MANAGING COVER CROPS IN CONSERVATION TILLAGE SYSTEMS

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INTRODUCTION

Conservation tillage is defined as a system that leaves enough crop residue on the soil surface after planting to provide 30% soil cover, the amount needed to reduce erosion below tolerance levels (SSSA). Today, however, most conservation tillage practitioners aim for greater soil cover because of additional benefits of crop residue. Cover crops are critical to producing this residue and have the potential to maximize conservation tillage benefits.

Benefits of *conservation tillage* systems include:

- reduced soil erosion
- decreased labor and energy inputs
- increased availability of water for crop production
- improved soil quality

Cover crops further benefit conservation tillage systems by:

- producing crop residues that increase soil organic matter and help control weeds
- improving soil structure and increasing infiltration
- protecting the soil surface and dissipating raindrop energy
- reducing the velocity of water moving over the soil surface
- anchoring soil and adding carbon deep in the soil profile (via roots)

Conservation tillage has been adopted on more and more acres since the 1970's thanks to improvements in equipment, herbicides and other technologies. Several long-term, incremental benefits of conservation tillage have emerged. The most important benefits have been attributed to the accumulation of organic matter at the soil surface.

This accumulation of surface organic matter results in:

- increased aggregate stability, which helps to increase soil water infiltration and resist erosion
- improved nutrient cycling and water quality, due to keeping nutrients in the field
- increased biological activity, which improves nutrient cycling and can influence diseases and pests

Additional benefits from conservation tillage systems compared to intensive or conventional tillage systems (89) include:

- Reduced labor and time—one or two trips to prepare land and plant compared to three or more reduces labor and fuel costs by 50% or more.
- Reduced machinery wear—fewer trips mean fewer repairs.
- Increased wildlife—crop residues provide shelter and food for wildlife, such as game birds and small animals, which can result in additional farm revenue.
- Improved air quality—by reducing wind erosion (amount of dust in the air), fossil fuel emissions from tractors (fewer trips) and release of carbon dioxide into the atmosphere (tillage stimulates the release of carbon from organic matter).

In an Iowa study comparing no-till and conventional tillage in a corn>soybean>wheat/clover rotation, corn and soybean yields were lower in no-till plots the first year. With yearly application of composted swine manure, however, yield of both corn and soybean were the same for both systems beginning in year two of the study. Wheat yields were not affected by tillage, but increased with compost application (385).

Cover crop contributions to conservation tillage systems

Biomass. Conservation tillage systems depend on having crop residues on the soil surface for most of the year. Cover crops help provide the additional biomass needed to meet this year-round requirement. A typical high residue cover crop should contain at least 4000 lb. biomass/A.

In low-fertility soils, you can increase biomass production of grass cover crops with the addition of a small amount of N fertilizer. Cover crops grown in soils with higher levels of organic matter, or following a legume summer crop like soybean, may not need additional N fertilizer. Remember, minimal cover crop residue or biomass translates into minimal benefits.

Soil improvement. Cover crop biomass is a source of organic matter that stimulates soil biological activity. Soil organic matter and cover crop residues improve soil physical properties, resulting in:

- greater water infiltration, due to direct effects of the residue coverage or to changes in soil structure
- greater soil aggregation or tilth, resulting in better nutrient and moisture management
- less surface sealing, because residue intercepts rain drops, reducing the dispersal of clay particles during a rainfall or irrigation event
- greater soil porosity, due to the macropores that are formed as roots die and decompose

Improvements in soil physical properties depend on soil type, crops grown and residue management system, as well as temperature and rainfall. Regardless of soil type, however, tillage will very quickly negate cover crop benefits associated with increased soil organic matter. Simply put, tillage breaks down organic matter much faster than no-till.

Improvements in soil physical properties due to cover crops have been documented widely in conservation tillage systems (25, 52, 106, 114, 115, 119, 238, 318, 419).

Erosion control. Cover crops and conservation tillage combine to reduce soil erosion and wind erosion (26, 115, 119, 223, 267).

In Kentucky, on a Maury silt loam soil with a 5% slope, soil loss was 8 tons/A for conventionally tilled corn with the corn residue and cover crop turned under in the spring. In contrast, for no-tillage corn with 3 tons/A of corn residue remaining on the soil surface, soil loss was 1 ton/A without a cover crop and 0.9 tons/A with a winter cover crop (91, 151).

Tillage breaks down organic matter much faster than no-till.

In Missouri, on a Mexico series silt loam soil with a claypan, inclusion of a rye or wheat cover crop reduced soil loss in no-tillage silage corn from 9.8 to 0.4 tons/A/year (437).

Rotation effects. Crop rotation provides numerous benefits to any cropping system. It is critical to reducing the incidence of diseases and pests, and is also credited with improving nutrient use and reducing weeds. Cover crops increase the complexity and intensity of crop rotations, effectively increasing crop rotation benefits. Note, however, as addressed throughout this book, that cover crops can adversely affect other crops in the rotation.

Cover crop management in conservation tillage systems

Nutrient management. Nitrogen and phosphorus are the two macronutrients most likely to be lost from cropping systems. Cover crops help reduce losses of these nutrients by:

- increasing infiltration—thus reducing surface runoff and erosion
- taking up nutrients—or acting as a 'catch crop'
- using water for cover crop growth during peak leaching season (late fall through early spring)—reducing the amount of water available to leach nutrients

Grasses and brassicas are better than legumes at reducing N leaching (106, 234, 265). Cereal rye is very effective at reducing N leaching because it is cold tolerant, has rapid growth, and produces a large quantity of biomass (111). Winter annual weeds do not effectively reduce N losses.

Cover crops may reduce the efficiency of N fertilizer in no-till systems, depending on the method of application. Surface applications of urea-containing fertilizers to soils with large amounts of cover crop residues can result in large losses of ammonia N. When applied to the soil surface, urea and urea-ammonium nitrate (UAN) solutions volatilize more than ammonium nitrate and subsequently lose more N to the atmosphere.

Injecting urea-containing fertilizers into the soil eliminates volatilization losses. Banding urea-containing fertilizers also reduces volatilization losses because banding minimizes fertilizer and residue contact, while increasing fertilizer and soil contact.

Nitrogen dynamics with nonlegume cover crops. Differences between nonlegumes and legume cover crops are mostly related to nitrogen management. Legumes fix N while nonlegumes can only use N already in the soil. Legume residues usually contain more total N that is more readily available to subsequent crops.

The addition of fresh crop residues stimulates growth of soil microbes and increases microbial demand for nutrients, particularly N. Microorganisms use C, N and other nutrients as a food source in order to break down the residues. If the amount of N in the residues is too low, the microorganisms use soil N instead, reducing N availability to the cash crop. This is called *N immobilization*. If the amount of N in the residues is greater than microbial demand, N is released and N availability for plant growth is increased, a process called *N mineralization*.

Small grain and other grass cover crops usually result in an initial, if not persistent, immobilization of N during the cash crop season. The N *content* of small grain cover crop residues varies greatly, but generally ranges from 20 to 50 lb./A for the aboveground biomass and 8 to 20 lb./A in the roots. The N *contribution* from small grain cover crops depends on N availability during the cover crop growing period, the total amount of biomass produced and the growth stage when the cover is terminated.

