Sustainable Cotton Production for the Humid South

Soil and cropping practices that can bring long-term profitability

by Preston Sullivan and Rex Dufour

With thanks to Marcia Gibbs of the Sustainable Cotton Project and the Community Alliance with Family Farmers (CAFF) and Dr. Glynn Tillman of USDA/ARS in Tifton, Georgia

No-till: Cotton planted directly into killed mulch, Georgia 2008. Photo: J. Phil Campbell, Sr., NRCS

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This publication focuses on ways you can treat your soil better, so that it will perform better for you.

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Sustainability and Why It's Important for Cotton Farmers

Aside from the farmer's experience, a farm's most important resources are its soil and water. Think of soil and water as the farm's "capital" and what the farm produces as the "interest" on that capital. Farmers need to be shrewd investors, able to live off their farm's production—the "interest"—while also building additional capital—their soil quality. Ignoring soil quality is like making withdrawals from your bank account without making any deposits. When you use cover crops, green manures, and good crop rotations in combination with no-till, you are making investments in your soil quality, in your farm. The return from this investment will be a more productive soil better able to produce profitable crops and withstand extremes of weather.

Until recently, it has been economically feasible to rely on relatively inexpensive synthetic fertilizers and pesticides rather than make longer-term investments in building soil health. But fossil fuel prices are high and likely to go higher, raising the costs of fertilizers and pesticides as well as the costs of applying them and pumping water for irrigation. So growers face important decisions. They can continue as before and hope that, somehow, efficiencies and profits can be maintained. Or they can begin to manage the soil as a living resource that requires feeding (organic matter) and care (crop rotations, reduced tillage, or no-tillage). This publication outlines some investments growers can make in their soil and cropping practices to help ensure long-term profitability.

For a practical example, let's say a farmer switches to no-till production. This decision not only saves him money but also improves water infiltration into his soil, thereby increasing water storage for crop use. No-till production, combined with a good rotation, also virtually eliminates soil erosion and steadily builds soil organic matter that contributes to the sustainable profitability of the farm.

No-till combined with crop rotation are tools—investments—that can conserve organic matter in the soil. "Perhaps the most dominant soil degradative processes are soil erosion and organic matter decline." *—B.A. Stewart, R. Lal, and S.A. El-Swaify. Sustaining the Resource Base of an Expanding World Agriculture. In:* **Soil Management for Sustainability.** *R. Lal and F.J. Pierce (eds.), 1991.*
Photo: J. Phil Campbell, Sr., NRCS

Let's say this same farmer decides to lengthen his crop rotation from continuous cotton to a rotation of cotton followed by corn, then winter wheat, and finally a double-crop of soybeans before returning to cotton. In a season or two this longer rotation breaks up weed, disease, and insect cycles, which reduces pesticide applications, diversifies income sources, spreads the workload and input costs out over the growing season, and reduces the risk of financial disaster that might result from failure of a single crop.

Let's say this same farmer decides to sell most of his corn crop to a neighbor who raises hogs, chickens and turkeys, and the neighbor agrees to sell his animal manure to the crop farmer. This arrangement keeps money in the local community. With the adoption of no-till, a longer crop rotation, and the mutually beneficial swap between neighbors, the social, financial, and environmental sustainability of this farm and the farm community increases. Many more opportunities for increasing farm sustainability exist. For a comprehensive understanding of sustainable farming, see the ATTRA publication ***Applying the Principles of Sustainable Farming*** at the ATTRA website, ***www.attra.ncat.org/attra-pub/trans.html#examples***.

What Is a Sustainable Cotton Production System?

A sustainable cotton production system takes full advantage of the low-cost services provided by soil organisms, green manures and cover crops, natural enemies of pest insects, and innovative weed control strategies that save money while protecting the soil and water.

Cotton should be one crop among several in a lengthy crop rotation. This helps diversify marketing and production risk. Including cover crops in the rotation provides additional low-cost soil fertility.

Farmers spend a lot of money dealing with problems that impact their yields—low fertility, compaction, nematodes, poor water infiltration, and poor water storage capacity in the soil, to name just a few. More often than not, these problems are actually symptoms of an underlying condition—poor soil health. These symptoms can be reduced or eliminated by investing in soil improvements that increase soil health over time.

A healthy soil:

- *feels soft and crumbles easily*
- *drains well; soaks up heavy rain with little runoff*
- *does not crust after planting*
- *warms up quickly in the spring*
- *stores moisture for drought periods*
- *does not require increasing inputs for high yields*
- *produces healthy, high-quality crops*

Such soils result from longer crop rotations that include cover crops and high-residue crops such as corn, the addition of animal manures where possible, and a minimum of tillage.

The Economic Case for Good Soil Management

Topsoil is the capital reserve of every farm. From the time humans created agriculture, topsoil erosion has been the single greatest threat to yield potential—and, consequently, to farm profitability. The major costs associated with soil erosion come from replacing lost nutrients and from reduced water-holding capacity. These two problems account for 50 to 75% of the lost productivity of the land. (Pimentel, 1995). Soil lost to erosion typically contains about three times more nutrients than the soil left behind and is up to five times richer in organic matter (Pimentel, 1995).

We must be good stewards of the soil for future generations.

Five tons of topsoil (the so-called tolerable soil loss level as defined by NRCS) can easily contain 100 pounds of nitrogen, 60 pounds of phosphate, 45 pounds of potash, 2 pounds of calcium, 10 pounds of magnesium, and 8 pounds of sulfur. Table 1 shows the effect of slight, moderate, and severe erosion on organic matter, soil phosphorus level, and plant-available water (water in the soil that plants can take up) on a silt loam soil in Indiana (Schertz, 1984).

When water and wind erode soil at a rate of 7.6 tons/acre/year, it costs $40 per acre (in 1991 dollars) each year to replace the lost nutrients with fertilizer and around $17/acre/year to pump enough irrigation water to compensate for the soil's lost water-holding capacity (Troeh et al., 1991). The total annual cost of soil and water lost from U.S. cropland amounts to approximately $27 billion (Pimentel, 1995). Fortunately several well-tested cropping practices (discussed later in this publication) can virtually eliminate soil erosion and help ensure the sustainability of any farm.

Protecting soil from erosion is the first step toward a sustainable agriculture. Since water erosion begins with rain falling on bare soil, any management practice that protects the soil from raindrop impact will decrease erosion and increase water entry into the soil. No-till mulches, cover crops, and crop residues serve this purpose well.

Conservation tillage systems that maintain year-round crop residue not only virtually eliminate erosion and increase water infiltration but also reduce labor, fuel, and equipment costs without compromising crop yields. No-till is popular among cotton growers, with 57% of

Table 1. Effect of Erosion on Organic Matter, Phosphorus and Plant-Available Water.

Erosion Level	% Organic Matter Remaining in Soil	Phosphorus (pounds/ac) Remaining in Soil	% Plant-Available Water Remaining in Soil
Slight	3.0	62	7.4
Moderate	2.5	61	6.2
Severe	1.9	40	3.6

From Schertz et al., 1984.

Money—and future profits—down the drain.
Soil lost to erosion typically contains about three times more nutrients than the soil left behind and is up to five times richer in organic matter (Pimentel, 1995). Photo: NRCS

them reporting in a recent survey that they used no-till or strip till (Anon., 2007).

Taking Advantage of "Solar" Fertilizers (Legumes)

Given the increase in commercial fertilizer prices, converting free sunlight to nitrogen (N) is becoming increasingly attractive. In a Florida study, Wiatrak et al. (2006) achieved maximum cotton yields with 69 pounds per acre of nitrogen fertilizer following a white lupine cover crop. They concluded that, in general, nitrogen fertilizer on cotton can be reduced by at least 53 pounds per acre where cotton follows lupine because of the legume's nitrogen contribution.

A group of Georgia researchers evaluated seven cover crops, each then followed by a cotton crop under either strip tillage or no-till on a sandy, coastal-plain soil in Georgia (Schomberg, 2006). Once the cover crops were established, they were fertilized with 15, 23, and 93 pounds of nitrogen, phosphorus and potassium, respectively, per acre. When cotton was planted into these killed cover crops the following spring, 71 pounds per acre of nitrogen was applied to the cotton crop in all plots. The cover crops, their above-ground yields, and nitrogen production are shown in **Table 2.**

Cotton grown behind black oats, rye, and oilseed radish had greater yields than cotton following the other four cover crops (Table 2). The authors concluded that rye and black oats were the best choices for sandy, southeastern coastal-plain soils (Schomberg, 2006).

NRCS Conservation Practice

Cover Crop (Code 340)

The Natural Resource Conservation Service (NRCS) can provide funds for farmers to implement new, resource-conserving practices on the farm. Look in your phone book under U.S. Government, USDA, to contact your local NRCS Service Center.

Definition: Crops including grasses, legumes & forbs for seasonal cover and other conservation purposes.

Purpose:

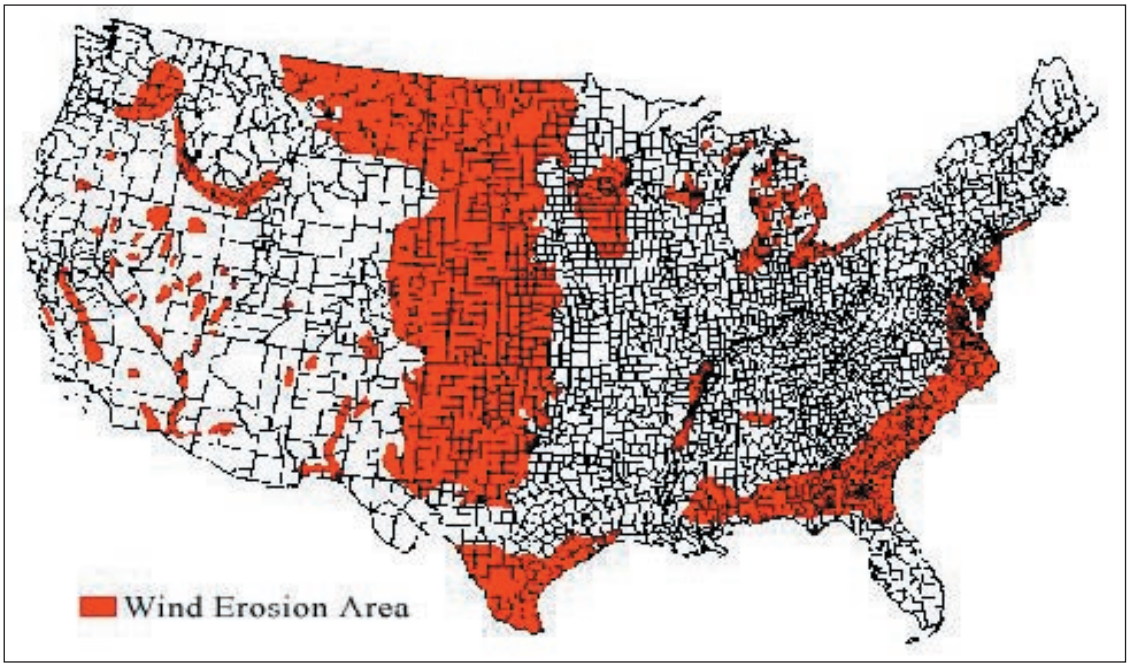
- √ Reduce erosion from wind and water
- √ Increase soil organic matter content
- √ Capture and recycle or redistribute nutrients in the soil profile
- √ Promote biological nitrogen fixation
- √ Increase biodiversity
- √ Weed suppression
- √ Provide supplemental forage
- √ Soil moisture management
- √ Reduce particulate emissions into the atmosphere
- √ Minimize and reduce soil compaction

Table 2. Cover Crop and Cotton Yields & Returns on a Coastal-Plain Soil (4-year average).

