.

No-till will also evolve because of herbicide-resistant weeds. These weeds will be the number one challenge in the future. In addition, weed control is a major limitation for the producers who want the soil quality of no-till and also want to be certified organic. For these producers, weed control options include hand pulling, thermal incinerations, and the allelopathy and shading effects of cover crops. If there is no effective organic weed control with strict no-till, then no-till for these producers will evolve, such as allowing shallow tilling only for weed control. The Winslow Farm has temporarily returned to conventional tillage for weed management on their organic fields. They are actively experimenting with different methods to manage weeds without chemicals or tillage, and are studying the effects of soil chemistry on various weed species.

Even those producers who are not interested in organic certification feel that herbicide-resistant weeds would be the only reason to consider abandoning no-till. However, the soil quality benefits of no-till are so significant that these producers are likely to try new weed management ideas first. The Brocks state that they look for herbicides that can move through the straw down to the soil. They have been identifying and removing Palmer amaranth to prevent its spread. Rawlins has had some problems with pigweed, particularly Palmer amaranth.

Triple J Farm reports that weeds are more problematic with cotton than with their other field crops. This is because the cotton plant canopy develops slower, allowing more time for weeds to grow in the sunlight.

Future Transitions Will Be Easier

All producers expect future transitions to conservation tillage will be easier. First, there is so much more information now. Second, implements have significantly improved. For example, shanks for subsoilers are narrower, row cleaners are available to brush loose residue from the path of the planter and press wheels have been modified. Third, and most importantly, there are more experienced producers who can be mentors.

Cover Crops

Cover crops will be used more often. The Davises expect cover crops to be blends, such as a vetch/rye mixture, to provide various services such as water channels, nitrogen and residue for the next cash crop. The future Davis Farm will be "never till" and "ever green." Most nutrient leaching to the groundwater occurs during the fallow period. A cover crop cycles nitrogen back up into plant material and reduces the amount leaching to the groundwater. As inorganic fertilizer prices increase, nitrogen-fixing cover crops such as vetch will more than pay for themselves. The Davis Farm is conducting a study to determine the ecotype of vetch that will grow the latest into the fall and break dormancy earliest in the spring.

New Technologies

The Davis Farm is working with Virginia Tech and the local SWCD to try new technologies such as Green Seeker for more accurate nitrogen fertilizer application. Winslow is experimenting with compost extract and fish fertilizers to reduce weed populations and to reduce plant pests and diseases. Triple J Farm has added a heavy coulter row cleaner by KMC. This has made planting into wheat easier, and they will try it with corn residue. If successful with corn, Triple J Farm will not have to mow corn stalks. Auto-steer technology guides the tractor by GPS, freeing the operator to more closely monitor the planting equipment.

New Market Opportunities

Paul Davis thinks that because no-till increases soil organic matter, there is a potential to participate in future carbon- and/or nutrient-trading markets. The Winslow Farm has built its own compost extraction process to experiment with new ways to inoculate the soil with organisms.

No-till will expand into other crops, especially when petroleum-based input prices increase faster than output prices. Rawlins has expanded no-till from corn and soybeans to cotton, and more recently to peanuts, watermelons and snap beans. If the labor and fuel costs become increasingly important to the farm budget, producers are likely to try no-till for additional crops.

SUMMARY

Conservation tillage on the Southern Coastal Plain and Atlantic Coast Flatwoods MLRAs grew dramatically with the introduction of herbicide-resistant crops, especially with the widespread use of glyphosate-resistant technology. Sole use of this technology has resulted in herbicide-resistant weeds. These weeds threaten the gain in growth of conservation tillage as some weed specialists are now recommending tillage as an option to control these weeds.

Whether resistant weeds are present or not, there are keys to successful conservation tillage management in these two regions.

- Manage residues. Use crop rotations and cropping systems that provide abundant residues to build soil organic matter.
- Get good stand establishment. Use planting or transplanting equipment capable of uniformly placing seeds or transplants into soils covered with residues.
- Manage weeds. Use crop rotations, management practices and herbicide mode-of-action rotations to combat herbicide-resistant weeds and reduce the chance of resistance developing.
- Manage soil compaction. Use crop rotations and cover cropping to build organic matter, and use subsoiling implements when necessary to overcome the inherent high bulk density in these soils.
- Find a mentor. Growers transitioning to conservation tillage from conventional tillage can benefit from a local mentor with experience in conservation tillage. A mentor can be a farmer, Cooperative Extension agent, or representative from the local SWCD, cooperative or NRCS office. Pull together a team to take advantage of local conservation tillage experience as well as government cost-sharing programs.

RESEARCH CASE STUDY

Reducing Soil Erosion and

Nitrogen Leaching through Sustainable Cropping Systems

Project Information

Project type: On-Farm Research Grant
Project number: OS06-030
Project dates: 2006–2007
Principal investigator:
Wade Tomason
Virginia Tech
Project reports: https://projects.sare.org/sare_project/os06-030/

Problem Statement

Heightened awareness about the environmental impact of inorganic fertilizer and intensive, non-diversified farming practices have gained attention in the mid-Atlantic states since the adoption of the Chesapeake 2000 agreement, a plan that seeks to improve water quality in the Chesapeake Bay region. Winter annual cover crops are highly valued for their ability to make use of soil nutrients, particularly nitrogen, which would normally be lost from the soil by runoff and leaching during the winter. Previous studies have shown that cover crops enhance soil stability and reduce erosion and runoff of sediment containing nutrient and pesticide residues. Additionally, cover crops have the potential to increase farm profitability by improving soil productivity. Increased water- and nutrient-holding capacity, greater organic matter and higher nitrogen levels are some of the beneficial effects to the soil associated with cover crops.

Scientists partnered with farmer Paul Davis and his family, whose farm is located on Virginia's Coastal Plain, for a study aimed at discovering which winter cover crops and planting dates would maximize winter soil cover, return the most biomass to the soil and bring the greatest level of nitrogen uptake.

Methods and Practices

The experiment followed a split-plot design with different crops and combinations of crops planted and then observed over a three-year period (2005–2007). Changes in soil nitrate levels were also closely monitored.

Cover crops of rye, oats, barley, triticale, crimson clover and vetch were planted on different plots either separately or as a mixture of species on three different dates (October 1, October 20 or November 10). Subplots received the following spring nitrogen application rates: 0, 28, 33 or 56 kilograms of nitrogen per hectare (kg N ha). Cover crops were seeded using a no-till grain drill. Each year of the study, all aboveground biomass was hand-trimmed twice. Crop samples were dried in a forced-air oven and sieved through a 2-millimeter screen in order to determine nitrogen uptake levels. Changes in soil nitrate concentration over the cover crop season were determined by taking soil samples at the planting and termination dates of the cover crops. Samples were taken at depths of up to 90 centimeters.

Results

In terms of biomass, rye and rye-vetch mixtures produced more than the other crops across the three years. For instance, for the early and mid-planted treatments in 2006, rye and rye-vetch both produced over 12 metric tons per hectare, compared to barley, which produced less than 8 metric tons per hectare. In terms of nitrogen uptake, rye and rye-vetch mixtures also performed best. In 2005, none of the cereal crops absorbed more than 100 kg N ha, while even late-planted rye had uptake rates of 115 kg N ha. Both biomass yield and nitrogen uptake rates responded positively to increased spring nitrogen application. In 2006 and 2007, for the subplots exposed to 30 kg N ha, biomass increased at an average of 1.45 metric tons per hectare and nitrogen uptake increased by 26 kilograms per hectare. Biomass and nitrogen uptake rates also responded positively to earlier planting dates.

The results of this and other studies led the Virginia Department of Conservation and Recreation to offer a payment of $5 per acre to farmers who plant rye as a cover crop. Presentation of these results at county and regional meetings have also led to a wider discussion on the best use of cover crops with farmers from across the Virginia Coastal Plain.

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CHAPTER 19

Alabama and Mississippi Blackland Prairie Case Studies

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Authors' note: Dennis Reginelli, area Extension agent for agronomic crops in eastern Mississippi, and Charlie Stokes, area Extension agent for agronomic crops in northern Mississippi, provided much help with the case studies in this chapter.

The Alabama and Mississippi Blackland Prairie major land resource area (MLRA 135A) has a land area of 6,370 square miles (4,076,800 acres) in central Alabama and eastern Mississippi [27] (Figure 19.1). About 53 percent of the total area is in Alabama and 47 percent in Mississippi. The region has a rolling topography with elevations ranging 100–590 feet. This area was once known as the "Canebrake" and was the center of cotton production in the 19th and early 20th centuries. Today, it is called the "Black Belt" or "Blackland Prairie."

The climate is hot and humid, with a long growing season. Annual frost-free days average 250 days across the region. Average annual rainfall is between 53–61 inches with wet winters, wet springs and relatively dry autumns. Although high intensity, convective thunderstorms occur during the summer, periods of short-term drought occur frequently during the growing season. Due to the depth to groundwater for irrigation wells and the associated pumping costs, little row-crop acreage is irrigated. A few farms have constructed large surface-water impoundment structures for supplemental irrigation of limited acreage.

Currently, about 16 percent of the land is used for crop production, 29 percent is in grasslands and 48 percent is in forests [27]. The rest is in urban or industrial development or water, including aquaculture production, which is expanding. Major crops include corn, cotton, soybeans and small grains. Most of the acreage in recent years has been in corn and soybean production with some wheat and wheat>soybean double-cropping. Beef cattle, principally cow-calf operations, occupy most of the grazing lands. At one time, dairies were a major user of the grassland areas. They have been replaced by catfish farms and other agricultural enterprises.

CASH CROP SELECTIONS AND ROTATIONS

Historically, crop rotations have been a minor consideration for most row-crop farmers in the region. From antebellum cotton plantations of the early 19th century to sharecropping farms of the early 20th century, cotton and corn were the staple crops with little opportunity for rotations. As in the rest of the South, erosion took its toll on the land and the people who farmed it. Improved pastures and Johnsongrass hayfields became the principal land use of the 20th century until soybeans became the dominant crop of the 1970s and 1980s. Grasslands were converted to large-scale, conventionally tilled, monoculture soybeans with some double-cropping with wheat. Rampant soil erosion ensued until overproduction of soybeans resulted in low commodity prices and USDA conservation reserve programs took most of the highly erodible land out of production. These fields

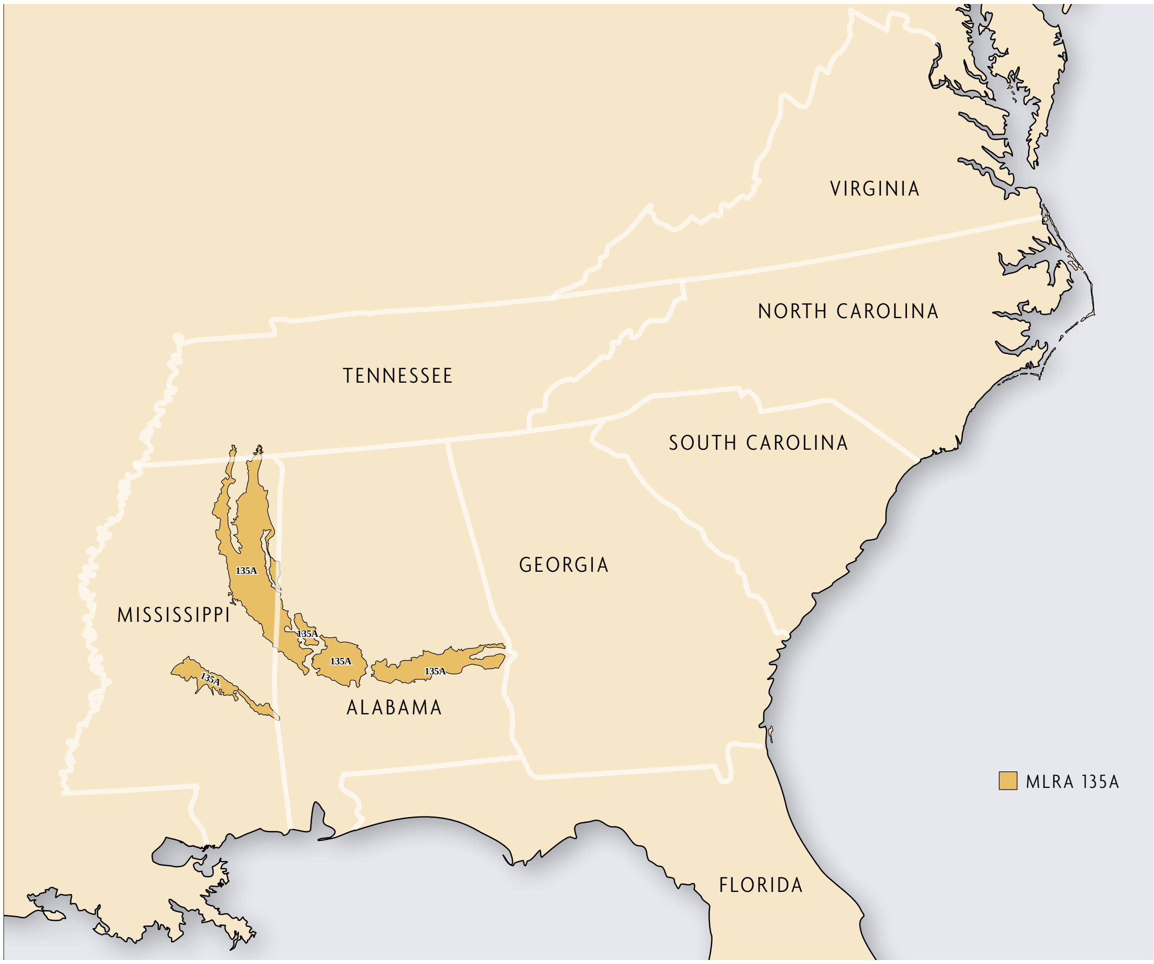

FIGURE 19.1. MLRA 135A (Mississippi and Alabama Blackland Prairie) [27].

were planted to trees or permanent grasslands. Today, typical crop rotations include rotations of corn>cotton, corn>soybeans, cotton>soybeans and soybeans double-cropped with a small-grain winter cover crop, usually wheat.