The **carbon to nitrogen ratio** (C:N ratio) of cover crop residue is a good indicator of whether immobilization or mineralization will occur. Values exceeding 30 parts carbon to one part nitrogen (C:N ratio of 30:1) are generally expected to immobilize N during the early stages of the decomposition process. For more information about C:N ratios and cover crop nutrient dynamics, see *Building Soil Fertility and Tilth with Cover Crops* (pp. 16).

The C:N ratio of small grain residues is mostly dependent on time of termination. Early termination of grass cover crops results in a narrower C:N ratio, typical of young plant tissue. If killed too early, this narrower C:N ratio results in rapid decomposition of a smaller amount of residue, reducing ground coverage.

Because of the need for residue in conservation tillage systems, small grain cover crops are often allowed to grow as long as possible. Termination date depends on crop rotation and climate. When small grain cover crops are killed at flowering, the C:N ratio is usually greater than 30:1.

In Pennsylvania, delaying rye termination date from early to late boot stage increased average above-ground dry matter accumulation from 1200 to 3700 lb./A with no negative effect on corn yield (118).

In Alabama, rye, black oat and wheat cover crops were terminated at different growth stages with a roller or roller-herbicide combinations. Biomass production was about 2.0 – 2.6 tons/A at the flag leaf stage and corresponding C:N ratio averaged 25:1, regardless of cover crop species.

At flowering, biomass averaged 4.2, 3.8, and 3.3 tons/A for black oat, rye and wheat, respectively, and the C:N ratio for all covers was 36:1. Killing at soft dough stage did not increase biomass production for any of the covers, but did increase the C:N ratios, which would increase N immobilization (13).

The wide C:N ratio of small grain residues must be taken into account for best N management. Nitrogen fertilizer rates for cash crops may need to be increased 25 to 30 lb./A following a high residue cereal cover crop.

In N-limited soils, early-season growth of the cash crop is usually enhanced if this N is applied as starter fertilizer. Although yield increases from starter N applications are dependent on rainfall and crop, they occur frequently enough to justify the practice. Starter fertilizer promotes more rapid canopy development, which reduces weed competition and can offset the negative effects of cool, wet soils often experienced with conservation tillage systems. Ideally, starter fertilizers should be placed near the seeding row in a 2 X 2 band, i.e. 2 inches to the side and 2 inches below the seed.

Legumes add N. Legume cover crops obtain nitrogen from the atmosphere through a symbiotic relationship with nitrogen fixing bacteria. The N content of legume cover crops and the amount of N available to subsequent crops is affected by:

- Legume species and adaptation to soil and climatic conditions
- residual soil N
- planting date
- termination date

Cover crop management affects the N content of legume cover crops and the contribution of N to the following cash crop. Early establishment of legume cover crops results in greater biomass production and N production. The nitrogen content of legume cover crops is optimized at the flowering stage. Legumes can contribute from 15 to 200 lb. N/A to the subsequent crop, with typical values of 50 to 100 lb./A.

In North Carolina, delaying the kill date of crimson clover 2 weeks beyond 50% bloom, and hairy vetch 2 weeks beyond 25% bloom increased the biomass of clover by 41% and vetch by 61%. Corresponding increases in N content were 23% for clover and 41% for vetch (427). In Maryland, hairy vetch fixed about 2 lb. N/acre/day from April 10 to May 5, resulting in an additional 60 lb. N/A in aboveground biomass (82, 83, 86).

The C:N ratio of mature legume residues varies from 25:l to 9:1 and is typically well below 20:1, the guideline threshold where rapid mineralization of the N in the residue occurs. Residues on the soil surface decompose more slowly than those incorporated in conventional tillage systems. Consequently, in conservation tillage systems, legume-residue N may not be readily available during the early part of the growing season.

Due to the initial lag in availability of N from legume cover crop residues, any additional fertilizer N should be applied to cash crops at planting in conservation-tillage winter annual legume systems. Splitting N applications to corn grown in these systems, as is generally recommended for conventional-tilled corn grown without legume cover crops, is not necessary (347).

Grass-legume mixtures. Mixtures of grass and legume cover crops provide the same benefits to conservation tillage but often mitigate the nitrogen immobilization of pure grass cover crops. The grass component scavenges residual nitrogen effectively, while the legume adds fixed nitrogen that is more readily available to the cash crop (86, 343, 344, 345).

The C:N ratio of grass-legume mixtures is usually intermediate to that of pure stands. In several studies in Maryland, the C:N ratio of mixtures of hairy vetch and rye never exceeded 25:1; the C:N ratio of pure rye ranged from 30:1 to 66:1 across several spring kill dates (81, 83, 84, 85, 86).

Water availability. Cover crops use soil water while they are growing. This can negatively affect cash crop yields. Once killed, however, cover crop residues may increase water availability by increasing infiltration and reducing evaporation losses.

Short-term soil water depletion at 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 crop development. A rainfall event following cover crop termination enables soil surface water recharge, which usually provides adequate soil moisture in humid regions to facilitate cash crop planting. Time of termination becomes more critical as the probability of precipitation decreases (423).

Cover crops increase water availability by:

- decreasing evaporation due to a mulching effect
- increasing infiltration of rainfall by decreasing runoff velocity
- increasing organic matter, which increases water-holding capacity
- improving soil structure and consequently increasing root interception of soil water

- protecting the soil surface from raindrop impact, thus reducing development of a surface seal or crust, which can greatly reduce infiltration

In Alabama, cover crop residue left on the soil surface reduced runoff and increased infiltration by 50 to 800% compared to removing or incorporating the residues (418, 419). In Georgia, infiltration rates were 100% greater *even after removal of crop residues* for a Cecil sandy loam when grain sorghum was no-till planted into crimson clover compared to a tilled seedbed without a cover crop (52).

In Maryland, pure and mixed stands of hairy vetch and rye did not deplete soil water or adversely affect corn yield. Rather, the additional residue from cover crops killed in early May conserved soil moisture and contributed to greater corn yield (84, 85).

In Kentucky, surface evaporation from May to September was five times less under no-till (which leaves a surface mulch) than with conventional tillage. Because less water was lost to evaporation, more water was available for the crop (91).

Cover crop use in *dryland systems* is often limited by moisture availability. A literature review of dryland cover crop studies on the Great Plains concluded that use of cover crops on dryland cropping systems of the Great Plains reduced yields of subsequent crops. However, in semi-arid Texas, 5 tons/A of wheat straw increased available soil water by 73% and more than doubled grain sorghum yields from 26 to 59 bushels/A (423).

The risk for early-season soil water depletion by cover crops is the same regardless of the tillage system. However, the full potential of cover crops to increase infiltration and conserve soil water can only be achieved in a conservation system where cover crop residues are left on the surface. Conservation tillage increased water use efficiency compared to a traditional wheat>fallow system with tillage (319, 135).

One way to reduce the risk of early-season soil water depletion by cover crops is to desiccate the cover some time prior to planting the cash crop. For example, yield reductions due to early-season depletion of soil water can be reduced by killing the cover crop 2 to 3 weeks before planting the cash crop (428, 290, 348). Depending on your situation, you could extend this window to terminate cover crops in conservation systems from 4 to 6 weeks prior to planting the cash crop.