Cover Crop	Plant Weight (Pounds/Acre)	Total Nitrogen (Pounds/Acre)	Cotton Lint Yield (Pounds/Acre)	Returns (Dollars/Acre)
Austrian Winter Peas	2312	75	1258	$150
Balansa Clover	1647	36	1260	$134
Black Oats	2777	45	1510	**$187**
Crimson Clover	1647	40	1179	$122
Hairy Vetch	2634	90	1240	$141
Oilseed Radish	2446	41	1365	$116
Rye	4082	45	1455	**$164**

From Schomberg, 2006.

Best choices for the sandy coastal-plain soils of the American Southeast.



Many cotton-growing areas in the U.S. are subject to soil loss through wind erosion.

Georgia Cotton, Peanut Farmers Use Cover Crops to Control Pests

Dr. Sharad Phatak describes his work with cotton and peanut farmers:

TIFTON,Ga.—Here in southwestern Georgia, I'm working with farmers who have had dramatic success creating biologically active soil in fields that have been conventionally tilled for generations. We still grow the traditional cash crops of cotton and peanuts, but with a difference.

We've added cover crops, virtually eliminated tillage, and added new cash crops that substitute for cotton and peanuts some years to break disease cycles and allow for more biodiversity.

Our strategies include **no-till planting** (using modified conventional planters), **permanent planting beds, controlled implement traffic, crop rotation**, and **annual high-residue winter cover crops**. We incorporate fertilizer and lime prior to the first planting of rye in the conversion year. This is usually the last tillage we plan to do on these fields for many years. Together, these practices give us significant pest management benefits within three years.

Growers are experimenting with a basic winter covercrop followed by a summer cash crop rotation. Our cover crops are ones we know grow well here. Rye provides control of disease, weed and nematode threats. Legume crops are crimson clover, subterranean clover or cahaba vetch. They are planted with the rye or along field borders, around ponds, near irrigation lines and in other non-cropped areas as close as possible to fields to provide the food needed to support beneficials at higher populations.

When I work with area cotton and peanut growers who want to diversify their farms, we set up a program that looks like this:

- **Year 1, Fall**: Adjust fertility and pH according to soil test. Deep till if necessary to relieve subsurface soil compaction. Plant a cover crop of rye, crimson clover, cahaba vetch or subterranean clover.
  Spring: Strip-till rows 18 to 24 inches wide, leaving the cover crop growing between the strips. Three weeks later, plant cotton.
- **Year 2, Fall**: Replant cereal rye or cahaba vetch, allow crimson or subclover hard seed to germinate.
  Spring: Strip-till cotton.
- **Year 3, Fall**: Plant rye.
  Spring: Desiccate rye with herbicides.
  No-till plant peanuts.
- **Year 4:** The cycle starts again at Year 1.

—Dr. Sharad Phatak in *Managing Cover Crops Profitably*

Economic Advantages of No-Till

Twelve years of research at the Milan, Tennessee, Experiment Station have shown that cotton can be grown successfully using no-till methods with the same yields as under conventional till (Bradley, 1993). The research team realized savings up to $60/acre by switching to no-till. They recommend that growers start no-till on a small acreage and add acres as they build on their experience. The Milan Experiment station's leader, Dr. Bradley, lists seven advantages for no-till cotton: 1) elimination of tillage; 2) ability to grow cotton on slopes; 3) reduced soil erosion on sloping land; 4) ability to broadcast fertilizer and lime on top of the soil; 5) firmer soil at harvest time resulting in fewer weather delays; 6) improved soil moisture-holding capacity and tilth; 7) reduced labor at planting time by more than 50%.

Planting cotton in a high-residue (greater than 4,000 lb/acre) conservation tillage system. Residue from a rye cover crop covers the soil. A roller-crimper was used to lay the straw down when the rye began to flower. Photo: J. Phil Campbell, Sr., NRCS

Three Mississippi State University agronomists prepared a concise Extension publication on getting started with no-till practices (McCarty et al., 2009). A summary of their publication follows.

The decision to go with no-till should be made on a field-by-field basis. Fields with fertility problems or perennial grass weeds should be avoided or the problems corrected before switching to no-till (McCarty et al., 2009). If soil pH requires lime, it is best applied and incorporated prior to switching to no-till. Generally, fertilizer can be surface applied as needed. Where surface residue is heavy, nitrogen can be applied in split applications, either on the surface or knifed-in one to two inches deep.

Wheat planted at one to two bushels of seed per acre makes a good cover crop to precede cotton. If no cover crop is used, stalks from the previous year's crop should be mowed after harvest to spread the residue and hasten its decomposition. Whether natural winter weeds or a wheat cover crop is used, all vegetation should be killed two to three weeks before planting so that a second treatment can be done if all the vegetation is not dead by planting time. If all vegetation is not dead at the time of planting, add a second burn-down herbicide to the pre-plant tank mix. A good no-till planter that can cut through the surface residue and soil while placing the seed at a uniform depth and spacing is essential.

Planting can start when soil temperatures at the 2-inch depth remain at or above 65 degrees for three consecutive days. Plant for a final stand of three to four plants per row-foot using quality treated seed and in-furrow fungicides to minimize soil-borne seedling diseases. Early crop insect scouting should proceed as with conventional cotton, with close attention being paid to cutworms in fields where they have been a problem in the past. Some herbicide recommendations are included in the MSU publication, and the scouting and herbicide recommendations are available from state Extension offices and private consultants.

Dabney and others (1993) compared no-till to conventional tillage in a North Mississippi field that had been in meadow for several years prior to the experiment. In the first year of their study, conventional till produced higher yields and profits than did no-till. During the third through the fifth years, however, no-till resulted in more cotton production, more profit, equal or better stand establishment, more rapid early growth, and earlier fruiting. The level of soil organic matter was higher, and under no-till, access to the fields was easier during wet weather (Dabney et al., 1993).

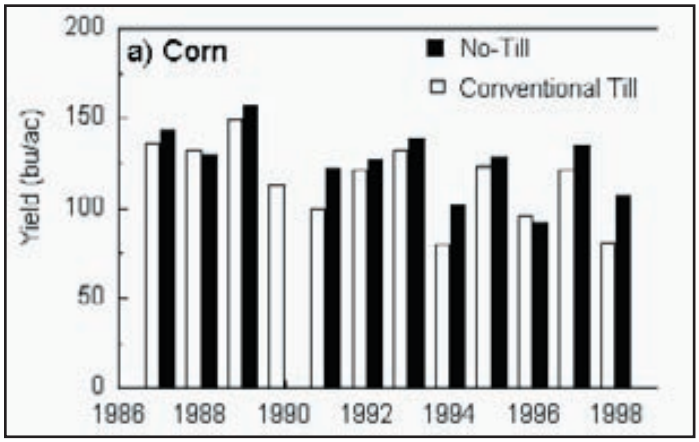
Crozier and Brake (1999) conducted an on-farm case study on no-till in the North Carolina blackland region. Their study involved Open Ground Farms, Inc., a large farm (35,000 acres) growing mostly corn, soybeans, and cotton. Managers at Open Ground were making the transition from conventional tillage to no-till in the late 1980s into the early 1990s to reduce wind erosion and labor costs. During that time, they grew primarily corn and soybeans and were reducing wheat and forage crops while adding cotton to the rotation. One of the primary benefits they realized was reducing the labor force from 24 to 10 people. They also recognized that the ground was firmer to drive equipment across. Corn and soybean yields during the transition are shown in **Figure 1.**

In addition to reducing fuel consumption, conserving soil moisture, and cutting labor-costs no-till farming also provides environmental benefits. Two South Caro-

lina scientists (Novak and Hayes, 2001) at Clemson University compared conventional tillage, phosphorus application, cotton varieties, and herbicides with what at that time (1996) were considered innovative practices. See **Table 3** for details on the two systems.

They ran their study for four years and collected data on cotton yields, water runoff from the two fields, and the amount of phosphorus, nitrogen and sediment contained in that water. As shown in **Table 4**, cotton yields were not statistically different the first year of the study but were higher under conservation tillage for the remaining three years.

Environmental benefits were also realized from the innovative system. Nearly 100 times more sediment eroded from the conventionally-tilled field than from the no-till field, while nitrogen loss was 61 times higher, and phosphorus loss was 10 times higher (**Table 5**). As mentioned in the beginning of the soil section, eroded topsoil typically contains three times more nutrients than the soil left behind. That's money out of the farmer's pocket.



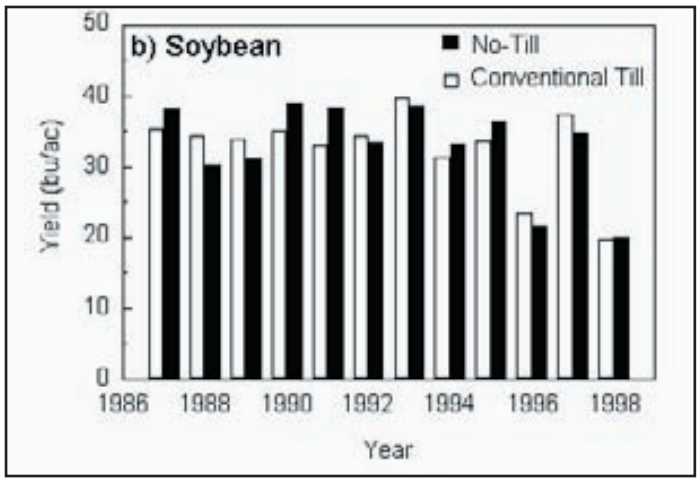


Figure 1. Corn and soybean yields from no-till and conventional till over a 12-year period at Open Ground Farms, Inc. (Crozier and Brake, 1999)

Table 3. Farming Practices Used in the Clemson Study (Novak and Hayes, 2001)

Traditional Practices	Innovative Practices
Discing, bedding, cultivating	No surface tillage
In-row subsoiling	Para Till subsoiling leaves more residue
Conventional cotton variety	BT/Roundup ready variety
Broadcast phosphorus application	Precision P application using GPS
Fluometuron, pendimethalin, sethoxydim, pyrithiobac, cyanazine herbicides	Glyphosate and pendimethalin herbicides

Table 4. Tillage Effect on Cotton Yield

Year	Conventional Tillage	Conservation Tillage
	Pounds per acre	Pounds per acre
1997	875	830
1998	574	785*
1999	285	354*
2000	596	687*

** Indicates a year where significant yield differences occurred between the two farming systems.*

Table 5. Water, Sediment, and Mineral Losses from Two Cropping Systems.

Cropping System	Water Runoff (Inches)	Sediment (Pounds/Acre)	Nitrogen (Pounds/Acre)	Phosphorus (Pounds/Acre)
Innovative	0.1	12	.09	.005
Traditional	2.4	1,176	5.5	.05

Note that nearly **100 times** more sediment eroded from the conventionally tilled field than from the no-till field, while nitrogen loss was 61 times higher, and phosphorus loss was 10 times higher.

NRCS Conservation Practices to Help Prevent Soil Erosion

Four Different Flavors of Conservation Tillage

Residue and Tillage Management, Mulch Till (Code 345)

Definition: Managing the amount, orientation and distribution of crop and other plant residue on the soil surface year round while limiting the soil-disturbing activities used to grow crops in systems where the entire field surface is tilled prior to planting.