SOILS

The soils in the region were formed from clayey sediments or from chalk limestone deposits (Figure 19.2). These soils are predominately loamy to clayey with smectite clay that shrinks as it dries and swells as it hydrates. The soils range from shallow to very deep and are moderately to somewhat poorly drained. Slopes range from 0–8 percent with moderate to rapid runoff.

Blackland Prairie soils have a reputation for being tough, sticky and hard to manage. The high proportion of clay coupled with a high water-holding capacity often creates low oxygen conditions in the soil. In addition, the clay results in low rainfall infiltration and poor water movement through the soil. Many of these soils never dry sufficiently in the spring to fracture, and when tilled, they form clods that are difficult to break up. This makes preparation of a suitable seedbed difficult.

Soil moisture recharge is different in these cracking soils compared to soils without the high shrink-swell clays, referred to as non-cracking soils. As the high shrink-swell clay soils dry, cracks form that facilitate rapid rainfall intake (Figure 19.3). This wets the lower part of the profile first. Surface drying is primarily a function of plant water use.

FIGURE 19.2. A profile of an undisturbed Faunsdale clay loam from Hale County, Ala.

While cracks improve soil-water intake, they can create other problems. Even though the cracks swell shut during hydration, there are zones of weakness that allow the same cracks to form at the same place during dry conditions on untilled soils. Crop roots find these cracks and follow them deeper into the profile. Inoculum of soil pathogens, such as *Pythium*, present from the previous year's crop can infect new roots and reduce crop yield potential. If the soil is tilled, the cracking patterns are disrupted and disease problems are reduced during the next crop cycle. For example, if the crop rotation is soybeans>corn, the pathogens for soybeans do not infect the corn [24]. This may partially account for the increased yields seen with a soybean>corn rotation. Corn yields increased by 16 percent and soybean yields by 12 percent [6].

The Blackland Prairie soil characteristics create challenges for conservation tillage systems that do not exist on adjacent river terrace soils and on sandy Southern Coastal Plain soils. The Blackland Prairie soils are highly susceptible to erosion when intensively cropped [25]. Continued loss of topsoil to erosion could expose the underlying chalk that is unproductive and not suitable for row-crop or grain production [16]. The depth of topsoil is highly correlated with yield [12], so adopting reduced tillage and other soil conservation practices is essential for the future of row crop agriculture in the region.

Not all soils in the region are cracking soils, and conservation tillage systems are different for soils with different characteristics. For soils that do not crack, the bare surface will seal from soil particles splashed during rainstorms. To increase moisture recharge, these soils are either cultivated or have a mulch cover. The mulch also feeds earthworms that create macropores for infiltration, and protects the soil surface from raindrops splashing soil particles. A strong positive correlation between mulch and no-till yield exists on non-cracking soils but is either absent or less defined on the cracking soils.

TILLAGE

Historically, conventional tillage for many crops included bedding the land in the fall and plant-

FIGURE 19.3. Most Blackland Prairie soils shrink when dry and swell when wet, such as this Vaiden soil in Dallas County, Ala., during dry weather in 2006.

ing on the "stale seedbed" in the spring. Bedding involves using tillage and plowing to elevate the soil surface of flat land into rows of broad low ridges that are separated by shallow and parallel channels that allow for drainage [26]. This helps assure adequate drainage for spring planting into the dry soil on top of the ridge or seedbed. When the stale seedbed technique is used, a seedbed is prepared prior to planting and weeds are allowed to emerge. The weeds are terminated prior to planting the cash crop [14]. Spring chisel plowing followed by disking and/or harrowing can be done if moisture conditions are suitable. Because of the gentle slopes of most arable Blackland Prairie soils, this technique, with 8–10 conventional tillage trips across the field annually for bedding and cultivation, often results in deep gullies forming between the rows or blowouts if the rows were contoured with the land. Blowouts occur during heavy rainfall events when water builds up behind a ridge and eventually overflows, taking the soil with it. Erosion rates of 12–25 tons per acre occur on bare fallow soil with a 3 percent slope using intensive tillage, meaning both a fall and spring chiseling [13]. These practices also create the highest runoff. In both no-till and conservation tillage systems, 80–85 percent of the soil erosion occurs from March through June [13]. In conventional tillage systems, spring tillage occurs when soil erosion potential is the highest due to severe thunderstorms that deliver large amounts of water in a short amount of time. After almost 200 years of erosion, many soils of the Blackland Prairie are no longer black. Both farmers and researchers have been looking for ways to incorporate the principles of conservation tillage systems to reduce erosion on these difficult soils.

Most of the tillage research in the Blackland Prairie has involved either corn or soybeans in a monoculture or in a rotation. Monocropped, true no-till soybeans produced lower yields than conventional tillage on the clayey soils of the region [4, 5, 11, 10]. This may be associated with drainage or other factors. Several studies indicate no-till yields on moderately drained soils were equal to or greater than conventional tillage [1, 7, 9, 19]. Conversely, on poorly drained soils, no-till corn often had slower emergence and growth, and yields were lower than conventional tillage. The lower yields with no-till may be due to lower soil temperatures that reduce growth in the wetter, poorly drained soils [10, 17]. Other reasons include increased incidences of soil pathogens [8, 29] and irregular emergence of seedlings [28].

In a dry year, Blackland Prairie soils did not produce yields greater than conventional tillage as occurs in other parts of the United States [20]. In years when rainfall during the growing season was above normal, no-till had comparable yields to conventional tillage in continuous soybeans or soybeans in a rotation with corn [4]. But in years when rainfall during the growing season was below normal, the yield for no-till soybeans was lower than for conventional tillage.

Crop yields in the Blackland Prairie are generally higher when crops are grown on raised beds due to better soil moisture conditions [16]. The beds are especially beneficial to corn emergence and early-season growth during periods of wet weather that often occur in March. Ridge-tillage is an alternative method to fall bedding. The ridge (bed) is formed through the use of a ridge-till cultivator once or twice during the growing season. This implement is equipped with two smaller sweeps per row and one large sweep that runs in the row middle and creates a 4- to 6-inch-high bed as it passes through the field. In studies on a Houston clay soil and a Vaiden silty clay loam soil, continuous ridge-tillage soybean yields were equal to conventional tillage and 12 percent higher than no-till. In continuous cotton with 30-inch row spacing, ridge-tillage yields were equal to conventional tillage [15, 18]. There has been little reported yield increase with ridge-tillage and a corn>soybean or corn>cotton rotation. Ridge-tillage during the growing season can reduce soil erosion. Stale seedbed systems combined with crop rotation minimize production costs, enhance productivity and meet conservation compliance [16]. The stale seedbed system is used on new raised beds formed by ridge-tillage after the previous growing season or on old raised beds that will be used again without tillage.

Although most crops are grown on beds, no-till corn can be planted flat and grown successfully on sloping land. Planting flat means without a raised bed. Corn yields in no-till systems planted flat are more variable than yields in conventional tillage systems without raised beds, but no-till had a higher three-year average yield and greater returns above total costs [22].

Where tillage must be done, fall chiseling without bush hogging corn stubble and/or fall bedding has distinct advantages over spring chiseling. Unlike soils in the Southern Coastal Plain or Southern Piedmont, the shrink-swell clays in this region will crumble when wet, although they may seem very hard when dry. In these soils, minimizing soil disturbance preserves soil structure and soil moisture, and can result in successful reduced-tillage crop production. Fall tillage with a one-pass coulter-chisel-harrow system leaves the ground rough with sufficient residue when used after corn harvest (Figure 19.4). Residue protects the soil during the winter and reduces runoff and erosion. Preparing the seedbed in the fall allows weeds to germinate and be terminated before planting the cash crop. Soybeans planted into a stale-seedbed system had the highest three-year average yield. The returns above total costs for this system were eight times more than conventional tillage and 44 percent more than no-till [22].

Deep tillage, including moldboard plowing, paratilling, ripping and subsoiling, is unnecessary on most Blackland Prairie soils, especially the cracking soils. There are no reported yield advantages to deep tillage with corn or soybeans [4, 15]. In fact, deep tillage caused water to seep down the long, gently rolling topography and pool at the end of the field.

COVER CROPS

Although most conservation tillage systems include cover crops, cover crops can present unique challenges with the clayey prairie soils. Winter annual legumes such as crimson clover, hairy vetch and lupine do poorly, while Balansa clover (*Trifolium michelianum subsp. Balansae (Boiss*) “Paradana”) has looked promising as a reseeding winter-legume cover crop in Mississippi tests [3]. Small-grain cover crops do well, but the residue that is valuable on sandier soils creates

FIGURE 19.4. A Blackland Prairie field ready for spring planting. The field was fall tilled with a one-pass coulter-chisel-harrow and left fallow through the winter. Note residue from the previous year's corn crop.

problems with timely planting and early-season crop growth. These problems can reduce yields, especially in wet years [23]. Surface residues increase soil moisture and contribute to anaerobic soil conditions that can cause nitrogen loss through denitrification [21]. The soil surface in conventional tillage dries more quickly without a cover crop. This reduced soil moisture at planting results in improved seed placement and seed-soil contact, as well as better stands and higher yields. However, tillage has to be balanced with the benefits of supplying a mulch to reduce surface crusting in the non-cracking soils of the region.

There has been limited research concerning the use of wheat as a cover crop planted in the furrow during the bed-forming operation as a one-pass tillage system. Using an air seeder that blows the wheat seed underneath the bedder sweep during the fall bedding operation resulted in a successful stand of wheat in the bed furrow [4]. However, corn yield was 13 percent lower than conventional tillage and no-till corn without cover crops. The lower corn yield may have been associated with the higher incidence of *Pythium spp.* and chinch bugs (*Blissus leucopterus*) when a wheat cover crop was used. Further research is needed to determine if the bed surface can be exposed to drying conditions when the soil is wet while the wheat protects the furrow from erosion. There are some farmers in the Blackland who use wheat or rye broadcast as a winter cover crop for corn or double-cropped with soybeans. They have experienced wet soil conditions that delayed herbicide application and corn planting in some years.

Double-cropping is effective for soil erosion control in this region. Double-cropped winter wheat and soybeans had the lowest runoff and lowest erosion rate when compared to monocrop tillage systems [13]. But historically, it often has not been the most profitable rotation due to low commodity prices and wet soil conditions that often delayed wheat harvest and soybean planting. Dry soil conditions at wheat harvest also result in delays in planting soybeans or seed germination since there is not sufficient soil moisture for germination. This can result in unprofitable yields.

OTHER CONSIDERATIONS

Conservation tillage systems are needed in the Blackland Prairie due to the high erosion rates associated with conventional tillage. That said, the rolling topography coupled with clayey soils presents special challenges. A raised-bed system works well for flat, bottomland fields with very little slope. But a winter cover crop may be necessary to preserve the ridges and protect the row middles from erosion. Planting no-till flat without soil disturbance may reduce gully and rill erosion on slopes greater than 2 percent where concentrated water flow is not a problem. The crops will do fine with the no-till planted-flat system in dry years. But in wet growing seasons, especially when the soil remains saturated for long periods, loss of nitrogen through denitrification can be severe and can result in reduced crop yield [21].