Cover crops can sometimes be used to deplete soil water on poorly drained soils, allowing an earlier planting date for the cash crop, but the practical advantage of this practice is not certain.

Soil temperature. Cover crop residues keep the soil cooler, reduce daily fluctuations of soil temperature, and reduce soil temperature maximums and minimums. The cooler soil temperatures, which benefit the cash crop throughout the summer, can delay spring planting compared to a system without a cover crop.

Spring soil temperature is particularly important in cover crop/conservation tillage systems. Where possible, plant your cash crop according to soil temperature rather than the calendar. Follow local recommendations about the appropriate soil temperature for your cash crop. As noted below, the use of row cleaners will allow faster soil warmup.

The harmful effects of planting when the soil temperature is too low were demonstrated in Colorado for conservation tillage with continuous corn (but not cover crops). Low soil temperatures contributed to reduced corn yields over 5 years (171, 172).

Insects and diseases. Conservation tillage systems alter pest dynamics, due in large part to residues left on the soil surface. Conservation tillage systems with surface residues create a more diverse plant/soil ecosystem than conventional tillage systems (137, 185, 416).

Cover crops may harbor insects, diseases, and nematodes that could be harmful to the cash crop. Before planting a cover crop, be sure to investigate specific pest/crop interactions that may become a problem (100). Understanding these interactions and the conditions that favor them helps you make good management decisions. For example:

- Cereal rye, orchardgrass and crimson clover may attract armyworms.

- Clover root curculio, a common pest of red clover, can attack alfalfa.
- Chickweed can attract black cutworm or slugs.
- Johnsongrass is a host to maize dwarf mosaic virus (MDMV), which also infects corn.

Conversely, cover crops can be used in conservation tillage systems to attract beneficial insects. One approach is to allow a live strip of cover crops to remain between crop rows to serve as habitat and a 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 (368, 416).

For more information about cover crops and beneficial insects, see *Manage Insects on Your Farm: A Guide to Ecological Strategies* (409, http://www.sare.org/publications/insect.htm).

Cover crop residues have been shown to reduce the incidence of several diseases in many different cash crop systems by reducing splash dispersal of pathogens. Small grain cover crops in conservation tillage have also 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 less incidence of damage from thrips, the vector of TSWV (49).

Some cover crops can serve as an overwintering host for nematodes and may thus increase the severity of nematode damage. This may be a greater concern where crops are not rotated, like continuous cotton in some areas of the South. On the other hand, cover crops such as brassicas can reduce nematode populations (48, 231, 283, 284, 285, 353, 430).

On a Maryland sandy soil, winterkilled forage radish increased bacteria-eating nematodes, rye and rapeseed increased the proportion of fungal feeding nematodes, while nematode communities without cover crops were intermediate. The Enrichment Index, which indicates a greater abundance of opportunistic bacteria–eating nematodes, was 23% higher in soils that had brassica cover crops than the unweeded control plots. These samples, taken in November, June (a month after spring cover crop kill), and August (under corn), suggest that the cover crops, living or dead, increased bacterial activity and may have enhanced nitrogen cycling through the food web (432).

Consult local experts to minimize the potential for pest problems

The need for sound crop rotation is greater in conservation systems than in conventional systems. Cover crops should be a key component of any conservation rotation system. With the vast number of potential combinations of crops, cover crops, and diseases, consult local experts to ensure that you manage cover crops in conservation tillage systems to minimize the potential for pest problems.

Weed management. Cover crops affect weeds and weed management in conservation tillage systems in several ways:

- Cover crops compete with weeds for light, water and nutrients.
- Cover crop residue can suppress weed seed germination; the more residue the better.
- Grass cover crops (high C:N ratio) usually provide longer-lasting residue than legumes.
- Some cover crops release weed-suppressing allelopathic compounds.
- Conservation tillage does not continually turn up new weed seeds for germination.
- Cover crops can become weeds.

Some legume, cereal and brassica cover crops release allelopathic compounds that can reduce weed populations and/or suppress weed growth (39, 45, 176, 177, 178, 336, 359, 410, 422). Unfortunately, these same allelopathic compounds can also stunt and/or kill cash crop seedlings, particularly cotton (24) and some small seeded vegetable crops. Allowing time between the termination date and the cash crop planting date reduces the risk to cash crops because these chemicals leach out of the cover crop residue and are decomposed by soil microorganisms.

Cereal rye is known to release phenolic and benzoic acids that can inhibit weed seed germination and development. In Arkansas, the concentration of these allelopathic chemicals varied 100-fold among ten varieties of rye in the boot stage, with the cultivar BONEL having the greatest concentration and PASTAR the least. Factoring in the yield of each cultivar with the concentration and activity of the inhibitors, BONEL, MATON and ELBON were considered the best rye cultivars for allelopathic use (66).

Conservation tillage and the allelopathic effects of cover crop residue can both contribute to the suppression of weeds in these systems (452). In Alabama, a conservation tillage system using rye or black oat cover crops eliminated the need for post-emergence herbicides in soybean and cotton (335, 349). Including rye or black oat increased yields of non-transgenic cotton in 2 of 3 years, compared to conservation tillage without a cover crop.

Economics of cover crop establishment and use

Using cover crops in any tillage system usually costs more time and money than not using cover crops. Depending on your particular system, you may or may not be repaid for your investment over the short term. If you are already using cover crops but are considering switching to conservation tillage, the economics are similar to using cover crops in conventional tillage systems, but the benefits may be expressed more in the conservation system (51).

Factors affecting the economics of cover crop use include:

- the cash crop grown
- the cover crop selected
- time and method of establishment
- method of termination
- the cash value applied to the environment, soil productivity and soil protection benefits derived from the cover crop.
- the cost of nitrogen fertilizer and the fertilizer value of the cover crop
- the cost of fuel

The economic picture is most affected by seed costs, energy costs and nitrogen fertility dynamics in cover crop systems. Cover crop seed costs vary considerably from year to year and from region to region, but historically, legume cover crops cost about twice as much to establish as small grain covers. The increased cost of the legume cover crop seed can be offset by the value of N that legumes can replace.

Depending on your system, legume cover crops can replace 45 to 100 lb. N/A. On the other hand, a rye cover crop terminated at a late stage of growth might require 20-30 lb. more N/A due to N immobilization by the wide C:N ratio rye residue. Thus, the difference in cost between a rye cover crop and a legume cover crop would be offset by the value of 65 to 125 lb. N/A. At a price of $0.45/lb. N, this would be worth $29 to $56/A.

Cover crop establishment in conservation tillage systems

The major challenges to cover crop adoption in both tilled and conservation tillage systems include seeding time and method, killing time and method, and cover crop residue management to ensure good stands of the cash crop. Success with cover crops requires adequate attention to each.