Purpose:

- √ Reduce sheet and rill erosion
- √ Reduce wind erosion
- √ Reduce soil particulate emissions
- √ Maintain or improve soil condition
- √ Increase plant-available moisture
- √ Provide food and escape cover for wildlife

Residue and Tillage Management, No-Till/Strip Till/Direct Seed (Code 329)

Definition: Managing the amount, orientation and distribution of crop and other plant residue on the soil surface year-round while limiting soil-disturbing activities to only those necessary to place nutrients, condition residue and plant crops.

Purpose:

- √ Reduce sheet and rill erosion
- √ Reduce wind erosion
- √ Improve soil organic matter content
- √ Reduce CO_2 losses from the soil
- √ Reduce soil particulate emissions
- √ Increase plant-available moisture
- √ Provide food and escape cover for wildlife

The Natural Resource Conservation Service (NRCS) can provide funds for farmers to implement new, resource-conserving practices on the farm. Look in your phonebook under U.S. Government, USDA to contact your local NRCS Service Center.

Planter operating in rolled residue. Note modifications to the planter: spoked closing wheels, heavy-duty down-pressure springs, row cleaners behind rippled coulter. Photo: J. Phil Campbell, Sr., NRCS

Residue and Tillage Management, Ridge Till (Code 346)

Definition: Managing the amount, orientation, and distribution of crop and other plant residues on the soil surface year-round, while growing crops on pre-formed ridges alternated with furrows protected by crop residue.

Purpose:

- √ Reduce sheet and rill erosion
- √ Reduce wind erosion
- √ Maintain or improve soil condition
- √ Reduce soil particulate emissions
- √ Manage snow to increase plant-available moisture
- √ Modify cool wet site conditions
- √ Provide food and escape cover for wildlife

Residue Management, Seasonal (Code 344)

Definition: Managing the amount, orientation, and distribution of crop and other plant residues on the soil surface during a specified period of the year, while planting annual crops on a clean-tilled seedbed, or when growing biennial or perennial seed crops.

Purpose:

- √ Reduce sheet and rill erosion
- √ Reduce soil erosion from wind and associated airborne particulate matter
- √ Improve soil condition
- √ Reduce off-site transport of sediment, nutrients or pesticides
- √ Manage snow to increase plant-available moisture
- √ Provide food and escape cover for wildlife.

Adding Cover Crops or Poultry Litter to No-Till Farming

Cover crops add organic matter to the soil, protect the soil from erosion during the off-season, and provide nitrogen (in the case of legumes). Some cover crops can even reduce soil nematode populations. When used as a no-till mulch, cover crops increase water infiltration and water storage in the soil by reducing evaporation. For more on cover crop management, see the ATTRA publication *Overview of Cover Crops and Green Manures* available at *www.attra.org.*

Poultry production is common throughout the southern cotton belt. Consequently, the poultry litter from these operations is widely used as fertilizer for pastures and forage crops. Some farmers may be reluctant to use poultry litter on cotton fields, however, fearing loss of nitrogen to volatilization and runoff, especially when the litter is surface applied. Additionally, some may fear cotton stalks will grow too tall resulting in yield reductions. The litter should be tested along with the soil to provide guidance on how much poultry litter or fertilizer is needed.

Wiatrak et al. (1999) studied the effects of conservation tillage and nitrogen rates on cotton yields in a sandy-loam soil in northern Florida. They planted cotton using either strip tillage or conventional tillage following either a cover crop of wheat or crimson clover or no cover crop. Nitrogen rates of 0, 60, 120, or 180 pounds per acre were applied for the cotton crop onto each cover crop treatment the following growing season. The results of their study showed that both tillage systems produced similar cotton lint yields (**Table 6**). Cover crops did increase lint yields. Higher lint yields were realized following crimson clover (756 lbs/acre) than after either fallow (694 lbs/acre) or wheat (705 lbs/acre).

Table 6. Effect of Tillage Methods* & Cover Crop on Lint Cotton Yields (3-year average).

Tillage method	Previous Crop			Average
	Fallow (No Cover)	Crimson Clover	Wheat	
	Pounds of Cotton/Acre			
Strip Till	712a**	748a	669b	709a
Conventional	677a	764a	739a	715a
Average	694a	756a	705a	712a

** Tillage methods were not significantly different at the 5% level.*

*** Within columns, numbers followed by the same letter were not significantly different at the 5% level.*

Planting into a killed cover crop protects the soil from erosion, and helps the soil retain moisture. Photo: Rex Dufour, NCAT

Endale and others (2002) fertilized cotton with poultry litter or commercial fertilizer under either no-till or a conventional-till rye-cover-crop system in Georgia. They grew a rye cover crop over their research plots each winter from November to May, then planted cotton directly into the killed rye or into plots where the rye had been chisel plowed and disked several times. Fertilizer rates were based on 54-pounds of nitrogen per acre, which required two tons of poultry litter per acre (based on 50% release rate the first year) on the poultry litter plots compared to 158 pounds of ammonium nitrate per acre to supply the recommended amount of nitrogen on the commercially fertilized plots.

All the plots received 50 pounds of N and 40 pounds of K per acre in the fall just prior to planting the rye cover crop. Cotton yield was 21 to 79% higher under no-till than conventional till each year except 1999—a drought year, when the yields were not significantly different. When averaged over the five-year period, yields were 31% higher from no-till than from conventional tillage (Endale et al., 2002)

Cotton yield from poultry litter was 4 to 12% higher than from commercial fertilizer when averaged over two tillage methods, except in 1999—a drought year, when commercial fertilizer yielded 7% more lint (Endale et al., 2002). Under no-tillage, there was no statistical difference between poultry litter and commercial fertilizer in any single year or averaged over all five years (Endale et al., 2002).

NRCS Conservation Practice
Nutrient Management, Code 590

Definition: Managing the amount, source, placement, form, and timing of the application of plant nutrients and soil amendments.

Purpose:

- √ To budget and supply nutrients for plant production.
- √ To properly utilize manure or organic by-products as a plant nutrient source.
- √ To minimize agricultural nonpoint source pollution of surface and ground water resources.
- √ To protect air quality by reducing nitrogen emissions (ammonia and NOx compounds) and the formation of atmospheric particulates.
- √ To maintain or improve the physical, chemical and biological condition of soil.

Switching to no-till often produces the same yields as under the conventional till for the first few years after the conversion, then higher yields thereafter.
—Boquet et al., 2004

Tewolde et al. (2008) studied poultry litter as a cotton fertilizer under different tillage systems in Mississippi. Their primary tillage treatments were no-till and conventional till. A third treatment under no-till was included, where the poultry litter was incorporated lightly after application, to determine the yield reduction due to the litter not being incorporated. All fertility needs were provided under each tillage treatment by poultry litter (litter-only treatment), litter plus supplemental nitrogen (litter plus N treatment), or exclusively by commercial fertilizer. Poultry litter was applied at a rate based on the nitrogen needs of the cotton crop and assuming a 50% N release rate from the litter. The litter-only treatments received 3.65 tons/acre of litter in 2003 and 3.4 tons/acre in 2004 and 2005, based on pre-application N analysis of the litter. The litter plus supplemental nitrogen treatments used 2.45 tons/acre litter plus 30 pounds/acre of urea ammonium nitrate (UAN–N) in 2003, 2.27 tons per acre litter plus 90 pounds/acre UAN–N in 2004, and 30 pounds/acre UAN–N in 2005.

Lint yields showed poultry litter to be a good source of fertility for cotton in any of the three tillage treatments (see **Table** 7). Litter alone outperformed fertilizing with conventional fertilizer or a combination of litter and fertilizer (Tewolde et al., 2008).

Incorporating the poultry litter at roughly 3.5 tons/acre improved cotton yields over surface application at the same rate. Where litter was incorporated approximately two inches deep, cotton yields increased from 932 to 1007 pounds per acre when averaged over the first and third years of the four-year study. A hail storm during the second year of the study damaged cotton so badly that yield was not presented, and the fourth year of the study was extremely dry (5.7 inches of rain during the growing season) and resulted in much lower yields than normal.

The researchers documented increases in soil carbon (organic matter), phosphorus, potassium, copper, and zinc concentrations where poultry litter had been used. At the end of the last year of the study, soil having litter applied to it contained 4.27 grams of organic carbon per pound of soil compared to 3.37 grams per pound of soil at the start of the study three-years earlier. The researchers concluded that poultry litter was a more effective cotton fertilizer than conventional inorganic fertilizers under tilled or no-till conditions (Tewolde et al., 2008).

Table 7. Cotton Yields Averaged Over 3 Years, by Tillage & Fertility (Tewolde et al., 2008).

Fertility Treatment	No-Till Yields-Pounds/Acre	Conventional Till Yields– Pounds/Acre
No Fertilizer	775c*	984c
Standard Fertilizer	883b	1006c
Tilled Litter + Nitrogen	938ab	1023c
Untilled Litter + Nitrogen	904b	1042bc
Tilled Litter Alone	1007a	1106ab
Untilled Litter Alone	932ab	1116a

**In each column, yield numbers followed by the same letter are not significantly different. Least significant difference is less than .10*

Combining no-till with a good cover crop not only protects your soil and seedlings (shown here just emerging), but also reduces production risk from lack of—or too much—rain.
Photo: J. Phil Campbell, Sr., NRCS

Boquet et al. (2004) studied cotton grown with a wheat cover crop, a hairy vetch cover crop, and no cover crop, under either conventional tillage or no-till, using several different nitrogen rates. Starting in year five of their study, they found consistently higher yields under no-till when adequate nitrogen was provided. In subsequent years, no-till on average increased yield by about 9% each year.

The researchers mention that shorter-term studies produced inconsistent yield responses to no-till production in the first few years after conversion from conventional till. They go on to say that most studies indicate that cotton yields are not reduced under no-till. To summarize, switching to no-till often produces the same yields as conventional tillage for the first few years after the conversion and higher yields thereafter (Boquet et al., 2004).

In the cover crop portion of their study, hairy vetch produced optimal cotton yields under both no-till and conventional till with no supplemental nitrogen fertilizer. Other studies—Boquet and Coco (1993) and Schwenke et al. (2001)—found that hairy vetch provided about half the nitrogen cotton needs. Where nitrogen was applied to hairy vetch at a rate above 105 pounds per acre, cotton yields declined, most likely due to excessive vegetative growth (Boquet et al., 2004). Under a wheat cover crop, excess nitrogen (greater than 105 pounds/acre) did not reduce cotton yields, most likely due to nitrogen immobilization from the high carbon-to-nitrogen ratios in the wheat residues (Boquet et al., 2004). Their data show that the optimal nitrogen rate for cotton following a non-legume cover crop was 105 pounds per acre.

Of all the tillage, nitrogen, and cover crop combinations, the only ones that had a net gain in soil organic carbon sequestration over the three-year study period were the no-till with cover-crop treatments.

All the rest suffered a loss of soil organic matter that could not be made up with cover crops or crop residue.

—Sainju, et.al, 2006

Carbon Markets and Government Incentive Programs

Worldwide awareness of the dangers posed by rising carbon dioxide (CO_2) levels in the atmosphere has motivated government agencies and others to find ways to sequester (remove from the air and store) carbon dioxide. Cap-and-trade programs will likely be paying landowners for using plants and soils to capture CO_2. Some strategies for sequestering CO_2 include establishing timber or grassland plantings or extending the durations for timber stands and grasslands. Annual cropland is also seen as a means for carbon sequestration under cap and trade. Typically, annual cropland has been a net contributor of CO_2 to the air. Conventional tillage speeds the decomposition of crop residue, converting the carbon in the crop residue back to atmospheric CO_2. Tillage also speeds the decomposition of soil organic matter, releasing even more CO_2. No-till, by minimizing soil disturbance, allows carbon to build up in the soil.