CASE STUDIES

Since the topography and soils are highly variable across the Blackland Prairie region, the conservation practices used by individual farms vary. Farmers select conservation practices that are profitable and sustainable, and that satisfy crop needs. Most often these practices will involve a one-pass fall tillage with or without a cover crop; spring planting no-till on old raised stale seedbeds; a precision-grade grass waterway; and pipe outlet terraces to control concentrated water flow. Wheat and rye are the cover crops used most often. These case studies illustrate that Blackland farmers recognize the challenges of farming these soils. They are adopting reduced tillage and other conservation practices that reduce soil erosion and improve potential yield and profitability. The four case studies provide insight into successful operations where some type of conservation tillage has been valuable on Blackland Prairie soils.

The farmer interviews were conducted between January and October of 2009. Each farmer was asked the same eight questions:

- What do you consider to be the biggest challenges in farming Blackland Prairie soils?
- What conservation tillage techniques work best for you?
- What are the biggest problems that you have encountered with conservation tillage techniques on Blackland Prairie soils?
- What are the biggest advantages, if any, of conservation tillage on these soils?
- What are the biggest problems with conventional tillage (e.g., moldboard plowing, disking, chiseling, etc.)?
- What are the advantages of conventional tillage?
- Do you use subsoiling under the row? Why or why not?
- Do you have any other comments or ideas about conservation tillage on Blackland Prairie soils, or ideas for future research?

CASE STUDY

Stanley Walters, Gallion, Alabama

Editor's note: This case study was updated in 2018.

Stanley Walters farms 6,000 acres of corn and soybeans in the Black Belt region of Alabama in partnership with his son Clay under the name of Walters Farming Company. The farm headquarters is in Gallion, located seven miles east of Demopolis, and it includes locations in Hale, Marengo, Dallas and Perry counties. Walters is a native of Linden, Ala., and a 1977 graduate of Mississippi State University. After graduation he began his farming career farming cotton on the Coastal Plains soils between Linden and the Tombigbee River. The continuing loss of Coastal Plains land to pine tree production, crop predation by whitetail deer and the need for better efficiency forced him to begin farming in the prairie regions of the county soon after. The crop mix on the farm has evolved and will continue to evolve: at one time the farm had 3,200 acres of cotton, and today it consists of 5,000 acres of corn and 1,000 acres of soybeans. The farm has 2,160 acres irrigated by center pivot. All farm acreage is under some form of conservation tillage.

What do you consider to be the biggest challenges in farming Blackland Prairie soils?

Blackland Prairie soils of Alabama and Mississippi are particularly finicky. After farming this land for 40 years I am yet to discover a simple solution to the complex riddle that is the property of these soils. Fertility, while generally good, is complex due to the high cation exchange capacity, and high pH is a constant issue, especially with some nutrient tie-ups due to excessive levels of calcium. Soil test results are always perplexing and soil fertility decisions on these soils are more akin to an art than a science. The good moisture-holding capacity of these soils is a big plus, but it has to be measured against their poor internal drainage. Poor drainage coupled with this region being a high rainfall area creates severe access problems during winter and spring. The sticky/clayey nature of the soil when wet creates problems with spring tillage. While fall tillage works best from an access and seedbed tilth point of view, it will create an erosion hazard. The simplest solution to erosion, no-till, is fraught with sustainability issues, and cover crops, if utilizing the most common cultural practices, can result in devastating results in a wet spring. Shallow spring tillage is an option if the ground is dry enough but is still subject to extreme risk from a seedbed moisture and timeliness standpoint.

What conservation tillage techniques work best for you?

The most universal tillage practice we use behind corn is to run a disk extremely shallow (less than 1 inch) and extremely fast (10 miles per hour). The ground needs to be dry and the tool has to be set to perfection. We run this twice at opposing angles. We are mainly cutting and sizing the stalks, knocking off any ridges and filling tracks. We don't create very much loose soil, so even in a big rain event there is little soil movement. The surface is usually covered fairly uniformly with residue that keeps us in compliance as far as our highly erodible land (HEL) conservation plan with the NRCS. As far as the soil profile is concerned, this is no-till—the planter opener will be going into undisturbed soil. The biggest issue has been if your first moisture in the fall comes as a big rain event the stalks will float around and create mats and bare patches. This situation will usually require another trip to "fluff and spread the residue" whenever it is dry enough. I prefer to no-till into standing corn residue (one year only) if we have no sprayer, grain cart, combine, pivot or planter tracks. The soil is in the best condition if it can be left alone for a full year. Behind soybeans I prefer to plant no-till into crop residue if possible or to use a small-grain cover crop if we have to correct tracks, as soybeans do not leave enough residues after even the light disking to protect the soil and stay in "compliance." We reshape and seed all of our ephemeral drains every year; a permanent fescue cover usually results in two gullies at every drain over time.

What are the biggest problems that you have encountered with conservation tillage techniques on Blackland Prairie soils?

We have not been successful using continuous no-till on prairie soils. The soil surface will become so unruly and riddled with rill erosion and equipment tracks over time that it will be rendered un-farmable and will actually suffer more severe erosion than if it were farmed using full tillage.

We have and will continue to utilize cover crops to protect soil that has to be worked but has insufficient crop residue. However, we have suffered terrible consequences when proper management and precautions were not observed to prevent excessive cover from establishing itself. This soil has poor internal percolation; if the sun and the wind can't get to the soil it will not dry and thus can't breathe.

The size and weight of modern agricultural equipment creates tracks and thus "heaves" or "bulges" on the field surface require correction. This is not to be confused with "ruts" as might be created when the ground it wet.

What are the biggest advantages, if any, of conservation tillage on these soils?

The biggest advantage to conservation tillage has been timeliness. We are generally able to plant much earlier than if the soil has been fully worked. The soil profile is as firm as it would be if no-tilled, which resists erosion and waterlogging and is more capable of supporting machinery when wet. Our horsepower usage and labor are less because we don't do much to the soil to get it into condition.

What are the biggest problems with conventional tillage (e.g., moldboard plowing, disking, chiseling, etc.)?

The horsepower requirements, as well as fuel and labor, are much greater; the erosion hazard is much greater; and the risk of being too wet to plant or harvest in a timely manner is much greater.

What are the advantages of conventional tillage?

Conventional tillage will give you a more consistent planting surface, will reduce the risk of nutrient stratification and should reduce the risk of volatilization of urea-based fertilizers.

Do you use subsoiling under the row? Why or why not?

We do not subsoil. Our soil naturally resists compaction. Upon the advice of an agronomist we ran in-line subsoil plows on 1,000 acres in 2016 and saw no advantages. Not wanting to make a determination based on one experience, in 2017 we subsoiled 100 acres with the same result. So, in 2018 the plows stayed in the shed.

Do you have any other comments or ideas about conservation tillage on Blackland Prairie soils, or ideas for future research?

The problems we have encountered with the prairie soils have remained constant. How we react to them is in a state of constant change. Rotation has always been a tool I have used, and I prefer to utilize a corn, wheat and soybean rotation. However, the profitability of wheat became untenable and we had to drop it from our mix. The combination of deer and iron-deficiency chlorosis are severely limiting soybeans as an option. Cotton may be an option in the future but restrictive NRCS compliance regulations in regard to utilizing a raised bed are why we left cotton to begin with. After a wet harvest, such as we encountered in 2017, we do have to deal with areas in the field with some compaction. It's a shallow compaction that should be short lived, but it is impactful to yields just the same. Cover crops will be a big part of farming these soils in the future, and I have requested that Auburn University begin a long-term research project at the Black Belt Experiment Station in Marion Junction, Ala., to study methods, varieties, rates, timing, etc. I understand work has already begun. I also requested research work to be done concerning waterway vegetation management. Waterway design and management may be the single biggest impediment to sustainable cropping systems in the Black Belt.

CASE STUDY

Annie Dee, Dee River Ranch, Aliceville, Alabama

Editor's note: This case study was updated in 2018.

Annie Dee manages a 4,000-acre row-crop farm near the Alabama-Mississippi border in western Alabama. She farms with her brother Mike, her two sons Seth and Jesse, and their families. Dee River Ranch has been featured in many state and regional publications as an innovative and modern farm that utilizes precision agriculture, energy conservation and energy alternatives. Although the farm has some cattle and timber, the main commodities are corn and soybeans. Most of the farm lies in the Blackland Prairie region on mostly Sugarnoochee (fine, smectitic, thermic Chromic Epiaquerts) clays or Vaiden (very-fine, smectitic, thermic Aquic Dystruderts) clays. All row crops are planted on 30-inch beds or hips using no-till. Fields are hipped in the fall (beds are rebuilt) and planted to a cover crop, either a single species or a mixture. Beds are maintained as long as fields remain in good condition, sometimes for up to 10 years. Running the sprayer or combine in wet conditions may cause rutting that would prompt the Dees to rework the beds. Their systems are constantly being modified and improved to improve soil quality and productivity by building soil organic matter.

What do you consider to be the biggest challenges in farming Blackland Prairie

soils?

Managing moisture seems to be Dee's biggest challenge. There seems to be either too much or not enough. She has worked hard trying to improve both surface and internal drainage, which is water entering and moving through the soil profile. Their largest field, the one they call the "Two Thousand Acre Field," is a testament to improved surface drainage systems with a series of precision ditches designed to get excess water off the fields rapidly. Dee River Ranch also installed reservoirs and irrigation on more than 3,000 acres to help address this challenge. That has made a tremendous difference in the farm's ability to produce excellent yields regardless of the rainfall. The first irrigation was installed in 2011 in two fields. That year, in one corn field, the irrigated yield averaged 185 bushels per acre while the non-irrigated yield averaged 28 bushels per acre. The average price the corn was sold for that year was $6.97. The difference in income for that field covered 75 percent of the total irrigation costs.

What conservation tillage techniques work best for you?

All crops are planted on beds that were made in the fall. These beds can be used for several years without disturbance. Cover crops are planted throughout the farm, and the corn or soybean crop is planted after killing the cover crop. The cover crop mixture depends on the crop following it and may include wheat, rye, oats, radishes, turnips, Austrian winter peas, rape, sunflowers and clover. They averaged more than 70 bushels per acre of wheat without any topdress nitrogen. Any tillage that must be done must be done in the fall, not the spring. Sometimes fall harvest may leave ruts in the field that requires some tillage to remove. All crops are planted in 30-inch rows.

What are the biggest problems that you have encountered with conservation tillage techniques on Blackland Prairie soils?

Drainage, drainage and drainage, both surface and internal. Small-grain stubble and even corn stalks can wick moisture out of the soil causing it to dry out too fast. To combat this potential problem, all crops are harvested as close to the ground as possible so as little stubble as possible is left behind to wick moisture. This seems to help.

What are the biggest advantages, if any, of conservation tillage on these soils?

Preventing erosion, building soil organic matter and building soil fertility Additional benefits include increased cation exchange capacity, improved soil structure, and increased earthworms and microbial activity. With the increase in organic matter Dee has seen improvements in water-holding capacity, water absorption and penetration, along with fuel savings, equipment savings and labor savings.

What are the biggest problems with conventional tillage (e.g., moldboard plowing, disking, chiseling, etc.)?

When it is too wet, you cannot get in the field anyway. When it is dry enough to till, tillage dries the soil out too much. Conventional tillage destroys the soil structure, causing compaction and reducing the pore space between soil particles. This reduces the organic matter as well as the water-holding capacity. It destroys earthworms and microbial activity in the soil, causing a decrease in overall soil health. Conventional tillage allows for an increase in soil erosion. When there is soil erosion, essential nutrients are lost to both the air and water, which causes pollution as well as a reduction in fertility.

What are the advantages of conventional tillage?

The main advantage of conventional tillage is the flexibility you have with weed control. This might decrease the need for some herbicides.

Do you use subsoiling under the row? Why or why not?

No. The use of cover crops has eliminated the need for subsoiling. There are benefits to the soil from using a mixture of crops. They will each have different rooting depths. The turnips have mellowed the soil. The radishes have a very deep taproot that can break up hardpans. The oats, wheat and rye have long, deep, fibrous roots that go through any hardpan. Sunflowers have a deep taproot that will bring zinc up to the surface and make it available to the next crop.

Do you have any other comments or ideas about conservation tillage on Blackland Prairie soils, or ideas for future research?

We did not come with any knowledge of these soils, and we continue to learn. We have found that fieldwork must be done in the fall, if at all, and we must use cover crops. Our goal is to build soil organic matter using no-till.

We have tried to build soil fertility to the point where a lack of nutrients is not a limiting factor for the high populations of crops that we plant. We do not want fertility to be a limiting factor.

I would like to work with some scientists on the number and kind of microorganisms in the soil and to research if different cover crops affect the microbe populations.