Plant cover crops on time. In order to maximize benefits—or to work at all—cover crops need to be planted early, sometimes before the summer crop is harvested. Timely planting results in:

- good root establishment and topgrowth before the crops go dormant
- reduced chance of winter kill
- more biomass production compared to later planting dates
- greater uptake of residual soil N

Timely fall planting is particularly important before early vegetables or corn. Corn is typically planted early in the spring, which forces an early cover crop termination date. A late planted cover crop that must be terminated early will not produce sufficient biomass to provide adequate soil protection and enhance soil quality.

Planting methods. Cover crops in conservation tillage systems are usually planted with a drill or broadcast on the soil surface, but several alternate methods can be used. Good soil-seed contact is required for germination and emergence. Most small seeded legumes require shallow seed placement (1/4 inch), while larger seeded legumes and small grains are generally planted up to 1.5 inches deep (see CHARTS, p. 62).

Conservation tillage drills can handle residue and provide uniform seeding depth and adequate seed-soil contact, even with small seeded cover crops. In some situations, preplant tillage can be used to control weeds and disrupt insect and disease life cycles.

Broadcast seeding requires an increase in the seeding rate compared to other methods (see CHARTS, p. 62). Broadcasting is often the least successful seeding method. Small-seeded species such as clovers tend to establish better by broadcasting than larger seed species. A drop-type or cyclone-type seeder can be used on small acreage and provides a uniform distribution of seed. Conventional drills work adequately in some conservation tillage systems—depending on the amount of residue—and may be more successful than broadcast seeding.

On larger areas, *aerial seeding* by fixed-wing aircraft or helicopter in late summer during crop die-down can be effective. As the leaves of the summer crop drop off, they aid germination by covering the seed, retaining moisture and protecting the soil.

In colder climates, *frost-seeding* can be used for some cover crop species (see *individual cover crop chapters in this book*). Seed is broadcast during late fall or early spring when the ground has been "honeycombed" by freezing and thawing. The seed falls into the soil cracks and germinates when the temperature rises in the spring.

Some legumes can be managed to reseed the following year. This reduces economic risks and seeding costs. Reseeding systems generally depend on well-planned rotations such as that reported in Alabama (311), where crimson clover was followed with strip-tilled soybean planted late enough to let the clover reseed. Corn was grown the next year in the reseeded clover. In this system, the cover crop is planted every other year rather than annually. Grain sorghum can be planted late enough in the South to allow crimson clover to reseed in a conservation-tillage system.

The introduction of legume cover crops that bloom and set seed earlier also improves their utility for reseeding in conservation-tillage systems. Auburn University in cooperation with USDA-NRCS has released several legume cover crops that flower early, including AU Robin and AU Sunrise crimson clover, and AU Early Cover hairy vetch (288). Leaving 25 to 50% of the row area alive when desiccating the cover crop allows reseeding without reducing corn grain yields. However, the strips of live cover crop may compete with the cash crop for water, a potential problem during a spring drought.

Decisions about when to kill the cover crop must be site- and situation-specific.

Spring management of cover crops in conservation tillage systems

Kill date. Timing of cover crop termination affects soil temperature, soil moisture, nutrient cycling, tillage and planting operations, and the effects of allelopathic compounds on the subsequent cash crop. Because of the many factors involved, decisions about when to kill the cover crop must be site- and situation-specific.

There are a number of pros and cons of killing a cover crop early vs. late. Early killing:

- allows time to replenish soil water
- increases the rate of soil warming
- reduces phytotoxic effects of residues on cash crops
- reduces survival of disease inoculum
- speeds decomposition of residues, decreasing potential interference with planter operation
- increases N mineralization from lower C:N ratio cover crops

Advantages for later kill include:

- more residue available for soil and water conservation
- better weed control from allelopathic compounds and mulch affect
- greater N contribution from legumes
- better potential for reseeding of the cover crop

After 25 Years, Improvements Keep Coming

By Pat Sheridan, Sheridan Farms, Fairgrove, Mich as interviewed by Ron Ross for the No-Till Farmer

Talk to 10 no-tillers and you'll probably hear 10 different viewpoints on why it pays to quit disturbing and start building the soil. At Sheridan Farms, we've got our list, too. We are able to better time planting, weed control and other production chores. And we've got the potential for sediment and nutrient runoff into Saginaw Bay on Lake Huron under control.

Like a lot of no-tillers would testify, however, these changes didn't come quickly, nor without some reluctance and skepticism along the way. In our first years of no-tilling, starting in 1982, we did just about everything wrong and had an absolute train wreck. We overcame a few hurdles early on, started adding more no-till acres and were 100% continuous no-till by 1990.

Cover Crop Success

We started working with cover crops about 20 years ago. We deal with about a dozen different soil types, 80 percent of which are clay loam. And much of our land is poorly drained, low-organic-matter lake bed soils.

Cereal rye has been a good cover crop year in and year out for this mixture of soils. We like the AROOSTOCK variety from Maine because it provides fast fall and spring growth and its smaller seed size makes it more economical to plant.

In late August, we fly rye into standing corn and also into soybeans if we're coming back with soybeans the following year. We learned that rye is easier to burn down when it's more than 2 feet tall than when it has grown only a foot or less.

The rye crop also helps us effectively manage soil moisture. If it looks like we're going to get a dry spring, we burn down rye with Roundup as soon as we can; but if it's wet, we let the rye grow to suck up excess moisture. We can be very wet in the spring, but Michigan also receives less rain during the growing season than any other Great Lakes state, on average. Moisture management is critical to us.

We've seen less white mold in no-tilled soybeans wherever we have heavy residue. We've had years with zero white mold when our conventional till neighbors faced a costly problem. It's become a simple equation: the heavier the residue mat, the less white mold.

An open mind welcomes a lot of ideas that, with a little tweaking, can deliver even more success to your fields.

Deep-Rooted Crops

We're looking for a cover crop that will help establish a more diverse rotation, so we can always follow a broadleaf crop behind a grass crop and vice-versa. Oilseed radish is beginning to show real promise. It has about the same tremendous appetite for nitrogen as wheat, and it develops a very deep root mass. It's an excellent nutrient scavenger.

This combination enables the cover crop to capture maximum nitrogen from deep in the soil profile to feed the following corn crop. No one has ever proven to me that we need nutrients down deep. It sounds good to have a plant food layer at 16 to 18 inches, but I much prefer the nitrogen and other nutrients near the surface where the crop can use them.

Deep-rooted cover crops like oilseed radish can help reverse the traditional theory of nitrogen stratification. Nitrogen allowed to concentrate deep in the soil scares us because it is more likely to leach into the tile lines and reach Lake Huron.

We've also tried wheat, hairy vetch, crimson clover and a dry bean and soybean mix for cover crops, and we'll keep experimenting. Recently, I traded oilseed radish seed to Kansas no-tillers Red and David Sutherland for Austrian winter pea seed. The Sutherlands have reported good moisture retention and nitrogen fixation with the peas. We like what we've seen with the peas, as well.

Less Nitrogen, More Corn

We partly credit the cover crop program with sharply reducing our fertilizer bills. In fact, the first time I hit a 200-bushel corn yield, I did it with only 140 to 150 pounds of nitrogen per acre, or about 0.7 to 0.8 pounds of nitrogen per bushel. As anyone who has been growing corn knows, the typical nitrogen recommendation has been about a pound-plus per bushel. Oversupplying nitrogen has absolutely no value. I think the whole nutrient cycle concept is intriguing; no-till in conjunction with cover crops really makes it work.