Sainju et al. (2006) studied changes in soil organic carbon (organic matter) that resulted from using cover crops and tillage on fields growing cotton or sorghum. They grew cover crops of hairy vetch, rye, a rye-hairy-vetch mixture, and winter-fallow weeds near the Fort Valley Agricultural Research Station in Georgia. Three nitrogen rates (0, 55 and 110 pounds per acre) were applied to the cotton or sorghum. The three tillage methods were no-till, strip till, and chisel-till (chisel plowed plus disc harrow).

Of all the tillage, nitrogen, and cover crop combinations, the only ones that had a net gain in soil organic carbon sequestration over the three-year study period were the no-till with cover-crop treatments. All the rest suffered a loss of soil organic matter that could not be made up with cover crops or crop residue. In the top four inches of no-till soil, the rye cover crop accumulated organic

Carbon Modeling Software

CQUESTR was developed by the USDA and simulates the effect of several management practices on soil organic carbon stocks. It does not consider livestock, farm fuels and by-products. The model has been calibrated and validated in temperate regions. (Fuller, et.al., 2003)

Century: The Century Soil Organic Matter model is a generalized biogeochemical ecosystem model that simulates carbon, nitrogen, and other nutrient dynamics. The model simulates cropland, grassland, forest and savanna ecosystems and land use changes between these different systems.

The Century Model was developed by CSU and USDA Agriculture Research Service (ARS). Various other models, including EPIC and COMET VR incorporate the Century model as part of their program.

COMET-VR: The **V**oluntary **R**eporting of Greenhouse Gases—**C**arb**O**n **M**anagement **E**valuation **T**ool (COMET-VR) is a decision support tool for agricultural producers, land managers, soil scientists and other agricultural interests. COMET-VR provides an interface to a database containing land use data from the Carbon Sequestration Rural Appraisal (CSRA) and calculates in real time the annual carbon flux using a dynamic Century model simulation. Additional information is available at: *www.cometvr.colostate.edu.*

Users of COMET-VR specify a history of agricultural management practices on one or more parcels of land. The results are presented as ten year averages of soil carbon sequestration or emissions with associated statistical uncertainty values. Estimates can be used to construct a soil carbon inventory for the 1605(b) program, which is USDA's voluntary greenhouse gas reporting system.

DAYCENT is a daily time-step version of Century. DAYCENT is a terrestrial biogeochemical model. DAYCENT has been applied to estimate N_2O emissions from various native and managed systems at different spatial and temporal scales, including its use to estimate annual N_2O emissions from cropped soils for the USA national greenhouse gas inventory.

A major strength of the model is the required inputs (daily weather, soil texture, vegetation cover, land management) are relatively easy to acquire for many systems. Major weaknesses are that the model does not account for all the factors related to denitrification (e.g. microbial community, lateral flow of water) and the factors that are accounted for are on relatively coarse spatial and temporal scales compared to the scales at which denitrification actually occurs. The model is available to the public and can be run from DOS or UNIX. The model is relatively user friendly for those with minimum experience in computer programming.

EPIC (Erosion Productivity Impact Calculator) is a widely tested and adapted model originally built to quantify the effects of erosion on soil productivity. It has since evolved into a comprehensive agro-ecosystem model capable of describing the behavior of many crops grown in complex sequences and tillage operations. (Williams, 1995)

The model contains parameters to simulate about 100 crops and up to 12 plant species in a field. EPIC contains routines to handle CO_2 fertilization effects on plant growth and water use (Stockle et al., 1992a,b), hydrological balance, N and P cycling, soil density changes, tillage, erosion, and leaching. The C and N dynamics captured from Century (another C modeling program) now interact directly with the soil moisture, temperature, erosion, tillage, soil density, leaching, and translocation functions of EPIC. (Izaurralde, et. al, 2001)

carbon at a rate of 267 pounds per acre/year; the hairy vetch accumulated 207 pounds per acre/year; and the rye-hairy vetch mixture accumulated 267 pounds per acre/year. Where no cover crop was grown on no-till soil, there was a net loss of 149 pounds per acre/year of organic carbon.

Other studies in the southeastern United States show that growing cotton under no-till increases soil carbon in the range of 429 to 499 pounds per acre compared to conventional till (Causarano et al,, 2006). When a cover crop was added to a no-till operation, soil carbon levels increased 561 to 597 pounds per acre. These increases in organic matter not only improve soil tilth, water holding capacity, and nutrient cycling, but can also be converted into cash through one or more USDA programs.

The Natural Resources Conservation Service (NRCS) has a tool known as the Soil Conditioning Index (SCI) that predicts changes in soil organic carbon based on tillage and cropping management. The SCI accounts for organic-matter additions, and field operations such as tillage, planting, fertilizing, and harvesting. Based on these practices, it also predicts soil erosion by water and wind (Hubbs et al., 2002). A negative SCI reading predicts soil organic carbon will decline, while a positive reading predicts an increase in soil organic carbon.

Benefits of Increasing Soil Organic Matter (SOM)

- SOM increases absorption of rainfall/irrigation and storage capacity of soil moisture.
- SOM acts as a reservoir for nitrogen.
- SOM helps provide phosphorus through mycorrhizal-mediated interactions.
- SOM increases Cation Exchange Capacity.
- SOM provides other micronutrients through an effective soil food web.
- SOM helps buffer soil pH.

—***Sustainable Soils**, B. Wolf, G.H. Snyder, 2003*

The SCI does not give a quantity of organic carbon present in the soil but rather a probability of achieving a change in organic carbon based on the cropping system. NRCS uses the SCI to help inform decisions about payments to landowners enrolled in some of its conservation programs. In **Tables 8 and 9**, SCI values are provided for two tillage and rotation systems that include cotton (Causaran et al., 2005).

Table 8. Soil Conditioning Index Values for Rotation in 2 Tillage Systems — Mississippi Valley Region.

Slope %	Soil Texture	Mono-Crop Cotton, Conventional Tillage	Mono-Crop Cotton, No-till	Rotated Cotton,* No-till
5%	Silty loam	-8.4	-1.9	.07
2%	Silty loam	-1.9	.03	.11
2%	Silty loam	-1.9	.36	.42
2%	Silty loam	-1.5	.08	.52

** Rotation was cotton/wheat-cover/corn/wheat-cover*

Table 9. Soil Conditioning Index Values for Rotation Under 2 Tillage Systems — Eastern Texas Region.

Slope %	Soil Texture	Mono-Crop Cotton, Conventional Tillage	Mono-Crop Cotton, No-till	Rotated Cotton,* No-till
2%	Clay	-1.1	.55	.53
2%	Clay loam	.71	.26	.36
2%	Silty clay loam	.70	.41	.51

** Rotation was cotton/corn.*

Negative Soil Conditioning Index (SCI) values predict a decline in organic matter. Positive values predict an increase in organic matter.

The NRCS Conservation Stewardship Program (CSP) provides financial and technical assistance to farmers for conserving and improving soil, water, and air quality among other things. Some of the practices that qualify under the program are conservation tillage, cover cropping, crop rotation, and grassed waterways. Learn more about the CSP program from the NRCS website, *www.nrcs.usda.gov/programs/new_csp/csp.html.* A 3-page list of CSP enhancements (stewardship practices that NRCS may help pay for) can be found at *www.nrcs.usda.gov/new_csp/cmt_scoring_pdfs/Enhancement_list_with_scores.pdf.*

Finally, a carbon-trading market has been established in the U.S. The Chicago Climate Exchange (CCX) offers trading of carbon credits at the present time. Carbon credits are created through consultants known as aggregators who gather project acres into a bundle large enough to offer for sale on the climate exchange. Each project has to be verified by an independent third party to be eligible for sale on the exchange. Continuous conservation tillage for a five-year period is one of the practices that qualify as a carbon-offset project. As the value of carbon credits rises, interest in carbon trading will increase. Learn more about carbon credits and carbon trading at the CCX website, *www.chicagoclimateexchange.com.*

Crop Rotations: Diversify Your Portfolio

Crop rotations are one of the most cost-effective means of breaking soil-borne pest-insect and plant-disease cycles. Likewise, many problem weeds are suppressed by the nature and timing of different cultural practices. Rotations also affect soil fertility in significant ways when forage legumes serve as a nitrogen source for subsequent crops.

Crop rotations are an affordable and low-cost method of risk management. Rotations can reduce input costs over the long-term and also reduce pest management risks. A farmer who produces only a single crop, such as cotton, is taking on greater risk because there is only a single market for the crop, and the repetition of cotton year after year will be certain to create pest problems.

One of the major benefits realized from rotation is improved control of weeds, insects and diseases by breaking or interfering with pest life cycles.

If instead farmers diversify crops and in some cases even integrate plant and animal production, they won't be reliant on a single market, and the rotations will benefit their soils, thereby further reducing risk. Increasing soil functions begins with crop rotations, which break weed and pest life cycles and provide complementary fertilization to crops in sequence with each other, as when grain crops follow nitrogen-fixing legumes. In many cases, yields are increased by the "rotation effect."

Three crop scientists (Wesley et al., 1993) compared cotton-soybean and cotton-sorghum rotations to each crop grown alone near the Stoneville, Mississippi, Experiment Station for five years. The study was done in two separate locations with either conventional tillage or ridge-till. Cotton yields were higher from the cotton-sorghum rotation than from cotton monoculture or cotton-soybean rotation in both conventional and ridge-till systems. Soybean yields were 16 to 19% higher when rotated with sorghum in conventional tillage and 40 to 80% higher under ridge-till (Wesley et al., 1993). Sorghum yields remained unaffected under either tillage regimen. In essence, sorghum increased and stabilized yields of both cotton and soybeans when rotated with either. The researchers noted that the high levels of crop residue produced by sorghum will aid producers who plant annual crops on highly erodible land in achieving compliance with their conservation plans required by USDA cost-share programs.

Planting cotton every year with 120 pounds N per acre as fertilizer and no winter cover crop has resulted in poor soil quality (less than 1% soil organic matter) and severe soil crusting in the spring. In spite of the difficulty of getting a stand of cotton with conventional tillage, long-term average yields have been only slightly less than the two-year or three-year rotation. This is typical of most cropping situations in the South.

A three-year rotation of cotton, winter legume, corn, small grain harvested for grain, and soybean results in more than 2.5% soil organic matter and the highest average cotton lint yields (two bales per acre). Only 60 pounds N is applied during the three-year rotation and that is applied to the small grain, which is either wheat or rye.

The two photographs above are from The Old Rotation—the oldest continuous cotton experiment in the world, started by Professor J. F. Duggar to demonstrate the benefits of winter legumes as a cover crop, and crop rotations on cotton and corn production in the South. Located on the campus of Auburn University, Alabama.

One important benefit realized from rotation is improved weed control due to changing herbicides from one crop to another. Following cotton with corn helps break up herbicide resistance that may be present in a field because different herbicides may be used on corn than on cotton. Another advantage is soil moisture conservation when cotton follows a soybean-wheat rotation. The wheat straw insulates the soil, thus reducing water evaporation, runoff, and erosion, while increasing water infiltration.