CASE STUDY

Roy and Donnie Tucker, Tucker Farms, Hamilton, Mississippi

Editor's note: This case study was written in 2009.

The Tucker brothers farm about 3,000 acres in Monroe County, Mississippi. Their farm's soils are about 75 percent Blackland Prairie clays and the rest are sandy loams and silt loams of nearby Southern Coastal Plain origin. In 2006, they had 1,600 acres of cotton. This fell to about 700 acres in 2007. At the time of this case study, their cotton acreage was down to 150. Corn and soybeans have become the crops of choice. About 35 percent of the farm is in some type of conservation tillage that includes no-till. The Tuckers' experience is that you cannot no-till forever. Some tillage is necessary to remake beds, to incorporate fertilizers and limestone, and to bury surface residue.

What do you consider to be the biggest challenges in farming Blackland Prairie soils?

Water is always a limiting factor, either too much or not enough. Wet soils are a particular problem when planting corn early. They can gum up planting equipment. We have solved this problem by eliminating a coulter, using trash wheels to remove residue from the old crop, using scrapers to remove soil on double-disk openers and using narrow dual press wheels. With cotton, getting good seed-soil contact can be a problem. If we plant shallow, the soil can dry out.

What conservation tillage techniques work best for you?

Corn is the easiest to no-till. Cotton does okay. Soybeans are the most difficult to no-till. We probably do more conservation tillage around here than anyone. Most folks plow bean and corn land every year. We plant using true no-till on old beds.

Cotton is normally planted no-till on beds behind corn. Everything is on 38-inch rows. We mow the corn stalks in the fall and plant on the bed in the spring. Once a bed is made, it can be used for several years before remaking it. Some of our land was hipped four years ago and has been no-till since then. When we do till, we apply fertilizer first.

We have to pick and choose where we use hippers to raise beds because of soil erosion. Where you need a bed, sometimes you cannot use it because of potential gully erosion problems in the middles. On rolling land, greater than 2 percent slope, with better drainage, we plant flat after a light do-all in the spring just to smooth the ground. A do-all is a generic name for a combination of different secondary tillage tools, including cultivators, harrows, disks and leveling devices [2]. We have a lot of land that is terraced with tile outlets. The terraces have helped to improve crop yield and reduce soil erosion. We feel it was a necessary investment. This is the land we plant flat. The most tillage we do will be a spring chisel followed by a field cultivator and plant. In the fall we bush hog the stalks or use a flail shredder.

What are the biggest problems that you have encountered with conservation tillage techniques on Blackland Prairie soils?

We do not use cover crops. Cover crops work best when it is dry but they tend to keep the soil too wet in the spring.

What are the biggest advantages, if any, of conservation tillage on these soils?

Conservation tillage controls erosion, uses less horsepower and saves trips across the field.

What are the biggest problems with conventional tillage (moldboard plowing, disking, chiseling, etc.)?

Erosion! Another is timeliness. With conventional tillage you may not be able to get in the field when you need to; it is either too wet or too dry.

Do you use subsoiling under the row? Why or why not?

We have a paratill but haven't used it in three or four years. We cannot hip or raise beds behind a paratill.

Do you have any other comments or ideas about conservation tillage on Blackland Prairie soils, or ideas for future research?

Controlled traffic is important in conservation tillage. All our equipment, including grain carts, can straddle four 38-inch rows.

SUMMARY

Successful farmers in the Blackland Prairie region recognize the challenges and the importance of reduced-tillage practices as well as other conservation practices such as wheat or rye in a double-cropping system, piped-outlet terraces and precision waterway drainage. They know these practices will preserve the land's productivity and profitability for future generations. Future research needs to focus on cover crop systems that have potential to protect the soil from erosion, enhance internal drainage and allow the soil surface to dry out for early crop planting and crop growth. Table 19.1 summarizes some of the research-based techniques used by the farmers in the case studies.

TABLE 19.1. Conservation tillage techniques that may benefit cracking Blackland Prairie soils in Alabama and Mississippi

Technique	Relative importance 0=low 5=high	Benefits	Potential problems
Fall chisel or light fall disking	5	Reduces erosion; leaves soil surface rough; leaves residue on surface; disrupts cracking; best on sloping land	Some erosion risk
Raised beds/ridge till in fall	5	Drainage; warmer soils in spring; early planting; best on flat lands	Erosion on sloping land
Stale seedbed planting	4	Early planting; fuel and labor savings	Pathogen carryover
No-till corn	3	High returns and low cost; low erosion	Highly variable yields
Small-grain cover crop	2	Reduces winter erosion; adds organic residues	Keeps soil wet in spring
Planting no-till into sod	2	Reduces erosion; fuel and labor savings	Complete kill of sod; appropriate equipment for planting; seed depth; closure of seed furrow
Small grain in furrows between raised beds	2	Controls in-row erosion	Pythium; insects; delayed planting; difficult to manage
Spring chiseling or disking	1	More uniform stand; disrupts cracking	Erosion; clods; not very timely in wet weather
Legume cover crop (e.g., Balansa clover)	1	Reduces erosion; adds nitrogen	Diseases; most legumes are not suitable for these soils; keeps soils wet in spring
In-row subsoiling/ paratill	0	Unnecessary except on sandy soils	High energy requirement

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CHAPTER 20

Southern Piedmont Case Studies

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Greg Hoyt, North Carolina State University
Bobby Brock, USDA-NRCS
George Naderman, North Carolina State University
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The Southern Piedmont major land resource area (MLRA 136) extends through Alabama, Georgia, South Carolina, North Carolina and Virginia, with a land area of 64,395 square miles (41,212,800 acres) (Figure 20.1). The area is a plateau just below the Appalachian Mountains and above the Coastal Plain, with elevations ranging 328–1,312 feet above sea level. The region is dissected by rivers and streams that produce well-defined drainage patterns with narrow to fairly broad upland ridge tops and short slopes adjacent to the major streams. The intermittent valley floors are narrow and occupy 10 percent or less of the land area.

The climate is relatively mild. Average annual temperatures in the region range from 57°F to 64°F with 205–235 frost-free days. Average annual precipitation is 45–55 inches, with the lowest rainfall generally in autumn. Much of the rainfall during the spring and summer is from high-intensity thunderstorms. In addition, the area is prone to large amounts of rainfall from tropical storms that arrive from the Atlantic Ocean or Gulf of Mexico. These two types of storms are responsible for most of the erosion, particularly when the storms occur during the spring planting season. Snowfall is infrequent and light. Precipitation, perennial streams and lakes are the major water sources. Groundwater supplies are relatively small.

Soils were formed from upland weathered rock sediment deposited by rivers or creeks, or by erosion in the valleys. Cecil and related soils are predominant in much of the Southern Piedmont. Surface horizons of Cecil soils are typified by sandy loams, or sandier if slightly eroded, and they approach sandy clay loam if severely eroded. The underlying B horizon is red, has moderate to strong subangular blocky structure and contains 40–60 percent clay. The soils are naturally infertile, with low cation exchange capacities and low base saturations. They are deep and usually well drained.

Early descriptions of the region by European settlers indicated that hardwood forest dominated the landscape but that areas of grasslands and savannas also existed. Native American settlements common in the Southern Piedmont contained agricultural fields and other larger openings as part of the landscape. Beginning in the late 1700s much of the land was cleared for cultivation. From 1800–1920, corn, cotton and tobacco predominated row crop agriculture. During this period, conventional farming practices with clean tillage exposed the highly erodible soils to intensive rainfall with disastrous results. Significant soil erosion occurred and most of the topsoil was lost. Research indicates cumulative soil losses of 5–10 inches throughout the region from 1700–1970 [19]. Yield differences between slightly eroded and severely eroded soils can range 40–100 percent unless corrective treatments other than fertilizers are used, such as rebuilding soil organic matter [7].

Beginning in the late 1930s, federal programs to promote soil conservation resulted in better land management, changes in cropping practices and significant reductions in soil erosion. Today, a majority of the land previously in row-crop agriculture has been converted to pasture and

FIGURE 20.1. MLRA 136 (Southern Piedmont) [20].

mixed stands of pine and hardwoods. Significant adoption of conservation tillage systems began in the late 1970s with the development of better equipment and weed control chemicals.

There are nearly 3.7 million acres of farmland in the Southern Piedmont, with about 1.2 million acres used for row-crop production and the rest used for pasture and hay production, and other agricultural enterprises [12]. Although more land is in pasture or forage production, crops such as corn, cotton, soybeans and small grains contribute to the agricultural enterprises in many counties. The extensive forage production supports beef cattle, dairy cattle, horses and smaller livestock. A major contributor to farm income in the region is poultry production. Most farms in the region are small, with an average farm size of 122 acres and a median farm size of 71 acres. The number of farms has declined over the past 10–15 years while the size of farms has increased [12]. Urbanization around major metropolitan areas has contributed to the decline in farmland.

CASH CROP SELECTION AND CROP ROTATIONS

Soybeans, corn, wheat and cotton occupy 39 percent, 20 percent, 17 percent and 8 percent, respectively, of the 1.2 million acres of harvested row-crop land in the Southern Piedmont region [12]. Corn acreage increased due to demand for its use in ethanol production. Other crops grown in the region include sorghum, tobacco, sweet potatoes, beans, orchard crops and vegetables.

The vegetable, fruit and wine-vineyard industries have grown rapidly over the past two decades, due in part to the rapid growth of urban centers that extend across the Southern Piedmont. Examples include Atlanta, Ga., Greenville-Spartanburg, S.C., and Petersburg-Richmond, Va. In North Carolina, urban centers include Charlotte, Winston-Salem-Greensboro and Raleigh-Durham. Land dedicated to vegetable production increased from 21,750 acres in 2002 to 32,104 acres in 2007, with the greatest increase seen in North Carolina, where the acreage doubled. Typically, vegetables and small fruits such as strawberries are produced using plasticulture. However, traditional organic mulch systems that incorporate cover crops and conservation tillage have increased to some extent. A variety of vegetables are produced in the region. Sweet corn, tomatoes, peppers, squash, eggplants, cantaloupes and peas are grown in the summer. Broccoli, cauliflower, cabbage, winter squash and pumpkins are grown in the fall.

Organic production is increasing, especially in areas near urban centers where the products are marketed directly to consumers and to the restaurant industry. Conservation tillage practices are not used to any appreciable extent in organic systems, though cover crops are used. Some innovative growers are using conservation tillage and heavy residue production as a way to reduce weed competition in their systems. Most organic growers recognize the soil quality improvements conservation tillage offers and would readily adopt the practice if improved methods of weed control were developed for organic systems. Weed management in reduced-tillage organic systems is discussed in Chapter 11.

Many producers in the Southern Piedmont include corn, wheat and soybeans in rotations. The most popular component of this rotation is double-cropping soybeans and wheat. The residue produced from a mature wheat crop increases biomass inputs and provides additional benefits associated with improved soil quality. Soybeans are also double-cropped following harvest of a small grain such as silage. Wheat and rye are good cover crops for this region because they produce significant amounts of biomass during the mild winter and early spring. These cover crops fit well within conservation systems for corn, full-season soybeans and cotton.

Row crop producers in the central South Carolina Piedmont focus on producing grains for dairy operations or as a cover crop in cotton production. Dairy operations create a demand for both grain and silage. Most use a corn>wheat>soybean>-fallow rotation where wheat is planted in fields harvested for silage. Harvesting for corn silage occurs earlier than grain harvest, and most of the corn plant is removed, leaving little residue. When corn is harvested for grain, the stalks, cobs and husks are left on the field. Soybeans are planted directly into wheat stubble. The rotation is fallow after soybeans because there is little time for a cover crop to grow and mature between soybean harvest and early corn planting. The need for a good short-season winter cover crop is also apparent in other parts of the region. Soybeans, corn and wheat are planted with no-till grain drills. Rotary headers that can harvest with or across rows are used to harvest corn silage planted on 15-inch rows.

Cotton producers in the region use rye and wheat as cover crops but are often planting into winter weeds due to the lateness of cotton harvest. Winter weeds are controlled with 2,4-D in March and cotton is planted either no-till or strip-till in late April to early May following a burn down of weeds with glyphosate. The amount of residue at the time of cotton planting is often minimal. Cotton production in the region continues to decline due to rising corn and soybean prices and losses in infrastructure such as gins. Producers are reluctant to invest in new or used cotton pickers because they are much less versatile than a combine. However, small pockets of producers scattered throughout the region continue to grow cotton profitably.