Organic Matter Boost

When we started no-tilling, we had heard stories from farmers and others that we could expect to see increased organic matter content in our soils after a few years. But some soil experts cautioned that this likely wouldn't happen. Fortunately, we've triggered significant humus development during the past 20 years, with organic matter increasing from about 0.5 to as much as 2.5 percent. This is a real bonus in addition to all the other benefits from no-tilling, and we expect to see even more improvement as we include more cover crops in our rotation.

What Works At Home?

Our county is part of the Saginaw Bay watershed, the largest in the state with more than 8,700 square miles. Everything we do as farmers can affect the water quality of the bay, and we're very conscious of that.

A group of about 150 farmers from three counties formed the Innovative Farmers of Michigan in 1994. Our objectives have been to reduce the amount of sediment entering the bay and change our farming practices to reduce nutrient and pesticide runoff. We don't want our soils in the bay. After a 3-year study, financed with an EPA 319 grant in 1996, we came up with some pretty dramatic results. We found that conservation tillage does not reduce yields; in fact we saw significant yield increases in corn.

Also, reduced tillage increases the soil's capacity to supply nitrogen and phosphorus to a growing crop. Water-holding capacity and water infiltration rates were higher on no-till fields. We reduced the potential for soil erosion from water by up to 70 percent and from wind by up to 60 percent, compared to conventional tillage. At the end of the project, we were getting a lot better handle on what no-till systems work best in our three-county area.

At Sheridan Farms, we'll keep looking for more diversity and hope to get back to a four- or five-crop continuous no-till system. The most valuable lesson we learned is there is no universal truth or no-till game plan that will apply for everyone. Eventually, we adapted a no-till system that fits our particular soil types, crops, climate, long-range goals and farming style.

—Adapted with permission from "The No-Till Farmer," May 2006. www.no-tillfarmer.com

As a general rule, cover crops, particularly cereals, need to be terminated 2-3 weeks ahead of planting to allow plant material to dry out and become brittle. Dry brittle cover crop residue allows tillage and planting equipment to cut through the residue more easily, as opposed to semi-dry cover crop residue. Semi-dry residue is tough and hard to cut, which can result in considerable dragging of the residue as implements traverse the field.

Allelopathic compounds can be a greater problem with crop establishment when fresh residues become trapped in the seed furrow, a condition known as "hairpinning." Hairpinning can be a problem even for residues that have been on the surface for a number of weeks if planting in the morning when residues are still moist from precipitation or dew. Hairpinning can reduce seed to soil contact and cash crop stands.

You can sometimes plant the cash crop directly into standing (live) cover crop, then kill the cover crop. This allows more time for cover crop growth and biomass production, and usually side-steps the problem of planting into tough cover crop residue. However, planting into standing green residue can increase the risk of allelopathic chemicals affecting sensitive cash crop seedlings, and can make it difficult to align rows when planting.

Killing methods

Many kill methods have been developed and tested. Some are described below. Be sure to check with Extension or other farmers for recommended methods for your area and crop system.

Killing with an herbicide. Killing cover crops with a non-selective herbicide is the standard method used by conservation tillage growers. They favor this option because they can cover many acres quickly and herbicides are relatively cheap. Herbicides can be applied at any time or growth stage to terminate the cover crop.

Killing with a roller-crimper. Cover crops can be killed using a mechanical roller (often called a roller-crimper). The roller kills the cover crop by breaking (crimping) the stems. The crimping action aids in cover crop desiccation.

The cover crop is rolled down parallel to the direction of planting to form a dense mat on the soil surface, facilitating planter operation and aiding in early season weed control. When using a roller alone for cover crop termination, best results are obtained when rolling is delayed until flowering stage or later.

Roller-crimpers work best with tall-growing cover crops. Small weeds are not killed by rolling. Weed suppression by the mat of rolled cover crop residue depends on cover crop, weed species and height, and the density (thickness) of the cover crop mat.

Rollers can be front- or rear-mounted. They usually consist of a round drum with equally spaced blunt blades around the drum. Blunt blades are used to crimp the cover crop. This is preferable to sharp blades that would cut the cover crop and dislodge residue that might interfere with seed soil contact at planting.

The roller-crimper is a viable way to kill cover crops without using herbicides. It also helps prevent planter problems that can occur when tall-growing cover crops lodge in many different directions after chemical termination

In Alabama, a mechanical roller was used to kill black oat, rye and wheat cover crops. The roller combined with glyphosate at one-half the recommended rate was as effective as using glyphosate at the full recommended rate to kill all cover crops. The key was to use the roller at flowering. Herbicides can be eliminated if the roller operation occurs at the soft dough stage or later, a good option for organic growers (13).

▼ **Precaution:** Applying non-selective herbicides at reduced rates could lead to weed resistance. The half rate of herbicide may not completely eradicate the weed, increasing the chance that the weed will produce seed. Under these circumstances, such seeds are more likely to be resistant to the herbicide. Therefore, it is safer to completely eliminate the use of the non-selective herbicide with a roller or use the non-selective herbicide at the labeled rate, with or without the roller.

Growers and researchers are addressing several barriers to the use of rollers:

- Operation speed was hampered by vibration. Using curved blades on the roller drum alleviates this problem.

- Most rollers are 8 rows or smaller, but growers have built wider rollers that can be folded for transportation.
- Rolling and planting can be done in one operation by using a front-mounted roller and rear-mounted drill, saving time and energy.

For more information about cover crop rollers, see ATTRA (11) and *Cover Crop Roller Design Holds Promise for No-Tillers*, p. 146.

Mowing/chopping. Mowing and chopping are quick methods to manage large amounts of cover crop residue by cutting it into smaller pieces. An alternative to the use of herbicides, it is more energy intensive.

In humid climates, mowed residues break down faster, negating some of the residue benefits of conservation tillage. In drier climates, cover crop residues do not decompose as fast, but wind and water may cause residue to accumulate in low areas or remove it from the field altogether.

Cutting residue into smaller pieces may adversely affect the performance of tillage and planting equipment because coulters designed to cut through residue may instead push small residue pieces into the soil. Use "row cleaners" or "trash whippers" to prevent this problem.

Living mulch. Living mulches are cover crops that co-exist with the cash crop during the growing season and continue to grow after the crop is harvested. Living mulches do not need to be reseeded each year (182). They can be chosen and managed to minimize competition with the main cash crop yet maximize competition with weeds. The living mulch can be an annual or perennial plant established each year, or it can be an existing perennial grass or legume stand into which a crop is planted.

Living mulch systems are dependent on adequate moisture for the cash crop. They can be viable for vineyards, orchards, agronomic crops, such as corn, soybean, and small grains, and many vegetables. Legumes are often used because they fix nitrogen, a portion of which will be available for the companion crop. If excess nitrogen is a problem, living mulches (especially grasses) can serve as a sink to tie up some of this excess nitrogen and hold it until the next growing season.

In conservation tillage systems, living mulches can improve nitrogen budgets, provide weed and erosion control, and may contribute to pest management and help mitigate environmental problems.