The Huerkamp brothers, who farm 3400 acres near Macon, Mississippi have found that continuous cotton doesn't work on their farm. When they rotate with corn, the corn stalks leave behind a good root system that decomposes into organic matter. Consequently, they realize better cotton plant development and higher yields (Horton, 2008).

Three Mississippi researchers studied the economic potential of a cotton-corn rotation. They interviewed 11 farmers in the Mississippi delta and developed enterprise budgets for their rotations (Martin et al., 2002). These farmers estimated their cotton lint yields were 150 to 400 pounds per acre higher the first year after corn. They reported corn yields ranging from 135 to 225 bushels per acre.

Most of the farmers saw some reduction in equipment use and lower labor costs resulting from the timing of corn planting and harvest in conjunction with cotton planting and harvest. In other words, the use of equipment was spread out over a longer period since corn was planted starting in March, then cotton was planted next. Corn was harvested in late summer and cotton in the fall. These savings resulted from greater ease in getting the two crops planted and harvested, since less of each crop went on the same total acreage that once grew only cotton. Net income results are shown in Tables 10 and 11 at left. Under both irrigated and non-irrigated cropping systems, a rotation of corn and cotton produced more net income than did continuous cotton, based on a corn price of $2.50 per bushel and cotton at three prices.

If forage crops can be included in the crop rotation, even more benefits can be realized. Sod crops, such as bahiagrass, not only keep the soil entirely covered but also have massive root systems that produce far more organic matter than is lost. Sod crops are the best soil-building crops—they can heal the damage done to soil by row cropping. Weed control improves when sod crops are added because the types of weeds encouraged by row-cropping systems are usually not adapted to growing in a sod/hay crop. An ideal rotation might include one year of sod crop for each year of row crop, and as

NRCS Conservation Practice

Conservation Crop Rotation, Code 328

The Natural Resource Conservation Service (NRCS) can provide funds for farmers to implement new, resource-conserving practices on the farm. Look in your phone book under *U.S. Government, USDA* to contact your local NRCS Service Center.

Definition: Growing crops in a recurring sequence on the same field.

Purpose: This practice may be applied as part of a conservation management system to support one or more of the following:

- √ Reduce sheet and rill erosion.
- √ Reduce soil erosion from wind.
- √ Maintain or improve soil organic matter content.
- √ Manage the balance of plant nutrients.
- √ Improve water use efficiency.
- √ Manage saline seeps.
- √ Manage plant pests (weeds, insects, and diseases).
- √ Provide food for domestic livestock.
- √ Provide food and cover for wildlife.

Table 10. Average Returns Above Survey Costs Per Acre for Continuous Cotton & Irrigated Corn-Cotton in Rotation. Corn yield: 165 bu/acre; cotton yield: 825 lbs/acre. (Martin et al., 2002)

Cotton Price	$0.55/pound	$0.60/pound	$0.65/pound
Rotation Corn Net @ $2.50/bu	$108/acre	$131/acre	$155/acre
Continuous Cotton Net Income	$-6/acre	$35/acre	$76/acre

Table 11. Average Returns Above Survey Costs Per Acre for Continuous Cotton & Non-Irrigated Corn-Cotton Rotation. Corn yield: 135 bu/acre; cotton yield: 750 lbs/acre. (Martin et al., 2002)

Cotton Price	$0.55/pound	$0.60/pound	$0.65/pound
Rotation Corn Net @ $2.50/bu	$97/acre	$119/acre	$140/acre
Continuous Cotton Net Income	$-7/acre	$31/acre	$69/acre

Under no-till cropping systems and perennial sod, earthworm populations increase along with all the benefits they provide, including improved rooting, aeration through worm channels, and better nutrient cycling from worms processing the soil. Conventional tillage diminishes surface residue, disrupts earthworm channels, and reduces worm populations.

many years of small grain or cover crops as make sense in the system.

One challenge of incorporating sod crops into a crop rotation is finding a market for the hay. Fortunately, land capable of producing a 100-bushel per acre corn yield will generally produce 5-ton hay yields, making the income potential quite good. With prices of $60 to $70 per ton being common for ordinary hay, and $3/bale for small 50-pound bales ($120/ton), gross revenues per acre from hay will exceed those from corn as long as corn is under $3.00 per bushel. The net income picture is even more encouraging, however, because conventional production costs for an acre of corn are quite a bit higher than for hay.

Katsvairo et al. (2006), in their extensive literature reviews, advocated including forage grass into a typical cotton-peanut rotation in the Gulf South. These southern scientists discussed the benefits of adding bahiagrass to the peanut-cotton rotation. Besides being drought-tolerant and well adapted to the South, bahiagrass roots can also penetrate a hardpan. When the roots die and decay, they leave channels that allow deeper water penetration into the soil and are large enough for cotton roots to grow through (Long and Elkins, 1983).

Perennial bahiagrass can reduce irrigation needs for a following annual cotton crop. This is attributable in part to deeper root penetration by the cotton plants when they follow perennial grass in rotation. Elkins et al. (1977) determined that for a typical coastal plain sandy-loam soil, a crop with a rooting depth of 12 inches will experience 60 drought days from May through August in 5 out of 10 years. However, with a 60-inch rooting depth, they would experience only 11 drought days. With climate change, the number of drought days may well increase, so getting your soils into shape by eliminating hard pans and increasing organic matter is a good investment and a good risk-management strategy.

Bahiagrass sod also dramatically reduces soil erosion, as does no-till cropping with cover crops. Including perennial grasses such as bahiagrass into a cropping system is a cost-effective way to hold and slowly build organic matter (Katsvairo et al., 2006). Building and maintaining organic matter enhances many soil functions. These functions include nutrient cycling by soil microbes and earthworms and resistance to soil-borne diseases through the buildup of beneficial nematodes and fungi. With increases of organic matter, we also see improvements in soil tilth, water infiltration, water storage capacity, and aeration.

No-till and perennial sod increase plant-surface residues that serve as food for earthworms. Thus, under these two cropping practices, earthworm populations increase along with all the benefits they provide, including improved rooting, aeration through worm channels, and better nutrient cycling from worms processing the soil. Conventional tillage, however, diminishes surface

Table 12. Earthworm Numbers from Three Crop Rotations in Florida Over a Two-Year Period.

Rotation	Earthworms/ square meter*
2004	
Bahiagrass–Bahiagrass–Peanuts–Cotton**	9.5 a
Cotton–Peanuts–Cotton–Cotton	1.2 b
2005	
Bahiagrass–Bahiagrass–Peanuts–Cotton	24.7 a
Cotton–Peanuts–Cotton–Cotton	7.0 c
Cotton–Peanuts–Cotton–Cotton	14.1 b

** Numbers followed by a different letter are significantly different at the 0.05 level.*

*** Underlined entries indicate the period in the rotation sequence when worms were sampled.*

residue and disrupts earthworm channels, thereby reducing worm populations.

Katsvairo et al. (2007) examined earthworm populations from two cotton rotations, one containing bahiagrass and the other a cotton-peanut rotation. Earthworm numbers were much higher in the bahiagrass rotation than in the cotton-peanut rotation (**Table 12**). This is primarily due to the additional food provided by the perennial sod roots, increased soil moisture under the sod, and the lack of soil disturbance from no-till. Earthworms, through their burrowing, increase soil aeration, water infiltration, and root proliferation. The researchers observed cotton roots penetrating the natural soil compaction zone, cotton roots following earthworm burrows, and earthworms burrowing through old bahiagrass root channels. Cotton yields were similar under both rotations when averaged over the two-year period.

Weed life cycles are broken when bahiagrass is included in a cotton-peanut rotation because the system shifts from annual crops to perennial sod. Different herbicides could be used on the grass from those normally used on cotton or peanuts. When the grass is grazed or hayed, there is additional weed suppression.

Higher peanut yields have been realized following bahiagrass sod. Norden et al. (1980) reported improved peanut yields for up to five years following a long-term bahiagrass rotation. In fact, peanut yield increased following even one year of bahiagrass in the rotation (Norden et al., 1980). Rodriguez-Kabana et al. (1988) reported a 98% decrease in root-knot nematodes at harvest for bahiagrass-rotated peanuts, compared to continuous peanuts, and this increased yield by up to 27%.

Rodriguez-Kabana et al. (1988) reported a 98% decrease in root-knot nematodes at harvest for bahiagrass-rotated peanuts, compared to continuous peanuts, and this increased yield by up to 27%.

Bahiagrass.

An interesting no-till double-crop rotation study was done on a sandy soil in Georgia (Gascho et al., 2001). The researchers set out to determine the optimum broiler litter rate and litter's effect on plant diseases and nematodes in a rather complex rotation under irrigated no-till management. The cropping sequence was cotton–fallow in year one, pearl millet–wheat in year two, then peanut–canola in the third year (**Table 13**). Broiler litter was broadcast one to three weeks before planting either winter or summer crops in the rotation at rates of two, four, or six tons per acre per year. Winter crops were no-till planted, while summer crops had in-row sub-soiling and strip tillage. No fertilizer was applied other than broiler litter during the entire four-year study. Crops were irrigated as needed.

Cotton yields increased from using either the four or six tons/acre litter rate during the first two years of the study (**Table 14**). But rates above two tons per acre did not increase cotton yields during the last two years of the study, possibly indicating a cumulative effect. Peanut yields actually decreased from poultry litter application. The researchers concluded that broiler litter was a cost-effective addition to all their no-till crops except peanuts. In the case of cotton, the yield gains were 583, 734, and 673 pounds per acre for two, four, or six tons of broiler litter per acre, respectively, averaged over the four-year study period. At a sale price of $.65/pound, that amounts to $379, $477, and $437 per acre gain above no litter or fertil-

Table 13. Cropping Sequence in the Double-Crop Rotation Study by Gascho, et al., 2001.

Year	First Crop	Second Crop
1	Cotton	Fallow
2	Pearl millet	Wheat
3	Peanut	Canola

Table 14. Effect of Poultry Litter on Yields of Various Crops Averaged Over the Four-Year Study Period.

Litter rate Tons/acre	Wheat Pounds/acre	Canola Pounds/acre	Cotton Pounds/acre	Pearl millet Pounds/acre	Peanut Pounds/acre
0	733	885	581	1965	2906
2	1781	1559	1164	3253	2654
4	2888	2008	1315	3505	2610
6	2949	1970	1254	3718	2420

izer. At a litter price of $15/ton, the per acre litter costs would be $30, $60, or $90 per acre, respectively.

Root-knot nematode numbers were generally low, with no galls showing up on any sampled plants throughout the study. Stubby-root nematodes increased in cotton, canola, and peanut with the age of the study but never reached harmful levels. Ring nematodes were low overall. The severity of Rhizoctonia limb rot in peanuts increased with litter rate during the middle two years of the study. Lodging in the canola crop during the last year of the study was caused by Sclerotinia and was related to litter application.

Soil Moisture Management

Drought Resistance

Your soil can be made more drought-resistant by increasing the organic matter in it. Since rainwater is free, why not capture as much of it as possible and store it in the soil for future plant use? And wouldn't it be good if plant roots could penetrate the soil and proliferate as much as possible? One way to achieve these benefits is through management of organic matter, which can increase water storage by 16,000 gallons per acre for each one percent of organic matter (Scott et al., 1986). That is roughly 1.5 quarts of water per cubic foot of soil for each percent of organic matter. **Figure 2** shows the relationship of organic matter to water-holding capacity.