Vegetable producers rely on alternating crops of different families to help with disease and pest control. Wheat or rye is usually used for a winter cover crop in vegetable production systems. Vegetables are grown later in the summer after the small-grain harvest. Producers that grow tomatoes, bell peppers, eggplants and other crops from transplants use no-till transplanters to plant directly into rye or wheat residue. Summer cover crops such as sorghum-sudangrass, millet, forage sorghum or buckwheat are grown to provide biomass and compete with weeds. Legumes such as cowpeas, soybeans, annual sweet clover, sesbania or velvet beans are used as summer cover crops to add nitrogen along with organic matter.

Organic producers in the region are experimenting with various cover crops. These include legumes such as crimson clover, lupine, winter peas and vetch; non-legumes such as oats, rye and brassicas; and mixtures of legumes and cereals. They are planted in the fall either by direct seeding or by overseeding a crop such as soybeans prior to leaf drop. A roller/crimper provides an optimum method for killing the cover crops. With this equipment, a roller is pulled over the cover crop at the flowering stage, crimping the stem and resulting in death of the plant (see figures 9.2–9.4 in Chapter 9). Corn, soybeans or another crop can be direct seeded into this vegetative mat using no-till planting practices. The vegetative mat remaining from the cover crop helps control weeds. Other benefits include improved soil moisture retention, increased organic matter, nitrogen added by the legumes and the biomass returned to the soil.

MANAGEMENT CONSIDERATIONS

Fertility in the region relies on both conventional fertilizers and poultry litter. Due to the clayey texture of the soils, all of the fertilizer needed for a crop can be applied at or before planting. There is no need for split-applications of nitrogen, as is recommended with sandier soils. In conservation tillage systems, application of fertilizers on the soil surface can result in stratification of nutrients, meaning there are more nutrients in the surface soil than deeper in the soil profile. In the Southern Piedmont region, this has not proven to be a problem for supplying the nitrogen, phosphorus or potassium needed for plant growth. Starter fertilizers containing both nitrogen and phosphorus may be needed for corn in the early spring because of cooler soils under cover crop residues. Long-term use of conservation tillage and cover crops increases soil organic matter and biomass inputs achieved by leaving small-grain residues in place and by using cover crops.

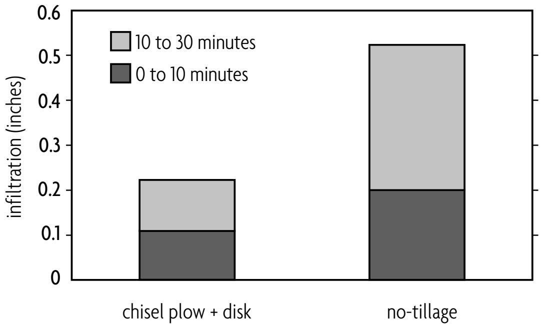

FIGURE 20.2. A comparison of rainfall infiltration under conventional tillage and under no-till. Rainfall was applied at 2 inches per hour for half an hour to simulate a summer rainstorm. Data provided by the Upper Piedmont Research Station in Reidsville, N.C.

Most soils in the region are highly eroded. This, together with many years of tillage, has resulted in mixing of the original topsoil with the underlying soil layer. In almost all cases the subsoil is finer in texture, commonly clay loam, clay, silt loam, silty-clay loam or silty clay. The current blended texture of the topsoil is often variable throughout a field because the side-slopes have suffered more erosion and mixing than the nearly level, upland areas. Soils with a finer surface texture are generally more crust-prone than the original sandier topsoil. Crusting can result in 50 percent or more of rainfall to be lost as runoff that causes soil erosion and environmental damage. The best defense against crusting is using cover crops.

For the more clayey-textured, sloping soils of the region, surface crusting can be reduced and water infiltration increased through surface residue management with continuous conservation tillage [7]. This will usually improve crop yields by reducing losses due to drought stress. An ongoing tillage study begun in 1984 in the North Carolina Piedmont demonstrated the benefits tillage can have on crop yields and water-use efficiency. Water was applied at 2 inches per hour for a half hour, which closely resembles common summer rainfall events. Infiltration in the no-till soil was more than double that of the soil that was annually chisel plowed and disked (Figure 20.2).

The no-till soil surface was not only protected by corn residue from previous crops, but it also benefited from the effects of surface residues on soil organisms. The soil organisms influence soil physical properties, which results in increased aggregation, reduced surface soil crusting and faster rainfall infiltration.

Leaving sufficient cover crop residues on soils is particularly important [3, 8, 9, 10]. An intensive cropping system that includes a winter annual cover crop followed by a summer crop that produces abundant residue is recommended. This results in a decomposing mulch on the soil surface at all times. Annual additions of 4.5–5 tons per acre of crop residue are typically needed [2, 4, 21, 22]. Barley, rye, triticale and wheat produce 5–6.5 tons of residues that can be either removed for silage or left for the following no-till corn crop (Figure 20.3). Removing small-grain residue can reduce yields. In a North Carolina no-till study, where the small-grain residues were removed, corn silage yields were reduced by 3.75–7.35 tons per acre (Figure 20.4). Economics favor leaving the small-grain residues in place because the value of small-grain silage is considerably less than the value of corn silage.

Cover crops and tillage also affect the need for subsoil management. Most of the subsoils in the region have a blocky structure that does not usually limit rooting depth. Cover crops and forages grow roots from late fall through spring when the soil is moist and less restrictive to root growth. As the roots mature and die, they leave organic matter that forms soil aggregates and pore spaces that enable future roots to exploit the soil volume more completely. Increasing the intensity of crop rooting in the subsoil increases the amount of water and nutrients available for crops. Improved yields, especially on eroded areas, also increase the amount of plant biomass returned to the soil, including root biomass. The key to successful crop production on Southern Piedmont soils is maintaining or increasing soil organic matter.

Researchers in North Carolina demonstrated the broad responsiveness of soils to long-term no-till in a survey of farm fields across the state [11]. In fields cropped to typical rotations of corn, cotton, peanuts, soybeans and small grains, three facts were confirmed:

1. Soil organic matter was critical for reducing soil bulk density.
2. Clayey soils accumulated more organic matter under conservation tillage than did sandier soils.
3. Sand, loamy-sand or sandy-loam soils at the 2- to 5-inch depth had low organic matter levels and soil bulk densities high

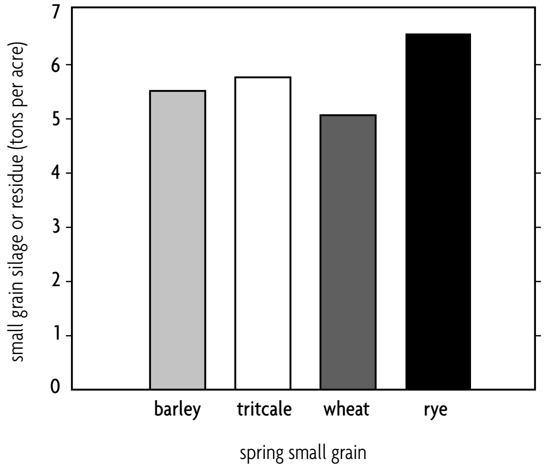

FIGURE 20.3. Small-grain biomass yields that are removed as spring silage or are left as residue for no-till corn. Data from Piedmont Research Station, Salisbury, N.C.

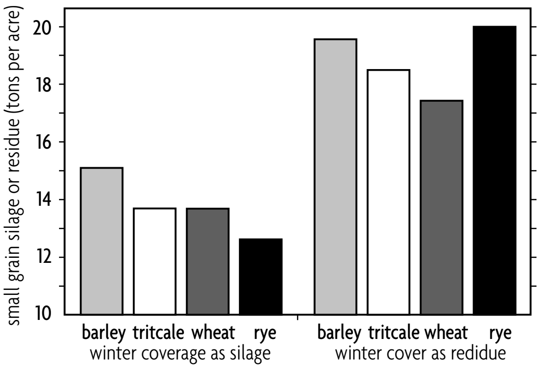

FIGURE 20.4. No-till corn silage yields averaged over three years where small grain was harvested as silage or left as residue. Notice the yield reductions where winter cover was harvested. Data from Piedmont Research Station, Salisbury, N.C.

enough to reduce root growth and activity, such as season-long nutrient and water capture.

Initial adoption of conservation tillage may require some type of subsoiling operation with a paratill (bent-leg) or rippers, along with strip-tillage. But subsoiling can be eliminated with proper management, including the use of cover crops to add organic matter to the soil [5, 13, 14, 15, 16]. A long-term study of grain sorghum grown on Cecil soil indicated yields were greater with in-row chiseling during the first four years but were greater with no-till the second four years [7]. A similar response was not seen for soybeans, due to weed and disease pressure, or for wheat, probably due to the extensive root system of wheat. In-row chisel plowing at planting results in greater cotton yields.

Variability of soil properties is common within Southern Piedmont fields. As a result, some areas need subsoil tillage while others do not. Newer technologies to map fields with GPS for yield and soil texture can be used to identify areas more likely to benefit from subsoil tillage. By identifying areas where subsoiling is not needed, these technologies reduce subsoiling costs. County-level soil maps available from the USDA Natural Resources Conservation Service can also help identify areas of fields needing special management. They include discussions of the textures typical of the surface and deeper horizons for soils in the county. Increasingly, new technologies help farmers predict and adjust to the variability that exists on their farms and to the changing demands of weather, markets and society.

Maintaining residue cover and adopting conservation tillage practices play an important role in maintaining or increasing yields (Table 20.1) [18]. Yield changes can occur in the first year, depending on such factors as soil characteristics, environmental conditions and the farmer's management intensity and experience. Due to variability in soil properties, measurable changes in the soil physical and biological properties that underpin yield gains usually require three to five years to occur.

OTHER CONSIDERATIONS

Conservation systems offer great potential for improving soil quality and reducing soil compaction. Compaction is reduced because there are fewer trips across the field with conservation

TABLE 20.1. Influence of tillage on corn and soybean yields and corn residue production for a Wedowee soil in the Southern Piedmont[1]

Tillage system	Corn yield[2]	Residue cover[3]	Soybean yield[4]
	bushels per acre	percent	bushels per acre
No-till with coulter	108	81	42
Strip tillage (10 inches wide)	104	60	35
Fall chisel plow, no-till planting	96	54	32
Spring chisel plow, no-till planting	91	20	28
Disk only	76	24	34
Fall chisel plow, spring disk	69	6	24
Spring chisel plow, spring disk	65	12	21
Fall moldboard plow, spring disk	55	2	17
Spring chisel plow, spring disk	60	1	17

[1] Data from H. P. Denton, M. W. Wagger and associates, Soil Science Department, North Carolina State University.
[2] Continuous corn, five-year average
[3] Residue cover from corn preceding the first crop of soybeans
[4] First crop of soybeans following corn

tillage and smaller, lower horsepower tractors are used. Modern equipment, GPS and autosteer allow tillage to be limited to areas where it is needed. Controlling surface traffic also reduces soil compaction. Management is critical to avoid problems of herbicide and insecticide resistance by crop pests.

The many benefits of conservation practices result in more efficient and profitable crop production in the Southern Piedmont. Crop rotation, including production of forage crops where feasible, remains a helpful tool for efficient agriculture that protects the environment. There are opportunities to diversify crop rotations, such as including multi-year or perennial forage crops for use as animal feed and/or as sources for renewable energy production.

CASE STUDIES

Corn-Soybean-Clover Seed Production

A grower in Rowan County, N.C., has developed a row-crop/cover crop system that is profitable and sustainable. A winter cover crop of crimson clover is planted in the fall. Seed is harvested from the crimson clover the following spring, and a double-crop of soybeans is no-till planted into the crimson clover stubble. That fall, crimson clover seed left on the surface germinates and grows similar to a fall-planted, interseeded crop below the fall-harvested soybeans. Crimson clover is grown through the winter and no-till corn is planted into the clover residue in the spring. All crops are no-till and the grower produces three crops in a two-year rotation: crimson clover seed>soybeans>corn. The farmer does not use nitrogen on the soybean crop and reduces the nitrogen application rate for corn due to the crimson clover residue and soybean stubble. The system is not only profitable but also reduces erosion and builds soil organic matter due to continuous no-till and crop residue buildup.

Sod-Based Tomato Production

A grower in the Southern Piedmont region of North Carolina has been able to utilize a sod-based system to grow hay and vegetables. This grower harvests a hay crop in the spring on a bottom soil near a stream. Following hay removal, a strip-till implement is used to cultivate beds 8–12 inches wide for tomatoes. Tomatoes are transplanted into the cultivated strips and grown using standard bare-soil production practices. During the summer, the sod is mowed with a riding mower. Inter-row areas receive considerable foot traffic due to twice-a-week harvesting, yet the sod holds the soil in place and provides a cleaner environment. The potential for soil to be splashed on tomatoes when it rains is reduced. Fields can be walked on immediately after rain due to the sod between the rows. Chapter 8 has more information about sod management and growing hay in dormant sod.