Living mulch systems are feasible in Midwest alfalfa-corn rotations (386). Use in corn-soybean rotations was also feasible but more challenging because soybean is more susceptible to competition from the living mulch. With adequate suppression, living mulches can be managed to minimize competition with corn with little or no reduction in yield. The system requires close monitoring and careful control of competition between the living mulch and grain crop to maintain crop yields.

Cash crop establishment. Cash crop establishment can be complicated by the use of cover crops in conservation-tillage systems. Cover crops can reduce cotton, corn and soybean stands if not managed well. Possible causes of stand reductions include:

- poor seed-soil contact due to residue interference with planter operations
- soil water depletion
- wet soils due to residue cover
- cold soils due to residue cover
- allelopathic effects of cover crop residues
- increased levels of soilborne pathogens
- increased predation by insects and other pests
- free ammonia (in the case of legume covers)

To prevent stand problems following cover crops:

- Check for good seed-soil contact and seed placement, particularly seeding depth.
- Be sure that coulters are cutting through cover crop residue rather than pushing it into the soil along with the seed.
- Desiccate the cover crop at least 2 to 3 weeks before planting the cash crop.
- Monitor the emerging crop for early season insect problems such as cutworms.

Small seeded crops like vegetables and cotton are especially susceptible to stand reductions following cover crops. Winter annual legumes may cause more problems due to allelopathic effects and/or increased populations of plant pathogens.

Residue management systems that leave cover crop residue on the surface can reduce the risk of stand problems provided the residue does not interfere with planter operation.

Good seed placement is more challenging where residues remain on the soil surface. However, improvements in no-till planter design have helped. Equipment that removes crop residue from the immediate seeding area can help to reduce stand losses (see equipment discussion, below).

Surface residues reduce soil temperature. The relative influence of this temperature reduction on crop growth is greater in northern areas of a crop's adapted zone. Removal of residue from the zone of seed placement will increase soil temperature in the seed zone and also decrease the amount of residue that comes in contact with the seed. This will result in better seed-soil contact and less allelopathic effects from residue to the developing seedling.

No-till planters. The key to successful no-till cash crop establishment in cover crop residues is adequate seed to soil contact at a desired seeding depth. No-till planters are heavier than conventional planters. The additional weight allows the planter to maintain desired seeding depth in rough soil conditions and prevents the planter from floating across the soil surface and creating uneven seed placement. Individual planter row units are typically equipped with heavy-duty down-pressure springs that allow the operator to apply down pressure in uneven soil conditions to maintain depth control.

Row cleaners are designed to operate in heavy cover crop residue. Manufacturers have developed different types of row cleaners that can be matched to various planters. All row cleaners are designed to sweep residue away from the opening disks of the planter units. Removing this residue reduces the chance of pushing residue into the seed furrow (hairpinning).

All row cleaners can be adjusted to match specific field conditions. Row cleaners should be adjusted to move residue but not soil. If too much soil is disturbed in the row, the soil will dry out and can crust over, which will hinder emergence. In addition, disturbed soil can promote weed emergence in the row creating unnecessary competition between weeds and the cash crop.

Spoked closing wheels improve establishment in poorly drained or fine-textured soils. On these soils, traditional cast-iron or smooth rubber closing wheels can result in soil crusting. Spoked closing wheels crumble the seed trench closed for adequate seed to soil contact, but leave the soil loose and friable for plant emergence.

Additional planter attachments to ensure adequate seed to soil contact in rough soil conditions include V-slice inserts and seed firmers. 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.

Strip-tillage equipment. Strip-tillage equipment is designed to manage residue and perform some non-inversion tillage in the row. In the South, strip-tillage refers to in-row subsoiling (14-16 inches deep) to reduce compaction, with minimal disturbance of residue on the soil surface. In the Midwest, zone-tillage typically refers to shallow tillage within the row designed to remove residue and enhance soil warming in the seed zone.

Regardless of manufacturer, strip tillage implements typically consist of a coulter that runs ahead of a shank, followed by such attachments as additional coulters, rolling baskets, drag chains, or press wheels. Depending on conditions, these attachments are used alone or in various combinations to achieve different degrees of tillage.

When strip-tilling in cover crop residue, the coulter should be positioned as far forward of the shank as possible and centered on the shank. This allows the coulter to operate in firm soil enabling it to cut residue ahead of the shank. By cutting the residue ahead of the shank, the residue can flow through the shanks more easily and not wrap up or drag behind the implement.

Fine-textured soils sometimes stick to the shank and may accumulate there, 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 help prevent blowout. 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. They fracture the soil at the bottom of the trench, preventing soil upheaval to the soil surface. The soil fracture created is analogous to stress cracks in concrete.

Row cleaners can be used on cool, poorly drained soils to enable faster soil-warming in spring. This may allow earlier planting and helps ensure optimal plant emergence conditions. Available for most strip-tillage implements, row cleaners function much like row cleaners for planters, sweeping cover crop residue away from the row. Adjustments for strip tillage row cleaners are not as flexible as those on planters.

Vegetable establishment. Adoption of no-tillage systems for transplanted vegetable crops was limited by equipment and stand establishment problems. This problem was overcome in the 1990's with the development of the Subsurface Tiller-Transplanter (287). The SST-T is a "hybrid," combining subsurface soil loosening to alleviate soil compaction and effective setting of transplants, in one operation with minimum disturbance of surface residues or surface soil.

The spring-loaded soil-loosening component of the subsurface tiller tills a narrow strip of soil ahead of the double disk shoe of the transplanter. The double-disk shoe moves through the residue and the tilled strip with relatively little resistance. In addition, the planter can be equipped with fertilizer and pesticide applicators to reduce the number of trips required for a planting operation.

Regional Roundup: Cover Crop Use in Conservation Tillage Systems

Midwest—*Tom Kaspar*

Soils. Soils of the Midwest contain high levels of organic matter compared to other regions. Research has yet to confirm if cover crops can increase soil organic matter contents beyond current levels. The possibility of using corn stover as a bioenergy source would leave the soil unprotected and much more vulnerable to degradation, but cover crops could offset any detrimental effects associated with corn stover removal. The degree to which cover crops could protect the soil following corn stover removal has not been investigated.

Farm systems. Midwest farms are large, averaging 350 acres. Cover crops and conservation tillage are most common in corn and soybean systems, with or without livestock. Cover crops are also commonly used in vegetable systems.

Cover crop species. Rye and other small grains are the primary cover crops used in the Midwest. Legume cover crop include red clover, hairy vetch and sweetclovers.

Cover crop benefits. Advantages of cover crops in the Midwest include reducing erosion, anchoring residues in no-till systems, suppressing winter annual weeds and nutrient management. The ability of cover crops to scavenge nitrates is particularly beneficial in the Midwest, where the majority of United States corn is produced, because the high N requirement of corn increases the potential for nitrate loss.

Drawbacks. Cover crops have reduced corn (but not soybean) yields when they are terminated at planting. Earlier termination helps reduce this problem, but residue benefits are reduced. The potential biomass production is complicated by the already short, cold cover crop growing season between harvest and planting of corn and soybean crops. Cash crop planting and harvest coincide with cover crop kill and planting dates.