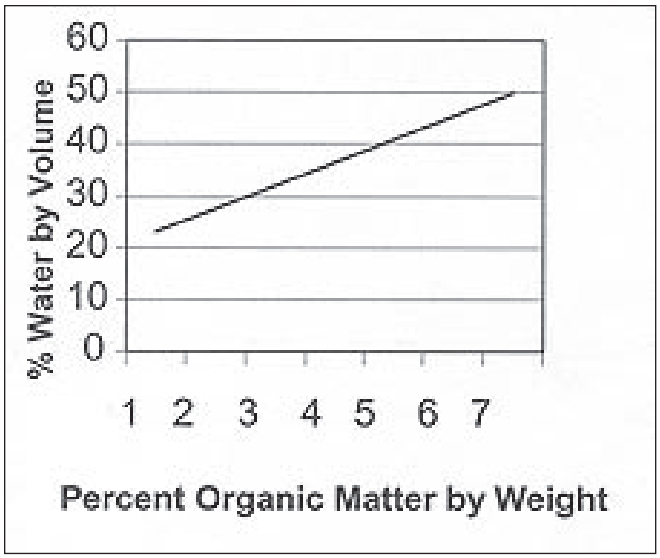


Figure 2. The soil's ability to hold water increases significantly as the percentage of soil organic matter increases. (Scott, H.D., et al., 1986)

Peanuts in straw mulch, Georgia. Photo: Rex Dufour, NCAT

You can drought proof your soils by:

- ***Increasing levels of organic matter (which stores water)***
- ***Using no-till and leaving mulch residues that protect the soil from the sun and increase water infiltration***

Ground cover can also reduce water evaporation from soil. In a Kentucky study, surface evaporation was five times less under no-till (which leaves a surface mulch) than with conventional tillage during the May to September season (**Table 15**). Because less water was lost to evaporation, more water was available for plants.

Tillage systems and equipment have enormous impacts on water infiltration, storage, and plant water-use efficiency. These impacts include mechanical stress on soil aggregates, adverse effects on soil microorganisms, and the tendency to create hardpans. Of most importance to drought-resistance, however, is the extent to which a surface cover is maintained.

Table 15. Water Evaporation and Transpiration* from Tillage Types Over a 5-Month Growing Season (Phillips, 1980)

Tillage Type	Evaporation mm of water (inches)	Transpiration* mm of water (inches)
No-Till	41 (1.6)	307 (12.1)
Conventional Till	191 (7.5)	242 (9.5)

** Transpiration is the release of water vapor by plants.*

This killed cover crop mulch conserves soil moisture and protects the soil from erosion. Georgia 2008. Photo: Rex Dufour, NCAT

Table 16 shows three different tillage methods and how they affect water entry into the soil. Notice the direct relationship between tillage type, ground cover, and water infiltration. No-till has more than three times the water infiltration of moldboard-plowed soil. Additionally, the no-till field would have higher soil particle aggregation from the organic matter decomposing on-site.

Table 17 shows the differences in water infiltration in dry soil between no-till and conventional tillage systems. With no-till, wet soil has more than double the infiltration rate compared to tilled wet soil.

In a dryland Texas study, Baumhardt et al. (2008) set out to determine tillage-system effects on soil water-storage and cotton yield. Typical crop rotation sequences in the study include a year of fallow between a wheat crop and a sorghum crop. To summarize, a June-harvested wheat crop is followed by fallow until the following June, when sorghum is planted. Following sorghum harvest in October, fallow ensues until the following October, wwhen wheat is planted again. In this study, cotton was substituted for sorghum in the typical rotation for that region.

Table 16. Tillage Effects on Water Infiltration and Ground Cover (Boyle and Frankburger, 1989)

	Water Infiltration (mm/minute)	Ground Cover Percent
No-Till	2.7	48
Chisel Plow	1.3	27
Moldboard Plow	0.8	12

Table 17. Effects of Tillage on Water Infiltration in a Silt Loam Soil (Mcgregor et al., 1991)

Tillage History	Dry Soil mm water/hour	Wet Soil mm water/hour
No-Till	43	22
Conventional Till	31	10

The study showed that crop residues increased soil water-storage during the fallow period. During the first year of the study, when less than three and one-half inches of rain fell, available soil water during the fallow period was five inches for no-till, four inches for sweep till, and two and one-half inches with disk tillage. In the second year of the study, when nearly 12 inches of rain fell, 8 inches of soil water was stored in all the tillage treatments.

Soil under no-till has more than three times the water infiltration of moldboard-plowed soil.

Irrigation

A team of North Carolina scientists compared overhead sprinkler irrigation with subsurface drip irrigation (Nuti et al., 2006). Lint yield averaged 1247 pounds per acre under overhead sprinkler irrigation and 1310 pounds per acre with subsurface drip irrigation. Though these yields were statistically similar, plants grown using subsurface drip exhibited more vigorous growth, improved fiber length, more second-position bolls, more total bolls per plant, and an improved percentage of fruit retention (Nuti et al., 2006). The researchers also recognized that with subsurface drip (SSD), cotton can be irrigated after bolls open, and subsurface drip can provide water in more precise increments.

Whitaker et al. (2008) also compared subsurface drip with overhead irrigation at two locations (Stripling and Lang) in Georgia. Irrigation treatments consisted of overhead irrigation that was activated when soil moisture reached minus 5.8 pounds/inch^2 at the 8-inch depth or minus 7.25 pounds/inch^2 at the 16- or 24-inch depths. When these soil conditions were met, one inch of water was applied to the cotton crop. Two subsurface drip systems were installed, one that was activated at the same time as the overhead irrigation and applied the same amount of water (SSD matched), and the other activated based on the same soil moisture conditions but applying only 0.3 to 0.60 inches of water (SSD reduced).

Table 18. Water Use at 2 Locations (Stripling & Lang) for 3 Irrigation Systems (Whitaker et al., 2008).

Treatment	Stripling 2004	Stripling 2005	Lang 2005
Not irrigated	1.1	0	1.4
Overhead	6.2	4.0	4.2
SSD* Matched	4.5	.79	4.0
SSD* Reduced	6.2	4.0	4.2
**Sub Surface Drip Irrigation*			

They found water use efficiency from subsurface irrigation was 23 and 15% higher than with overhead irrigation in two locations (Whitaker et al., 2008). Lint yields were similar for all irrigation methods at both locations but 42% higher than non-irrigated for overhead, 62% higher than non-irrigated for subsurface drip based on similar soil moisture (SSD Matched), and 54% higher than non-irrigated for subsurface drip applied at the same time (SSD Reduced) as the overhead system. They concluded that subsurface irrigation provided the same benefits to cotton as overhead irrigation while using less water (**Table 18**). Subsurface drip irrigation can also reduce weed germination from seeds on the surface of the soil, saving on weed management costs.

Cost Share Option for Subsurface Drip Systems

NRCS Conservation Practice

Irrigation System, Surface and Subsurface, Code 443

Definition: A system in which all necessary water-control structures have been installed for the efficient distribution of water by surface means, such as furrows, borders, contour levees, or contour ditches, or by subsurface means.

Purpose: This practice is applied as part of a conservation management system to achieve one or more of the following:

√ Efficiently convey and distribute irrigation water to the surface point of application without causing excessive water loss, erosion, or water quality impairment.

√ Efficiently convey and distribute irrigation water to the subsurface point of application without causing excessive water loss or water quality impairment.

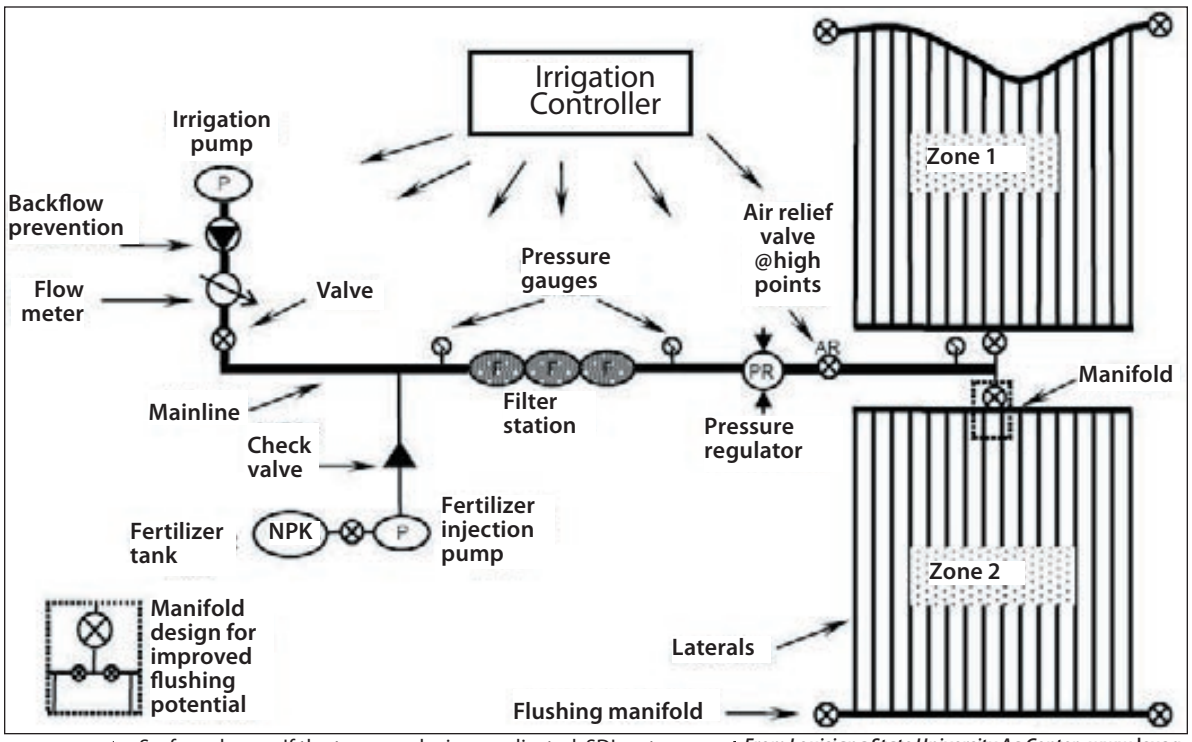
√ Apply chemicals and/or nutrients as part of an irrigation system.

Advantages of Subsurface Irrigation:

- Potential for more precise management of water near the crop roots
- Allowance for spoon-feeding nutrients (especially important in locations where rainfall can leach significant nutrients)
- Installation of systems in fields with irregular shapes
- Minimizing losses due to evaporation
- Zoning of irrigation areas based on limited water supplies and differing water needs of soils and crops

Considerations:

- High initial cost, can last up to 10 years with careful maintenance
- Water supply: Need sufficient quantity & good water quality, slightly acid, as alkaline pH will tend to precipitate minerals within the system
- Energy source must be considered & designed into the system
- Soil limitations—Plow pans must be taken into account with respect to their effect on distribution of water
- Surface slope—If the topography is complicated, SDI systems should be designed with pressure-compensating emitters



From Louisiana State University Ag Center, www.lsuagcenter.com/en/crops_livestock/crops/Irrigation/Subsurface+Drip+Irrigation+in+the+Southeast.htm

IPM for Cotton

Integrated Pest Management (IPM) is based on preventing problems by understanding how the life cycle of the crop interacts with its pests and beneficials. An important component of this system is often overlooked—maintaining healthy, functioning soil. It takes a lot of money, in the form of fertilizers, pesticides and application costs, to try to grow a healthy plant on a low-functioning soil. So one of the pillars of preventing pest problems is good soil management—crop rotations and regular additions of organic matter. These practices support a healthy plant that is more resistant to pests and has more resilience to recover from pest damage (Altieri and Nichols, 2003). This section describes in detail some IPM practices that can be integrated with good soil management.