This sod-based system will work for conventional producers and may have promise for organic producers. Conventional producers can keep the tomato rows free of grass weeds with an herbicide. Organic producers could use a mulch to reduce grass growing into the tomato rows. Trickle chemigation, or the delivery of nutrients or pesticides through a closed irrigation system, can be used for these crops, reducing overhead spray. The grower produces hay and a vegetable crop in this conservation tillage system. Peppers, eggplants and tobacco will work in this system. As with tomatoes, the potential for soil to splash on to vegetables is reduced.

No-Till Wheat

Steve Gibson is a retired North Carolina State University agricultural Extension agent in Cleveland County. He remembers that producers in the Southern Foothills region of North Carolina faced real challenges getting land prepared for small-grain planting after the summer crop (soybeans, cotton, corn or grain sorghum). Tillage operations following summer harvest usually meant late small-grain plantings and, sometimes, poor stands. Beginning in the late 1980s, producers started adopting no-till planting of wheat following their summer crop, and by the mid-1990s nearly all of the small grains in the region were no-till planted. Improvements in no-till drills really helped farmers successfully make this change. Also, the availability of combine straw choppers and chaff spreaders made planting even into heavy corn or grain sorghum stubble possible. In 1989, the Cleveland County Extension program decided to no-till plant all variety tests and demonstrations. This helped promote the practice to the point where the vast majority of crop fields are now under continuous no-till.

Many of the problems producers thought would arise by switching to continuous no-till did not materialize. Instead, producers have learned over the past 20 years that seeding rates for no-till are about the same as conventional tillage, and establishment is similar. The incidence of Hessian fly and head scab has not increased with no-till, even with no-till wheat planted into corn residue. Diseases like leaf and glume blotch remain as troublesome as they were in conventional systems. Gibson says the keys to successfully growing no-till wheat are careful variety selection, timely but not too early planting, appropriate seeding rates, and using scouting and weather forecasts to dictate the need for foliar fungicides.

Producers are discovering many unforeseen advantages to continuous no-till systems, such as improvements in soil quality. A field in Cleveland County was monitored with extensive soil sampling after the conversion to continuous no-till. In four years the soil's humic matter and cation exchange capacity doubled. No-till has indeed made field-crop production much more sustainable.

Corn Silage No-Till System

Ray Styer, a livestock farmer from Rockingham County, N.C., uses a cover crop seed mixture of 20 pounds of Abruzzi rye, 8 pounds of hairy vetch, 4 pounds of Daikon radish, 10 pounds of winter peas and 5 pounds of crimson clover per acre in his no-till corn-silage production system. The mixture of winter cover crops, rather than just one species, pays dividends on production costs and provides the bonus of soil improvements. The only time he deviates from this mix is when experimenting.

Planted early and allowed to achieve a reasonable level of maturity before termination, the rye residue provides summer-long ground cover to conserve moisture, while the legumes supply nitrogen for the corn. The rye also scavenges any residual soil nitrogen not taken up by the previous summer crop, thus reducing the possibility of nitrate leaching into the groundwater. The radishes will winter kill, so they need to be planted early to maximize growth. Styer cautions that a high-biomass cover crop may negatively affect water availability to the following crop at planting. On the other hand, a thick mulch helps conserve moisture later in the growing season. Styer points out that it is important to ensure the planter is getting through the residue and that seeds are placed at the proper soil depth.

Styer stopped applying nitrogen fertilizer in 1996 and stopped applying a starter fertilizer a few years later after taking tissue samples. Instead, cover crops and manure have improved water-holding capacity, stopped erosion and supplied nutrients to grow his crops. He relies on the legume to provide fixed nitrogen and on the rye to supply some nitrogen scavenged from the previous year. Lots of farmers think cover crops cost too much, but in 2004 Styer figured if he applied nitrogen alone at 125 pounds per acre it would cost $34.50. On the other hand, the cover crop system per-acre costs were $32. (At that time he was planting a rye/hairy vetch/crimson clover mix: $8 for rye seed, $12 for hairy vetch seed, $5 for crimson clover seed and $7 for planting.) For a fewer dollars, he gets the nitrogen, plus the ground cover and soil improvements.

While it may seem impossible for every farm to use an extensive cover crop system like Styer's, he thinks there are systems that can work for just about every situation. A rotation can be implemented to include a cover crop. Each species has a particular benefit. All of them accomplish the basic goal of covering the soil. Styer believes the soil should be covered at all times of the year, preferably with a growing crop, or at least with heavy residue.

SUMMARY

Conservation tillage, cover crops and other practices that rebuild soil organic matter are critical to increasing crop productivity and reversing the negative impact of historical topsoil loss in the Southern Piedmont region. The bottom line is that improvements in soil properties associated with conservation tillage and increased biomass inputs are the keys to increasing crop productivity and achieving sustainability. Conservation tillage is critical to keeping residues on the soil surface [17]. Measurable changes in soil physical and biological properties usually require three to five years to occur due to the variability in soil properties. Yield changes can often be seen in the first year, depending on the producer's experience and management intensity, soil physical factors and environmental conditions. Maintaining residue cover and decreasing tillage intensity are important factors for maintaining or increasing yields [18].

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Appendix

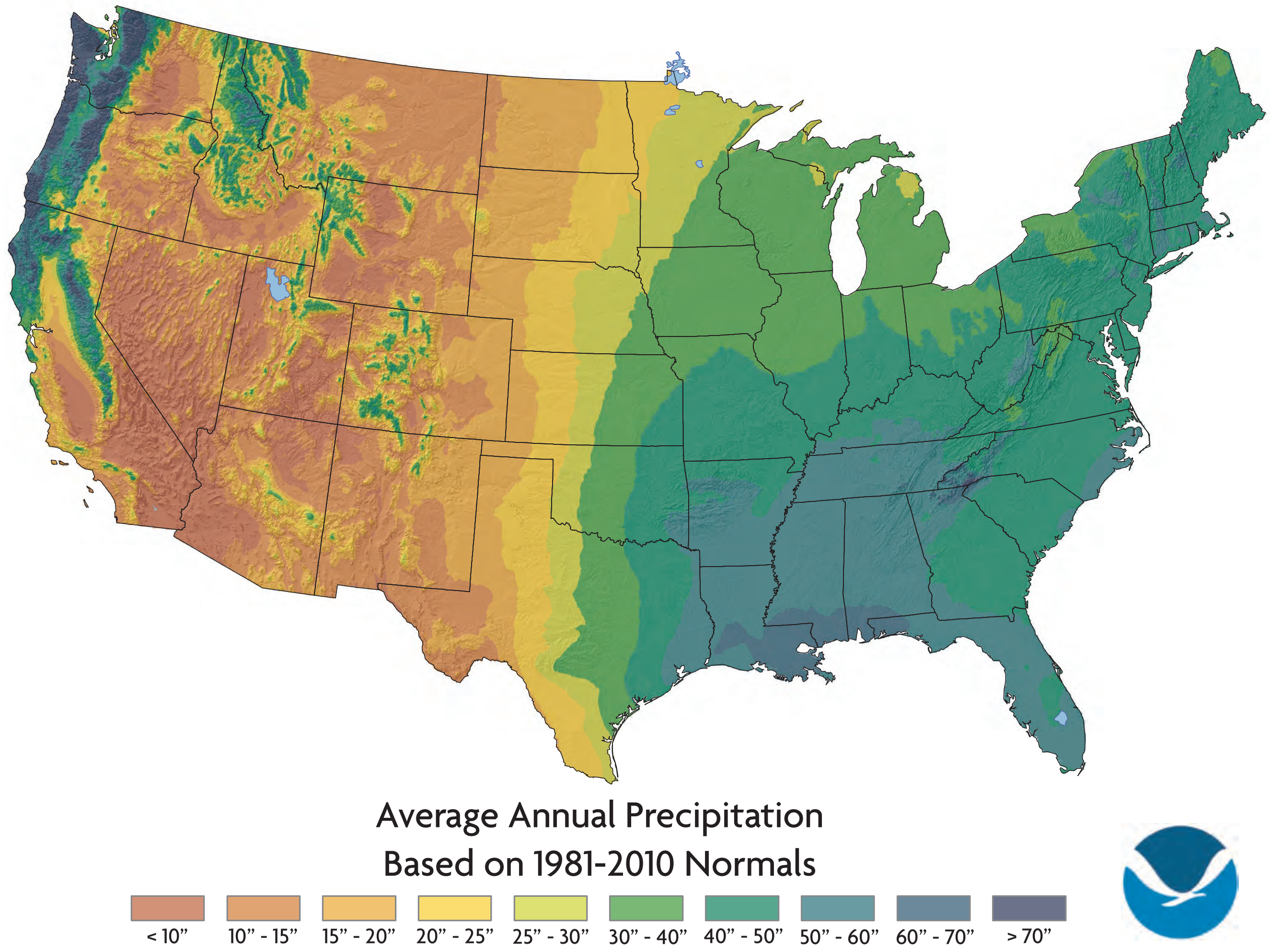


FIGURE 1. Average Annual Precipitation Based on 1981–2010 Normals
National Oceanic and Atmospheric Administration. (NOAA). 2016. *Average annual precipitation based on 1981–2010 normals.* NOAA National Centers for Environmental Information.