Management. Cover crops need to be planted at the same time farmers are harvesting corn and soybean to ensure adequate biomass production. Producers would benefit from alternative cover crop establishment methods, such as overseeding before harvest, seeding at weed cultivation with delayed emergence, or frost seeding after harvest. Environmental payments or incentives may entice growers to try alternative practices.

Northeast—*Sjoerd Duiker*

Cover crops are becoming an integral part of crop production in the Northeast. This is due in large part to the increasing adoption of no-tillage systems, because cover crops can be managed more easily than with tillage, while cover crop residues in no-till systems lead to multiple benefits.

Soils. There are many soil types in the Northeast, including soils developed in *glacial* deposits or from melt water lakes; sedimentary soils formed from the *sedimentary* rocks sandstone, shale and limestone; *Piedmont* soils, remnants of a coastal mountain range with complex geology, characterized by a gently to strongly undulating landscape; and *coastal plain* soils, developed in unconsolidated material deposited by rivers and the ocean, often sandy with a shallow water table.

Soil and nutrient management in the region aim to address soil erosion, clay subsoils, fragipans, shallow water tables and the nutrient enrichment caused by the high density of animal production.

Farm systems. Farms in the Northeast are diverse, tend to be small, and include cash grain, perennial forage, dairy, hog, poultry, fruit and vegetable operations. Nutrient management regulations in some states encourage the use of cover crops and conservation tillage practices, particularly for the application of manure. Farmer organizations such as the Pennsylvania No-Till Alliance actively promote cover crops for their soil-improving benefits, while government programs such as the 2006 Maryland cover crop subsidy of $30-$50 per acre led to a dramatic increase in cover crop acreage.

Cover crop species. Cover crop options and niches are as diverse as the farming systems in the region. Rye, wheat, oats and ryegrass are the most common grass cover crops; hairy vetch, crimson clover and Austrian winter pea are important legumes; buckwheat finds a place in many vegetable systems and brassica crops such as forage radish are increasingly being tested and used in the region.

Cover crop benefits. Cover crops are planted for erosion control, soil improvement, moisture conservation, forage and nutrient management, particularly the nitrogen and phosphorus from intensive animal agriculture. Cover crops can fit into many different niches in the region, particularly fruit and vegetable systems (1, 2, 3, 4). Recent work with forage radish (*Raphanus sativus* L.) suggests that its large taproot can penetrate deep soil layers and alleviate compaction (446).

Drawbacks. Barriers to the adoption of cover crops include the time and cost of establishment and management, water use, and, for some systems, the length of the growing season.

Management. Farmers and other researchers fit cover crops into many different niches using:

- timely seeding, overseeding into standing crops, or interseeding, including some use of living mulches
- various termination methods, including mowing or rolling standing cover crops
- manipulation of cover crop kill and cash crop planting dates to maximize cover crop benefits

Southeast—*Kipling Balkcom*

High-residue cover crops are essential to the success of conservation systems in the Southeast.

Soils. Soils in the Southeast are highly weathered, acidic, and often susceptible to erosion due to their low organic matter content. Decades of conventional tillage practices have exacerbated their poor physical and chemical condition.

Farm systems. Southeast farms raise various combinations of cotton, soybeans, corn, peanuts and small grains. Some include livestock, have access to irrigation or raise fruit and vegetables.

Cover crop species. Rye, wheat, oats, hairy vetch and crimson clover are the cover crop mainstays for grain and oil crop systems.

Cover crop benefits. Cover crop biomass is needed on the weathered soils of the Southeast to add organic matter and improve soil physical, chemical, and biological properties. Cover crop residues reduce soil erosion and runoff, increase infiltration and conserve soil moisture, particularly beneficial in dry years or on drought-prone soils.

Drawbacks. Major concerns are:

- water management
- integration of different cover crop species into southeastern crop production
- reduced effectiveness of pre-emergence herbicides in high-residue systems

Producers are also concerned about residue interference with efficient equipment operation, adequate soil moisture at planting, and stand establishment problems. In addition, some are not willing to commit to the additional management level or perceived costs.

Management. Producers like the idea of reducing trips across the field, which reduces fuel and labor costs and saves time. Significant increases in the use of cover crops and conservation tillage systems in the Southeast have paralleled the adoption of new genetic varieties of corn, soybean and cotton that are herbicide resistant or have incorporated genes for improved insect resistance. These genetic changes reduced some of the challenges associated with weed and insect management, making the conservation tillage systems easier to manage. The relatively longer growing season usually allows ample time to plant cover crops after cash crops.

Northern Plains—*Jorge Delgado*

Rainfall and moisture availability are the major factors affecting the use of cover crops in conservation tillage systems.

Soils. Soils of the Northern Great Plains are exposed to high wind conditions with enough force to move soil particles off site in minimum tillage conditions where soil cover is low. Crop systems do not, in general, leave substantial residue on the soil surface, due in part to low annual rainfall in non-irrigated systems.

Farm systems. Farms in the Northern Plains tend to be large and can be divided into irrigated and non-irrigated systems. Crops rotations include potato, safflower, dry bean, sunflower, canola, crambe, flax, soybean, dry pea, wheat and barley.

Cover crop species. Rye, field pea (Austrian winter pea, trapper spring pea), sweetclover and sorghum-sudangrass are commonly grown.

Cover crop benefits. Cover crop residues improve water retention, helping to increase soil water content and yields. Cover crops reduce wind erosion and nutrient loss, and increase soil carbon. High crop residue and winter cover crops also sequester carbon and nitrogen and increase the availability of other macro- and micronutrients (7, 113).

Drawbacks. Rainfall amount, the availability of irrigation and water use by cover crops are critical considerations for the region. Cool, wet spring weather is exacerbated by cover crop residues that delay soil-warming. Cover crops and conservation tillage often reduce cash crop yields, even in irrigated systems (171, 172).

Management. Management is key to increasing nutrient use efficiencies and reduce nutrient losses to the environment (112, 113, 114, 371). Management is also the key to increasing water use efficiency.

Southern Plains —*Louis Baumhardt*

Conservation tillage was first introduced for soil erosion control on the Great Plains. It followed inversion tillage that incorporated crop residue and degraded the soil's natural cohesiveness and aggregation. Combined with the 1930's dry and windy conditions, this intensive tillage produced catastrophic wind erosion known historically as the "Dust Bowl" (26). Use of conservation tillage practices for much of the Southern Great Plains seems to lag behind other regions, but may be underestimated, in part, because insufficient residue is produced in dryland areas to qualify as conservation tillage acres.

Soils. Soils of the Southern Great Plains were formed from a range of materials including, for example, an almost flat aeolian mantle in the north (Texas High Plains and western Kansas) and reworked Permian sediments of the Texas Rolling Plains extending towards western Oklahoma. These soils have varied mineralogy, are frequently calcareous, and generally have poor structure and low organic matter content (37). All Southern Great Plains soils are managed for wind erosion control and water conservation.

Farm systems. Farm systems on the Southern Great Plains vary with irrigation. They are larger and more diverse as irrigation declines to distribute risk and meet production requirements. Principal crops include cotton, corn, peanut, grain sorghum, soybean, and sunflower. Grain and forage crops support the regional cattle industry.