NRCS Conservation Practice
Pest Management, Code 595

Definition: Utilizing environmentally sensitive prevention, avoidance, monitoring and suppression strategies, to manage weeds, insects, diseases, animals and other organisms (including invasive and non-invasive species), that directly or indirectly cause damage or annoyance:

Purpose: This practice is applied to support the following purposes:

- √ Enhance quantity and quality of commodities.
- √ Minimize negative impacts of pest control on soil resources, water resources, air resources, plant resources, animal resources and/or humans.

Weeds

Weeds compete well with cotton, more so than with crops such as corn and soybeans. Mature weeds at harvest time can also be a greater problem in cotton than those same weeds in other row crops. Weeds can also affect lint quality. Therefore, effective weed control remains a top priority for optimal cotton production.

Crop rotation helps break up weed lifecycles by allowing different control practices to be applied to weeds at different times of the year and different growth stages. Growing cotton year after year will increase the chances of herbicide-resistant weeds, whereas rotating to corn and other crops will allow different herbicides to be used. A longer rotation that includes wheat and perhaps a root crop like peanuts and a hay crop like bahia grass would be even better for breaking up weed lifecycles.

Cover crops used as no-till mulch can provide some weed control, but without supplemental herbicides, cotton yield reductions are likely. Reeves et al., (1997) studied black oats, wheat, and rye for their impact on weed populations in a subsequent no-till cotton crop. The fall-planted cover crops were killed with glyphosate at one pound of active ingredient per acre three weeks before cotton planting. Three days following the glyphosate application, the cover crops were rolled with a stalk chopper to flatten them to the ground. None of the cover crops were effective in controlling weeds without additional herbicides. Black oats gave 35% control, while rye gave 25% control. In the second year of the study, the results were opposite, with rye providing 54% and oats 18% due to winter kill on the oats from severe cold that year. Weed control from wheat averaged 14% and 19% for the two years.

Weed control using a new mechanical cover-crop kill method, roller-crimping, shows promise. The cover crops can be killed with the roller-crimper that lays the cover crop flat on the ground, or a combination of the roller-crimper plus glyphosate (Kornecki et al., 2006, Jones et al., 2007). A three-year study (Price et al., 2007) found that rolling alone provided the same or

Georgia farmer Lamar Black built this front-mounted roller from his own design. Rolling a cover crop provides the double benefit of soil protection and weed control. Note that the crimpers are not straight across the roller. Wrapping the crimpers around the roller prevents the unit from bouncing as it rolls. Photo courtesy of Steve Groff.

Rodale Institute's cover crop crimper/roller, designed and built by TRI farm manager Jeff Moyer and neighboring farmer John Brubaker, with the assistance of a NE SARE grant. Photo: *rodaleinst.org*

higher yields as rolling plus use of glyphosate. In one year, rolling alone yielded less lint, likely due to the immaturity of the rye crop at the time of rolling. When considering the use of rolling, the maturity of the rolled cover crop is an important consideration.

For cover crops to be effective in weed reduction, high biomass production is necessary. Generally speaking, the higher the cover-crop biomass, the better the weed control. Morton et al. (2006) determined that rye production levels needed to reach 2.5 tons per acre to effectively reduce weed levels enough that a pre-plant herbicide could be omitted. This high yield of rye provides a thick no-till mulch that completely covers the ground making weed emergence nearly impossible. Additionally, rye and some other cereal grains have the ability to chemically inhibit the growth of other plants around them through what is know as allelopathy. When left undisturbed on the soil surface, these chemicals leach out and prevent germination of small-seeded weeds. Weed suppression is effective for about 30 to 60 days (Darr, 1986). If the rye is tilled into the soil, the effect is lost. To achieve high biomass production, rye and other cover crops need to be planted at optimum seeding rates, at the proper depth, at the proper time, and into a soil with adequate fertility. Additionally, they need to be allowed to grow until they reach the onset of flowering before they are killed, and in some cases rolled with a crimper, to form a no-till mulch into which cotton will be planted.

Morton et al. (2006) also calculated a crimson clover yield of two tons per acre would be necessary to be cost-effective for a corn crop assuming a savings of $22.20 from nitrogen production (60 pounds of N/acre), and $7.47 from the elimination of one pre-plant herbicide application. Crimson clover does not provide the level of weed suppression that rye does, however, because it decomposes faster and lacks the allelopathic effect of the rye. Combinations of legumes and rye or wheat can increase cover crop production higher than either component crop grown alone. Hairy vetch and rye can be grown in combination at a seeding rate of 18 pounds of vetch and 60 pounds of rye per acre for a high yielding, weed suppressing, nitrogen providing cover crop (Sullivan et al., 1990). With any of these cover crops, some post-emergent herbicide applications will be needed during the season for the cotton.

With the advent of transgenic cotton varieties, herbicide selection has shifted away from pre-plant herbicides and more toward post-emerge herbicides like glyphosate. Increased use of glyphosate-based herbicides has created weeds resistant to glyphosate, so it is very much in the grower's interest to develop a diverse crop rotation that allows for use of non-glyphosate weed management strategies. Herbicide-resistant weeds require new weed management strategies, which can be incorporated into crops rotated with cotton. For more information on managing resistant weeds, see *www.weedresistancemanagement.com* and *www.weedscience.org.*

Herbicide manufacturers have developed detailed guidelines that farmers are expected to follow when using herbicide-resistant cotton varieties. For example Monsanto provides a Stewardship Technology Use Guide for

Glyphosate weed resistance is a fact of life that southern farmers need to plan for—horsenettle, marestail, and pigweed are already problems, not to mention giant ragweed and lambsquarter. In a 2006 Syngenta-sponsored survey of southern farmers who grow more than 500 acres of cotton, 39 percent reported having glyphosate-resistant weeds. Of these growers, nearly 25 percent indicated 100 percent of their acreage has glyphosate-resistant weeds. This same survey indicated that more than half (53 percent) of southern farmers surveyed believe new products will solve the problem. Mark Swinney, who heads Syngenta's product development program in the United Kingdom, contends that this is not likely in the near future. In order to preserve the effectiveness of the available herbicides, it is in farmers' long term interest to integrate crop rotation as part of their weed control strategy. (Roberson, 2006)

farmers under contract to use their biotech seed. The Use Guide provides season-long recommendations for Roundup-Ready cotton and Roundup-Ready-Flex cotton. Flex cotton has improved resistance to Roundup herbicides allowing them to be sprayed over-the-top up to seven days prior to harvest. Detailed guidelines are also provided for managing glyphosate-resistant weeds in their biotech crops.

Insect Management

The use of transgenic Bt cotton varieties to manage some moth larvae (tobacco budworm and cotton bollworm), along with the near-eradication of the boll weevil in most states, has reduced the need for expensive control measures for these pests. Reductions in pesticide applications have resulted in the re-emergence of some pests, such as stinkbugs, which had previously been managed as a byproduct of weevil or worm sprays. When growers use fewer sprays, they can conserve and even enhance beneficial insect populations, (such as green lacewings, big eyed bugs, lady bird beetles, minute pirate bugs, and various wasps which parasitize pest eggs, larvae and adults) which can save growers money.

This section provides information about managing insects by using selective insecticides, and by use of plant-or crop-based strategies such as crop rotations, intercropping, trap crops, and insectary hedgerows that can attract beneficial insects to the cotton crop. These practices, used together in an Integrated Pest Management (IPM) program or in various combinations, can reduce insect-control costs.

An important component of this type of program is scouting for both pests and beneficials. Most cotton IPM plans focus only on pests, and the level at which their populations will become economically damaging (the economic threshold). It's important to the bottom line not to ignore biological controls and their impact on pest populations as well. This is more difficult to quantify than pest damage, and few thresholds have been developed relating beneficial populations to pest populations.

A Word About Non-Transgenic Refuges

In order for the Bt cotton crops to continue to be effective in the future, it is important that insects not develop resistance to the Bt toxin. That means maintaining pest populations that have had little exposure to the Bt toxin

Economic Thresholds & Biological Control

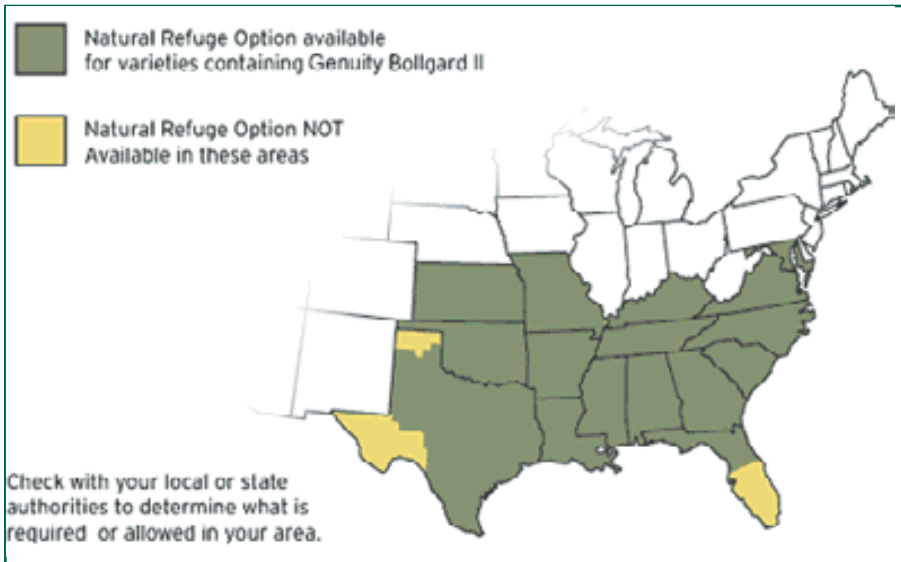
A threshold is the level of plant damage or the number of insects at which some kind of treatment is recommended. The threshold is generally calculated so that the expected benefits of reducing the pest population will be higher than the cost to control the pests.

Threshold numbers are usually expressed in terms of the percentage or number of insects or instances of damage seen per 100 units (plants, leaves, stems, etc.) inspected. The most helpful thresholds are developed from local research, and can form the basis for sound treatment decisions. Thresholds are periodically refined on the basis of new research results or changes in the status and behavior of the various pests. Thresholds, however, are only general guidelines useful for a particular region.

An experienced IPM advisor may be able to modify a threshold, depending on a field's history of insect problems, the weather, the number of beneficial insects observed in the field, operations on adjacent fields which might affect pest populations, and other factors. An experienced IPM advisor may also want to modify any recommended treatments—such as using pesticides that are "softer" on beneficials—in order to conserve the good bugs.

Good bugs (either released or conserved on site) are like any animal in that, if provided habitat (pollen, nectar, prey, and a place to hang out and meet other good bugs), they thrive. A thriving population of beneficial insects creates "environmental pressure" against pest populations, and the likelihood of pest populations exceeding threshold levels is decreased. Biological controls are not as fast acting as pesticides, but they do their work for free, and with prudent management by the grower, these "mini-livestock" can thrive and provide valuable, money-saving pest management services.

Most cotton IPM plans focus only on pests. It's also important to the bottom line to take biological controls into account. This scout is monitoring insect populations. Photo: NCSU Cotton Insect Corner



The U.S. Environmental Protection Agency (EPA) has approved a natural refuge option for Genuity Bollgard II Cotton insect-protected cotton planted from Texas east, excluding some Texas counties.