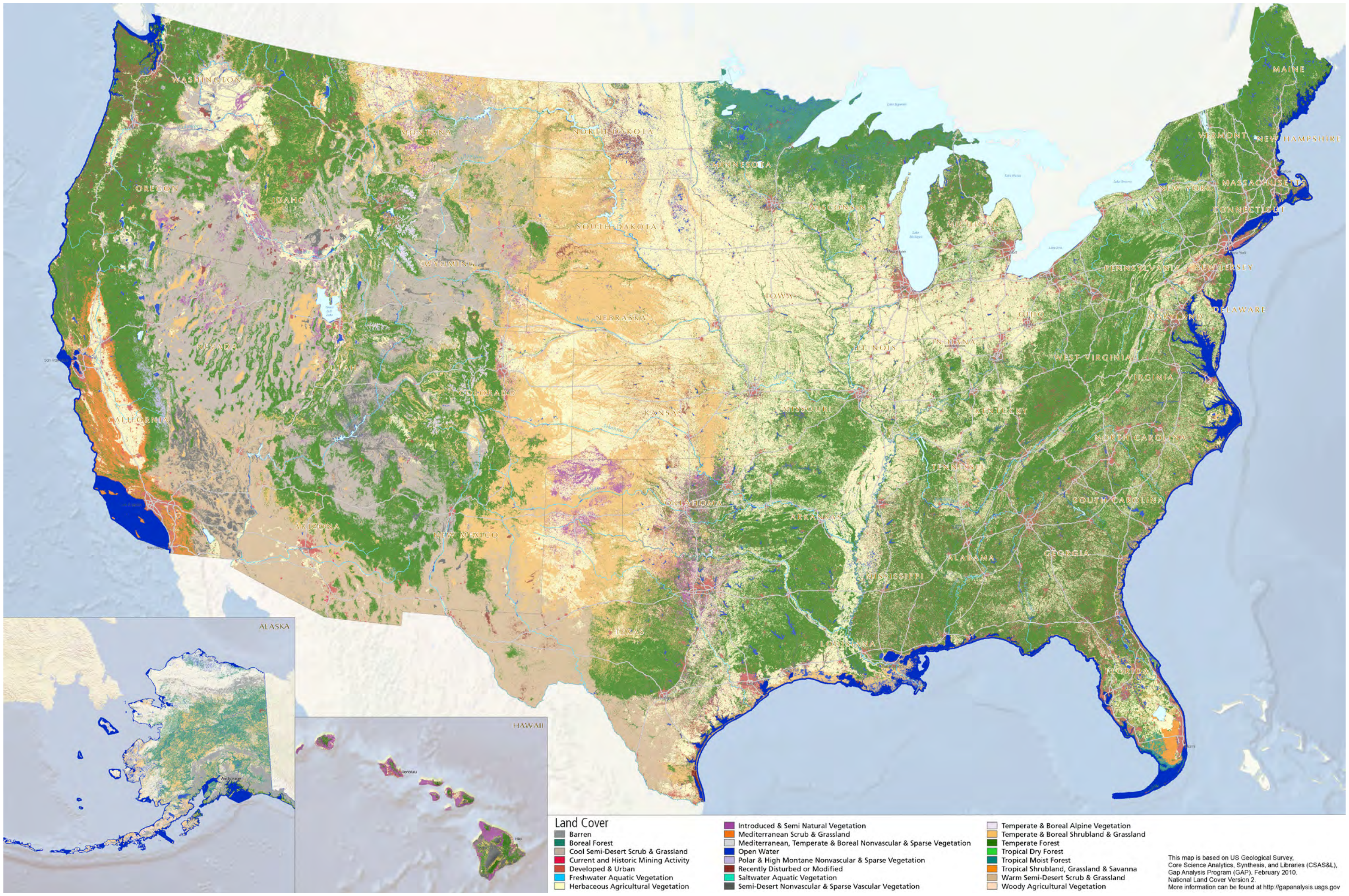
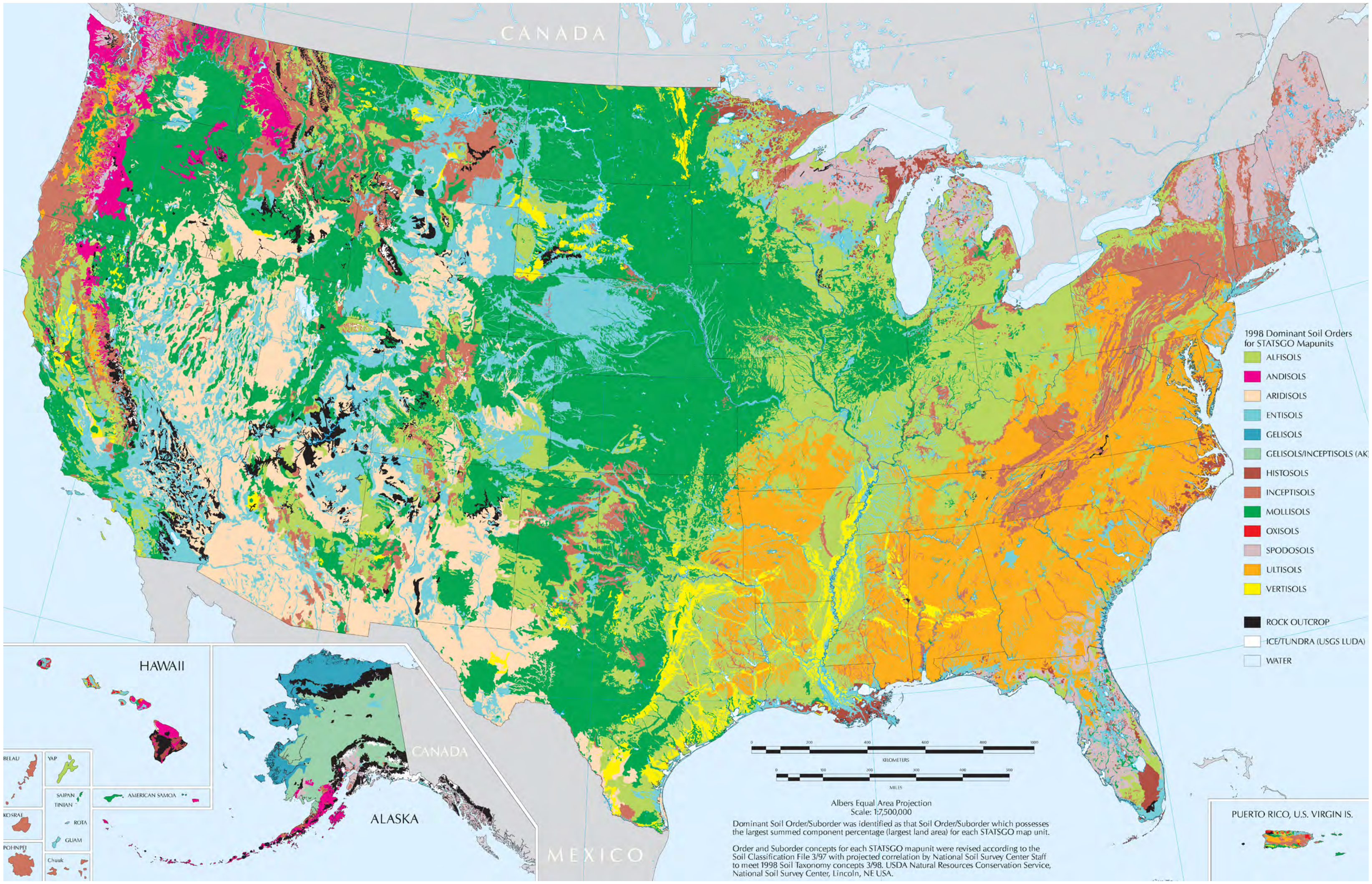


FIGURE 2. Land Cover of the United States

U.S. Geological Survey. 2014. *National Gap Analysis Program (GAP), Land Cover Data Viewer*. U.S. Department of Interior.



Albers Equal Area Projection
Scale: 1:7,500,000

Dominant Soil Order/Suborder was identified as that Soil Order/Suborder which possesses the largest summed component percentage (largest land area) for each STATSGO map unit.

Order and Suborder concepts for each STATSGO mapunit were revised according to the Soil Classification File 3/97 with projected correlation by National Soil Survey Center Staff to meet 1998 Soil Taxonomy concepts 3/98. USDA Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE USA.

FIGURE 3. Figure 3. Dominant Soil Orders of the United States.
USDA Natural Resources Conservation Service (NRCS). 1998. *Dominant Soil Orders of the United States*. USDA NRCS National Soil Survey Center: Lincoln, NE.
Land Cover of the United States

Glossary

ACCase inhibitors. Herbicides belonging to Aryloxyphenoxypropionate (FOPs), cyclohexanedione (DIMs), and phenylprazolin (DENs) chemistries. These herbicides inhibit the enzyme acetyl-CoA carboxylase (ACCase), which catalyzes the first step in fatty acid synthesis and is important for membrane synthesis.

Actinobacteria. Most are found in soil; they include some of the most common soil life and play important roles in decomposition and humus formation.

Adjusted gross income. Defined by the income tax system as gross income minus specific deductions to income.

Aflatoxin. Toxic metabolites produced by certain fungi in or on foods and feeds. Aflatoxins have been associated with various diseases in livestock, domestic animals and humans.

Aggregate stability. A measure of the proportion of the aggregates in a soil that do not easily slake, crumble or disintegrate.

Aggregates. The structures, or clumps, formed when soil minerals and organic matter are bound together with the help of organic molecules, plant roots, fungi and clays.

Allelopathy. Suppression of the germination or growth of one plant by another. The chemicals responsible for this effect are produced during the growth of a plant or during its decomposition.

ALS inhibitors. Acetolactate synthase (ALS)-inhibiting herbicides inhibit the enzyme common to the biosynthesis of branched-chain amino acids. ALS-inhibiting herbicides affect vascular plants (i.e., those with conducting tissue that can move water and minerals throughout the plant), bacteria, fungi, yeasts and algae.

Alter-row spacing. To space crops apart with another crop in order to establish better and more-productive plants.

Amortized annual cost. The accumulated portion of the recorded cost of a fixed asset that has been charged to expense through either depreciation or amortization.

Anaerobic. Growing in the absence of molecular oxygen (such as anaerobic bacteria).

Anion. Atoms or molecules that have a negative charge due to the presence of more valence electrons than protons. These types of ions include chlorine, nitrate, sulfate and phosphate.

Anion exchange site. The site of the chemical process in which anions are exchanged or removed.

Base saturation. The ratio of the quantity of exchangeable bases to the cation exchange capacity.
The value of the base saturation varies according to whether the cation exchange capacity includes only the salt extractable acidity or the total acidity determined at pH 7 or 8. Often expressed as a percent.

Beneficial insects. Insects that prey on pests, thereby reducing insect damage to crops.

Bioenergy. Energy derived from the conversion of biomass where biomass may be used directly as fuel or processed into liquids and gases.

Biofuels. Fuel composed of or produced from biological raw materials as opposed to fossil fuels.

Biomass. Biological material derived from living or recently living organisms.

Biorefinery. A facility that converts biomass to energy.

Bt corn. A variant of maize that has been genetically altered to express one or more proteins from the bacterium Bacillus thuringiensis, including Delta endotoxins. The protein is poisonous to certain insect pests and is widely used in organic gardening.

Bulk density. The dry weight of soil per unit volume of soil. Bulk density considers both the solids and the pore space, whereas particle density considers only the mineral solids. It is an indicator of compaction and is typically expressed in grams per cubic centimeter (g/cm^3).

Capillary action. The movement of water within the spaces of porous material due to the forces of adhesion, cohesion and surface tension.

Capital recovery method. A process to estimate the amount required to regain the cost of an asset.

Carbon sequestration. The process by which atmospheric carbon dioxide is taken up by trees, grasses and other plants through photosynthesis and stored as carbon in biomass (trunks, branches, foliage and roots) and soils.

Carbon-to-nitrogen ratio (C:N). The amount of carbon in a residue divided by the amount of nitrogen. A high ratio results in low rates of decomposition and can also result in a temporary decrease in nitrogen nutrition for plants, as microorganisms use much of the available nitrogen.

Catch crop. A crop that reaches maturity in a relatively short time, often planted as a substitute for a crop that has failed or at a time when the ground would ordinarily lie fallow, as between the planting of two staple crops.

Cation. Atoms or molecules that have a positive charge due to the presence of less valence electrons than protons. These types of ions include calcium, magnesium, potassium, ammonium, hydrogen and sodium.

Cation exchange capacity (CEC). The amount of negative charge that exists on humus and clays, allowing them to hold onto positively charged chemicals (cations). This process helps keep nutrients in place and in a form easily exchangeable with plant roots.

Cellulose. An inert carbohydrate and the chief constituent of the cell walls of plants and of wood, cotton, hemp, paper, etc.

Chaff. The seed covering and other debris separated from the seed when threshing grain.

Chisel plowing. A tillage system that fractures the plow layer with a minimum amount of incorporation of surface residue.

Clean tillage. Any system that leaves the soil surface more or less free of residue.

Compaction. Soil compaction occurs when soil particles are pressed together, reducing pore space between them. Heavily compacted soils have a reduced rate of both water infiltration and drainage from the compacted later.

Compost extract. Liquid versions of solid compost material, commonly known as compost teas. They contain soluble plant nutrients and a complex community of beneficial microorganisms.

Cone index. A parameter of soil strength that measures the bearing capabilities of the soil. A soil's cone index is greatly influenced by tillage types and is related to soil density.

Cover crop. A crop grown for the purpose of protecting the soil from erosion during the time of the year when the soil would otherwise be bare. It is sometimes called a green manure crop.

Deep Banding. The placement of immobile nutrients in a band at a depth of 4–6 inches below the soil surface. This placement is frequently used in conservation tillage systems.

Denitrification. The process by which microorganisms convert nitrate to a gas, causing nitrogen losses from the soil into the atmosphere. This occurs when soils are water saturated and oxygen is low.

Dicotyledonous plants or dicots. A grouping of flowering plants whose seed typically has two embryonic or first leaves of a seedling plant.

Dinitroanilines. A mode of action for certain herbicides. Dinitroaniline herbicides are considered selective preemergence herbicides.

Double crop. Two different crops grown on the same space in the span of one growing season.

Draft force. A measure of the amount of force required to move tillage implements through a field.

Drainage. Movement of water out of the soil profile.

Dry matter. The portion of feed remaining after the removal of water.

E horizon. A mineral horizon in the soil profile in which the main feature is loss of silicate clay, iron, aluminum or some combination of these, leaving a concentration of sand and silt particles, and in which all or much of the original rock structure has been obliterated. See also *Horizonation*.

E85. Ethanol-gasoline blends containing a high level of ethanol, from 51–83 percent ethanol. E85 can be used in flexible fuel vehicles.

Economic threshold. The density of a pest population at which a control treatment is necessary to provide an economic return.

Ecosystem services. The benefits people obtain from ecosystems, including provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational and cultural benefits; and supporting services such as nutrient cycling.

Ecotype. A genetically distinct geographic variety, population or race within a species, which is genotypically adapted to specific environmental conditions.

Eluviated. The removal of soil material in suspension (or in solution) from a layer or layers of a soil. Usually, the loss of material in solution is described by the term "leaching." See also *Leaching*.

Enterprise budget. Used to record the revenue, expenses and returns for a single crop or livestock enterprise on a per unit basis.

Evapotranspiration. The sum of evaporation and transpiration.

Fragipan. Dense subsurface layers that severely restrict water flow and root penetration.

Generalist pests. Attack a wide range of plant species. Examples include wireworms, seed corn maggots and aster leafhoppers.

Giant cells. Feeding sites created by plant-parasitic nematodes on the roots of plants. The plant loses nutrients at these sites.

Glomalin. A coating found on the hyphae (hair-like projections) of arbuscular mycorrhizal fungi (AMF). AMF are microorganisms that evolved with plants to aid in acquiring nutrients, especially immobile nutrients like phosphorus. Glomalin keeps water and nutrients from getting lost on the way to and from the plant.