Wheat-sorghum-fallow is a common rotation and permits cattle grazing on wheat forage and sorghum stubble (27). This and similar rotations may include additional years of sorghum or a wheat green fallow before cotton.

Cover crop species. Water governs cover crop species selection, but wheat, rye, and oats are most common. Wheat is commonly grown for grain or forage and as a green fallow crop between annual cotton crops (29).

Cover crop benefits. Cover crop residue helps meet the 30% cover requirement for conservation tillage, helps control wind erosion in low residue crops, and provides other water infiltration and storage benefits.

Drawbacks. Cover crop use in the region depends on precipitation or the availability and economy of irrigation to produce residue. Some crops such as cotton produce insufficient residue for soil cover, but establishing cover crops competes for water needed by the subsequent cotton crop (28). Grazing crop residues and cover crops also limits the amount of crop residue left on the soil surface and must be balanced against the value of the forage.

Management. Southern Great Plains producers often use cover crops to control wind erosion in annual crops like cotton that produce insufficient cover to protect the soil. During years with limited precipitation, cover crops compete for water resources needed to establish primary cash crops (28). Nevertheless, producers wishing to grow cotton on soils subject to wind erosion have successfully introduced residue producing winter cereal crops with minimum irrigation input.

Conservation tillage increases storage of precipitation in the soil through increased infiltration and reduced evaporation. This additional water supplements growing season precipitation and irrigation to meet crop water needs on the semiarid Southern Great Plains.

Pacific Northwest *—Hal Collins*

Under dryland conservation tillage systems in the Pacific Northwest (PNW), winter precipitation and limited water availability are major factors affecting the use of cover crops. With irrigation, heavy crop residues from previous grain crops can negatively impact cover crop stand establishment. Annual precipitation in agricultural regions of the PNW ranges from 15 to 76 cm, due to orographic effects of the Cascade and Blue Mountain Ranges that strongly influence total precipitation and distribution patterns in Washington, Oregon and Idaho.

Soils. Soils of the PNW have developed from aeolian and flood deposits originating from volcanic activity and the last continental glaciations (~12,000 years BP) under shrub-steppe vegetation. Soils that developed on wind blown loessal deposits are typically silt loams with moderate to strong structure and soil organic C contents ranging from 1-2%. Soils developing on the flood deposits of Glacial Lakes' Missoula and Bonneville in the Columbia Basin of Washington, Oregon and Idaho are predominately sands to silt loams with weak soil structure and low soil organic C (<1%). Cultivated soils of the region are exposed to severe soil erosion from water and snow melt in the higher precipitation zones and due to high wind conditions in low rainfall areas (Columbia Basin).

Farm systems. Farms in the dryland and irrigated regions of the PNW tend to be large (2,000+ acres on average). Dryland regions are commonly cropped to wheat, barely, canola, oats, grass seed and dry peas. Crop rotations under irrigation are diverse, vegetable based rotations that include potato, onion, carrots, field corn, sweet corn, fresh beans and peas, sugar beets, mint, canola, mustards, safflower, dry pea, grass seed, alfalfa, wheat and barley.

Cover crop species. Field pea (Austrian winter pea), sweetclover, hairy vetch, sudangrass, small grains (wheat, triticale) and a variety of brassica species are used in the region.

Cover crop benefits. Cover crop residues improve water retention, infiltration and storage, soil structure, soil carbon reserves, microbial activity and crop yields. Cover crop residues have been shown to reduce water and wind erosion and nutrient loss from leaching and overland flow of sediments. High crop residues and the use of winter cover crops under irrigation sequester carbon and nitrogen and increase the availability of other macro and micronutrients. Cover crop residues can meet or exceed the 30% cover requirement for conservation tillage in low rainfed areas.

Drawbacks. Rainfall amount and distribution, the availability of irrigation and water use by cover crops are critical considerations for the dryland regions. Heavy residues under irrigation inhibit stand establishment. Cool, wet spring weather exacerbated by cover crop residues delay soil warming and seedling emergence of cash crops. Absentee land owners combined with the diversity of cropping under irrigation of high value vegetable cropping has limited adoption of conservation tillage and cover crop use. Cover crops and conservation tillage can reduce economic benefits and crop yields under some situations.

Management. Management of cover crops is complex and differs in dryland and irrigated systems. Cover crops are managed to reduce nutrient losses, increase nutrient use efficiencies and reduce severity of soil pathogens (88, 111, 115, 430). Management is also key to increasing water use efficiency and can affect protein content of small grains.

California —*Jeffrey Mitchell*

Despite the many benefits of cover cropping and conservation tillage, adoption by row crop producers in California has been limited. Cover crops are used on less than 5% of California's annual crop acreage and conservation tillage practices are used on less than 2% of annual cropland.

Soils. A wide range of soil types are used for agricultural production in California. Cover crops and conservation tillage are used predominantly on finer-textured clay loams or loam soils. More recently, conservation tillage is increasingly used in dairy forage production systems on coarser soil types.

Farm systems. Most cover crop use in conservation tillage systems in California has been for processing and fresh market commercial tomato production systems (187). Research is underway evaluating cover crops in CT corn and cotton systems (281).

Cover crop species. In tomato systems, the most successful and manageable cover crops are mixtures of triticale, rye and pea. Vetches are used for field corn.

Cover crop benefits. California farmers use cover crops to reduce intercrop tillage, suppress winter weeds, reduce pathogen buildup and manage nutrients.

Drawbacks. Producers are most concerned about cooler temperatures above and below mulch, slower maturing crops, cover crop regrowth and specialized management required. In-season weed management options may be limited in conservation tillage systems.

Management. Cover crops are normally grown from mid-October to mid-March in California's Central Valley. Aboveground biomass production can reach 11,000 lb. of aboveground dry matter/A without irrigation (279, 280). The cover crops are mowed or chopped in March using ground-driven stalk choppers, or merely allowed to collapse following herbicide application.

Tomatoes can be no-till transplanted directly into the mulch or transplanted following a strip-till pass using either narrow PTO-driven rotary mulchers or ground-driven strip-till implements modified for tomato beds (250). Because of inadequate weed control by the cover crop mulch itself, high residue cultivators that effectively slice through residues while cultivating weeds are necessary for in-season weed control.

Field corn has also been successfully direct seeded into flail mowed vetch cover crops in the Sacramento Valley. Corn yield is similar to "green manure" systems in which winter cover crops are incorporated.

SUMMARY AND RECOMMENDATIONS

Cover crops benefit conservation tillage systems by:

- decreasing soil erosion
- providing crop residues to increase soil organic matter
- improving soil structure and increasing infiltration
- increasing availability of water for crop production
- improving soil quality
- aiding in early season weed control
- breaking disease cycles

To enhance the beneficial effects of cover crops:

- Plant in a timely fashion.
- Consider additional N fertilizer for small grain covers only if residual N is low.
- Terminate covers 2-3 weeks ahead of anticipated planting date to allow soil moisture recharge and reduce problems associated with allelopathy, pests, and planter operation.
- Take advantage of equipment modifications designed for tillage and/or planter operations in heavy residue.