Glycoprotein. A complex protein containing a carbohydrate combined with a simple protein.

Green manure. A crop grown for the main purpose of building up or maintaining soil organic matter. It is sometimes called a cover crop.

Hairpinning. The process by which residue is trapped in the seed furrow due to the dragging of fresh, wet residue by implements following termination. Hairpinning reduces seed-to-soil contact, resulting in poor seed germination.

Herbicide-resistant weed. Weeds that resist herbicide application at doses that usually give effective control of the species. Resistant weeds are a consequence of evolutionary processes.

Herbicide-resistant variety. Inherited ability of a plant to survive and reproduce following exposure to a dose of an herbicide normally lethal to the wild type. In a plant, resistance may be naturally occurring or induced by such techniques as genetic engineering or selection of variants produced by tissue culture or mutagenesis.

HG types. Subspecies groups of the soybean cyst nematodes that are morphologically identical but may infect and reproduce on different soybean varieties in different ways.

High-residue cover crop. A cover crop that produces at least 4,000 dry matter pounds per acre.

Hipper. A common-use term for a piece of equipment used to make raised beds.

Horizonation. Soil profiles are made up of discrete layers, called horizons, with distinct characteristics. They are typically parallel with the ground surface.

Humus. The very well decomposed part of the soil organic matter. It has high cation-exchange capacity.

Hydraulic conductivity. A quantitative measure of a saturated soil's ability to transmit water when subject to a hydraulic gradient. It can be thought of as the ease with which pores of a saturated soil permit water movement.

Immobilization. Process by which microorganisms and plants store nutrients in their bodies.

Inoculum. The pathogen or part of the pathogen that causes infections. Inoculum for plant-parasitic nematodes consists of eggs and vermiform life stages of the nematode.

Input costs. The costs of crop establishment and production (e.g., seed or fuel costs).

In-row subsoiling. The soil surface and residue are left undisturbed except for strips up to one-third of the row width. Within these strips, soil below the surface is disturbed or loosened using deep-tillage implements. Other names for in-row subsoiling include strip-till, row-till and slot-till. Depending on the type of tillage shank used, names for this practice may also include paratill or terra-till.

Integrated pest management (IPM). An ecosystem-based strategy that uses a variety of biological and cultural practices to limit pest damage. Pesticides are used only when monitoring indicates they are needed to avoid an economic loss.

Internal drainage. The continuing process in a soil that results in water removal under natural conditions.

Interseeding. The general practice of sowing a crop into another standing, growing crop late in the season, usually to enhance biomass production or erosion control, or to increase soil organic matter. This practice is also known as overseeding.

Inversion tillage. Tillage that flips over a layer of soil, burying surface residues in the process.

Invisible seeding. Furrowing with minimum soil movement.

Leaching. The downward movement of dissolved nutrients in the soil profile with percolating water.

Lignocelluloses. Any of several closely related substances consisting of cellulose intimately associated with lignin and constituting the essential woody cell walls of plants.

Macropores. Large pores responsible for preferential flow and rapid, far-reaching transport.

Major land resource area. Geographic area characterized by a particular pattern of soils, climate, water resources, land uses and types of farming.

Microbial biomass. The living component of soil organic matter. Microbial biomass consists mostly of bacteria and fungi, which decompose crop residues and organic matter in soil. This process releases nutrients, such as nitrogen, into the soil that are available for plant uptake.

Microbial degradation of pesticides. The process by which the pesticide compound is broken down by living organisms, usually bacteria.

Microflora. The constellation of living microorganisms, such as bacteria and fungi, that are found on or in a particular location, such as the soil environment.

Mineralization. Process by which soil organisms change organic elements into the "mineral" or inorganic form as they decompose organic matter (e.g., organic forms of nitrogen are converted to nitrate).

Mode of action. The way in which a pesticide destroys or controls the target pest (e.g., affecting an insect's nerves or molting).

Mortality factor. A factor of, or contributor to, insect mortality that brings about population regulation.

Natural enemy. A species that preys on another species for food.

Nitrification. The conversion of ammonium to nitrate by bacteria.

Nitrogen fixation. The conversion of atmospheric nitrogen by bacteria to a form that plants can use. A small number of bacteria, which include the rhizobia living in the roots of legumes, are able to make this conversion.

Nodulation. A symbiotic event between a host plant and a bacterium. The plant gains a steady supply of nitrogen, and the bacterium gains a steady supply of carbon.

Non-inversion tillage. Also known as conservation tillage. Includes systems of tillage that involve fewer passes than conventional tillage but that incorporate crop residue into the surface soil layers, while leaving at least 30 percent of crop residue on the soil surface. Also includes direct drilling, which leaves the soil completely undisturbed from harvest until seeding and all crop residues remain on the surface. With direct drilling, seed placement is achieved by discs, coulters or chisels opening a narrow slot where the seed is delivered.

Nonpoint source pollution. Pollution that cannot be traced to a single point source such as a pipe or smokestack. Nonpoint source pollution comes from many diffuse sources, generally from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification. It may be caused by rainfall or snowmelt moving over and through the ground.

Non-selective herbicide. Herbicides that tend to kill all plant species they are exposed to rather than being designed to kill particular types of weeds such as grasses and broadleaves.

No-till. Soil is undisturbed by tillage during the entire year. Crop residues left on the soil surface may be disturbed in strips up to one-third of the row width for planting or drilling seed. Other common terms for no-till include direct seeding, slot planting and zero-till.

Nutrient cycling. The process of storing, moderating the release of, and cycling nutrients and other elements by soil. During this process, nutrients can be transformed into plant-available forms, held in the soil or lost to air or water.

Opportunity cost. When presented with multiple potential uses of a resource, this cost represents the lost value associated with those potential uses that are not pursued.

Organoarsenicals. These chemicals have been used in pesticides and insecticides, as well as in additives in animal feeding operations.

Overseeding. See *Interseeding*.

Paraplow. A slant-shank chisel plow that fractures and loosens soil to a working depth of 12–16 inches. The soil surface is left smooth with little disturbance of the standing stubble.

Parasitoid. Insects that spend a portion of their lives in a pest host, ultimately killing the host.

Paratill. See also *In-row subsoiling*.

Partial budgeting. Used to analyze the effects of proposed changes in cropping systems or farm systems. Partial budgets only consider changes in revenue and expenses due to a management change or the adoption of a new technology. Partial budgeting is used to determine if the proposed change will have a net positive or net negative effect on farm profits.

Pegging (peg). A stage in the life cycle of the peanut plant. After pollination, when the plant's petals begin to wither and fall, a stalk called the peg forms and begins to grow toward the ground.

Penetrometer. An instrument in the form of a cylindrical rod with a cone-shaped tip designed for penetrating soil and for measuring the end-bearing component of penetration resistance. The resistance to penetration developed by the cone equals the vertical force applied to the cone divided by its horizontally projected area.

Percolation. The movement of water within the soil. Percolation rate controls the infiltration rate and is controlled by grain size.

Photosystem II inhibitors. A mode of action that interferes with the electron transfer chain of Photosystem II, which is essential for the production of photosynthetic energy.

Physiological races. Subspecies groups of plant-parasitic nematodes that are morphologically identical but may infect and reproduce on a given set of plant host varieties differently.

Planting flat. Not using a raised bed.

Post-emergent (POST) herbicides. Herbicides applied after the crop has germinated and must be used when the plant is actively growing.

Precision ditch. Technique using contour intervals of less than 2 inches to show where to put drainage ditches so they will channel water off of the field.

Precision grade grassed waterway. Constructed graded channels that are seeded to grass or other suitable vegetation. The vegetation slows the water and the grassed waterway conveys the water to a stable outlet at a non-erosive velocity.

Pre-emergent (PRE) herbicides. Herbicides applied at planting or within a few days before crop emergence. They are designed to prevent the germination of seeds by inhibiting a key enzyme.

Primary tillage. Also known as plowing, primary tillage is used to invert the top layer of soil, break up compaction, turn under residues and bury weed seeds. Precedes secondary tillage in conventional agricultural production.

Rainfed. Term used to describe farming practices that rely on rainfall for water.

Raised bed. A raised cultivated area between furrows or wheel tracks of tractors specially prepared, managed and/or irrigated to promote the production of a crop.

Residue mat. A layer of biomass that remains following the termination of a high-residue cover crop.

Residues. Plant material remaining after harvest, including leaves, stalks and roots.

Ridge till. Specialized planters and cultivators are used to form and retain permanent ridges on which cash crops are grown. Crops are planted on the top of the ridge after removing residue from the top of the ridge. Residue is left between ridges. Cultivation is used to form and maintain ridges and to manage weeds.

Ripping. Mechanical soil treatment aimed at improving infiltration rates in machine-compacted or water-repellent soils.

Risk management. Addressing concerns about weather, prices, yields, government policies, etc. that impact farming and can cause wide swings in farm income. Risk management involves choosing among alternatives that reduce the financial effects that can result from such uncertainties.

Roll. A broadcast, secondary tillage operation that crushes clods and compacts or firms and smooths the soil by the action of ground-driven, rotating cylinders.

Root exudates. Compounds exuded by plants into the soil. Root exudates maintain and support a highly specific diversity of microbes in the rhizosphere of a given plant species.

Salvage value. Estimated resale value of an asset at the end of its useful life.

Scavenging. The trapping of excess nutrients that would otherwise move out of the root zone.

Secondary tillage. Includes harrowing and/or disking the soil, resulting in smooth, clod-free seedbeds. Follows primary tillage in conventional agricultural production.

Selective herbicide. An herbicide that is designed to kill specific types of weed species.

Short-rotation woody crops. Woody tree species that have been bred and selected to have extremely high rates of growth, allowing them to be harvested after a short growing period.

Skip row. A pattern of planting in which a planted row or rows is followed by a row or rows that are not planted, or skipped rows.

Sod-based rotation. A rotation that alternates sod-forming grasses and legumes with row crops and cereal grains.

Soil fertility. The ability of the soil to supply essential plant nutrients and soil water in adequate amounts and proportions for plant growth and reproduction in the absence of toxic substances that may inhibit plant growth.

Soil health. See *Soil quality*.

Soil quality. The continued capacity of soil to function as a living ecosystem that is capable of sustaining plants, animals and humans while maintaining environmental quality. Also referred to as soil health.

Soil strength. A soil's resistance to penetration and an increase in bulk density (an indicator of soil compaction). See also *Bulk density*.

Soil tilth. The physical condition of soil, especially in relation to its suitability for planting or growing a crop.

Spatial Plant Analysis Development (SPAD). Measures the relative greenness of leaves, which is proportional to the amount of chlorophyll present. This indicates the photosynthesis potential of the plant. The meter used in SPAD measures transmittance from the leaf at two wavelength ranges (600–700 nanometers and 499–500 nanometers)

Split applications. The division of fertilizer treatments into two or more applications.

Stale seedbed. Using cultivation to encourage weeds to germinate prior to sowing a crop. Each "flush" of weeds is destroyed by further cultivations or herbicide prior to sowing the crop. This should reduce the number of weed seeds left to germinate in the crop.

Strip cropping. Growing two or more crops in alternating strips, usually along the contour or perpendicular to the prevailing wind direction.

Strip tillage. See *In-row subsoiling*.

Stubble mulch. A blade plow or sweep plow cuts weeds at the roots and leaves most of the residue anchored at the surface with minimum disturbance of the soil surface.

Subsoiling. See *In-row subsoiling*.

Surface dribbled. Fertilizer placed on the soil surface rather than below the surface. This is likely to result in lower productivity but also in lower input costs.

Tennessee Biofuels Initiative. A research-business collaboration for biofuels development.

Terra-till. A method for in-row subsoiling that lifts and bends subsoil to remove hardpans.

Traffic pan. Compacted soil horizon created by the action of machinery, such as trucks or tractors, over the soil.

Transgenic crops. Contain a gene or genes that have been artificially inserted instead of the plant acquiring them through pollination. An example is Bt corn, which produces its own insecticide. Plants containing transgenes are often called genetically modified or GM crops.

Vegetative reproduction. The process by which some plants reproduce through vegetative parts such as roots, bulbs or stolons (runners) as opposed to reproducing through seeds. This is asexual reproduction, allowing a plant to propagate in isolation.

Volatilization. The process by which surface-applied fertilizers, such as nitrogen, are transformed into gas and lost to the atmosphere.

Volunteer plants. Plants found growing without having been planted, as by natural regeneration, and if undesired, are considered weeds.

Wash. A soil erosion effect caused by runoff of water.

Zone tillage. A reduced tillage method that limits soil disturbance to the area of the planting row and leaves the areas between the crop rows undisturbed.