Now cotton producers in these eligible regions can take advantage of noncotton crops and other plants as a refuge for certain pests and will not be required to plant a non-Bt cotton refuge for Genuity Bollgard II Cotton. A structured, non-Bt cotton refuge continues to be required as part of an insect resistance management (IRM) program for Bollgard cotton in all states, and for Genuity Bollgard II Cotton planted outside eligible areas.

to breed with those that have survived exposure to Bt cotton or corn. Manufacturers of transgenic crops have developed resistance management protocols for their contract growers which minimize insect-resistance to their crops. These protocols should be available from the manufacturer's website. When growers fail to follow these guidelines, the risk of insect resistance to Bt cotton increases.

Generally speaking, Bt cotton has controlled some cotton insect pests but provides little or no control of others (see **Table 20**). With Bt cotton, the number of budworm and bollworm sprays is reduced, which has an impact on other cotton insects. Under reduced-spray conditions, some insects increase while others decrease. Generally, less spraying means more beneficial insects to help control aphids, whiteflies, mites, armyworms, and loopers, as well as a slower rate of resistance development by these insects to pesticides (Layton, 1997). Less spraying also reduces control of lygus bugs, stinkbugs, and fall armyworms (Layton, 1997).

Table 20. Relative Activity of Bt Transgenic Cotton on Cotton Pest Insects

Tobacco budworm *(Heliothis virescens)*	**Excellent**
Bollworm *(Helicoverpa zea)*	**Good (except in blooms)**
Loopers	**Suppression**
Beet Armyworm	**Suppression**
Fall Armyworm	**Little activity**
Cutworms	**Little activity**
Non-caterpillar pests (aphids, whiteflies, tarnished plant bugs, stinkbugs, thrips, etc.)	**None**

Beneficial Insects

Beneficial insects are free sources of pest control, even in fields that are sprayed. Without "beneficials," profitable cotton production would be nearly impossible. Severe outbreaks of pest insects seldom occur unless the balance of beneficial insects has been disrupted. Beneficials can be divided into two major categories: predators and parasites. A survey of 21 Extension and Research entomologists (summarized below) across the cotton belt helps distinguish which beneficials contribute the most to reducing pest insect numbers (McGriff and Roberson, 1999). From this survey, the top ten predators of cotton pest insects in order of importance were minute pirate bugs, big-eyed bugs, lady beetles, lacewings, spiders, damsel bugs, fire ants, ground beetles, Syrphid flies, and assassin bugs. The top ten parasites and pathogens in order of importance are shown in **Table 21.**

The conservation of beneficial insects should be a primary objective of anyone seeking to reduce pesticide use on cotton. Conserving beneficial insects involves practices that enhance their survival, increase their lifespan, increase their reproduction rates, and enhance their effectiveness in killing pest insects. Especially for wasp parasites, having sources of nectar close by the cash crop will generally extend their longevity and effectiveness. Conservation practices may include providing supplemental food and shelter, habitat management, and reducing habitat disturbance (tillage, use of broad-spectrum pesticides, burning, etc). Habitat management may be imple-

Alfalfa must be managed to keep it physiologically "young." That is, parts of a strip need to be mowed on alternate dates to spur new growth. Once the tarnished plant bugs/lygus detect that the alfalfa is becoming "old," and thus less palatable, they will migrate to cotton. Photo: Luis Gallegos, CAFF

mented within the crop, at the field or farm level, or at the larger landscape level. Underlying these practices is the understanding that farm landscapes often fail to provide adequate resources for beneficial insects to thrive at the right times and places.

Habitat management does not always require big changes in farming practices. Some strategies fit well into current farm activities and are easy and inexpensive to implement. Research and development of dependable habitat management practices for beneficial insects is relatively recent. Writers of a recent review on conservation biological control found close to 80% of the articles they studied were published since 1990 (Landis et al., 2000). More development work needs to be done in this area both in research settings and on farms. The next section summarizes some studies related to insect habitat management. These practices promote populations of beneficial insects, or inhibit pest insect populations.

Table 21. Top 10 Parasites and Pathogens of Pest Insects in Order of Importance.

Species	Host
Lysiphlebus testaceipes wasp	Aphid parasite
Trichogramma spp. wasp	Parasitizes over 200 species of moth eggs
Cardiochiles wasp	Budworm parasite
Cotesia marginiventris wasp	Parasitizes budworms, armyworms, and cutworms
Tachinid flies	Parasitizes caterpillars, stink bugs, and others
Microplitis croceipes wasp	Tobacco budworm and corn earworm parasite
Neozygites fresenii	Cotton aphid fungus,
Various	Whitefly parasites
Hyposoter wasp	Whitefly parasite
Copidosoma wasp	Egg parasite of loopers

Cover Crops and No-Till for Conserving Beneficial Insects

Two fairly common strategies currently used for conserving beneficial insects are no-till and cover crops to maintain year-round habitat for beneficials. Fall tillage destroys habitat for all insects, including those beneficials which overwinter in the crop residue or upper layers of the soil. Winter cover crops encourage beneficial populations to build up early in the cotton-growing season. From the cover crops, they can move onto the cotton.

Growing cotton no-till can help reduce pest insects by increasing populations of fire ants and other beneficials. Fire ants feed heavily on the eggs and larvae of caterpillars such as budworms and bollworms. On the other hand, fire ants will guard and exploit sucking insects like aphids and three-cornered alfalfa hoppers that produce honeydew the ants eat.

Other management practices that foster beneficials include intercropping (growing two or more crops in close association with each other), the use of pest-specific insecticides (such as microbial insecticides, insect growth regulators, and Bt cotton) instead of broad-spectrum insecticides, and the use of economic thresholds to minimize all pesticide applications. Most beneficials are very susceptible to broad-spectrum pesticides such as some of the pyrethroids commonly used in cotton. Their

Fire ants in killed cover crop mulch and cotton, Georgia 2008. Photo: Rex Dufour, NCAT.

No-Till Cover Crops Yield Soil and Pest Benefits

From: *Manage Insects On Your Farm: A Guide to Ecological Strategies* by M.A. Altieri, C.I. Nicholls, and M.A. Fritz. 2005. SARE. Pg. 27-28.

With slopes as steep as 7 percent and winds that sandblast his seedlings, Mark Vickers decided to try no-till production and cover crops on his Coffee County, Ga., farm nine years ago. A fourth-generation cotton and peanut grower who also plants corn or soybeans when the market is right, Vickers assumed his conservation-tillage system would keep his highly erodible soils in place.

It did that, but it also did a whole lot more. Along with regular manuring with poultry litter, Vickers' new farming practices eased many of his pest problems. Moreover, it made a "night and day" difference in his soils. "There's just no comparison," he says. "It's beginning to resemble potting soil rather than clay."

No- till rye field residue provides soil conservation and pest management benefits. Photo: J. Phil Campbell, Sr., NRCS.

Production Costs Decrease By Up to a Third

With the cover crop acting much like "a jacket," Vickers' healthier soils hold moisture, prevent runoff and stretch his irrigation dollars. In its entirety, his farming system trims a quarter to a third off Vickers' production costs — mostly for labor, equipment and fuel. He sidedresses a bit of nitrogen and applies several conventional herbicides, but cutting back to just one preplant insecticide in his peanuts slashed the insecticide share of his budget by 50 to 60 percent.

Vickers now plants Bt cotton against bollworms and hasn't used insecticides against any cotton pests for the past two years. Ladybugs, fire ants, wasps, assassin bugs and bigeyed bugs are abundant in his fields. "It took between three and four years to build up the beneficial populations," he says. "I still have the same pests, but the beneficials seem to be keeping them in check and not letting them get over the threshold numbers."

Historically, Vickers has rarely been plagued with insects in his peanuts. When corn earworms uncharacteristically erupted last year, he treated them with pyrethroids. On the other hand, infestations of white mold and tomato spotted wilt virus were common occurrences before Vickers began using cover crops. He hasn't seen either of those diseases in his peanuts since.

Standout Cover Crop is Rye

Although Vickers grows wheat, rye and oats as high-residue winter covers — and also sells the oats — it's the rye that's made him a believer in the value of cover crops. He uses it to prevent root-knot nematode problems and credits it with "dramatically" boosting his weed control, deterring weeds and "shading everything out."

Vickers sows his cover crops all the way to his field edges and even into his roads. He feeds them lightly with nitrogen if he thinks they need it. In spring, when he plants his summer cash crop, he kills the cover crop with a herbicide and plants either peanuts or cotton right into the standing litter. When he grows corn, he sows that directly into the green cover crop.

Vickers' improved farming practices let him produce profitable cash crops without hiring labor. "I do all of it myself — everything — but there's plenty of time to do it," he says. "If I weren't doing it this way, I couldn't farm. There would not be enough time for me to do everything that needed to be done to plant a crop."

Table 22. Beneficial Insect Counts in Conservation vs. Conventional Cotton (Lewis et al., 1997).		
Insects	Conservation	Conventional
Beneficial Insects on the ground	----	----
Carabid beetles and spiders	17,275	1,235
Fire ants	150,000	65,000
Beneficial Insects on cotton plants	----	----
Big-eyed bugs, pirate bugs, spiders, and anthicid beetles	2.7	3.9
Fire ants	5.2	3.0
Aphids (pest) for comparison	26.1	17.4
Insects on spring cover crops	----	----
Big-eyed bugs, pirate bugs, spiders, and aphid predators	55	----
Aphids (pest) for comparison	132	----
Predation on Heliothis eggs	75%	25%

numbers will be greatly reduced following application of these pesticides, resulting in the need for repeated applications for the remainder of the growing season.

Researchers in Georgia (Lewis et al., 1997) sought to develop an IPM approach to manage the natural enemy/pest complex in an overall cotton-production system. They monitored eight fields in Georgia, five of which were conservation-tilled with cover crops and three that were conventionally tilled. Using various collection methods, they monitored populations of beneficials and Heliothis (bollworm and budworm) insects. The number of ground-dwelling predators was ***14 times higher*** in the conservation fields than in the conventional fields (Table 22). Since the conservation fields have more cover-crop residue, they can hold more predators than a field with only bare ground, and the ground habitat of these predators was disturbed only slightly by planting. Crop residue provides particularly good habitat for spiders, which do not have a hard exoskeleton like insects, and are sensitive to extremes of temperature and humidity.

Five Reasons for Using Cover Crops to Increase Spider Habitat

- Spiders are able to rapidly colonize an area through parachuting. Ballooning spiders are often the earliest predaceous colonizers of agricultural fields.
- Spiders are known to attack a number of cotton pests, including bollworms, budworms, and tarnished plant bugs (Malony et al., 2003).
- The presence of spiders changes pest insects' feeding behaviors, and so decreases damage to crops.
- Spiders can cause cucumber beetles, Japanese beetles, leptodoptera larvae in apple orchards, cutworms, greenbugs, leaflys, leafhoppers, and planthoppers to abandon plants.
- Spiders often kill more insects than they can consume. The Chinese have augmented spider populations in field crops as a pest management strategy for centuries.

Fire ant populations were much higher in conservation cotton fields, while most other predators were lower. This situation could be due to the fire ants repelling other predators to protect aphids, since more aphids were also on the conservation cotton. Predation of Heliothis eggs was three times higher in conservation cotton than on the conventional cotton. The primary Heliothis egg predator appeared to be fire ants (Lewis et al., 1997).

Input costs were nearly identical between the two crop-management systems while lint yields were 94 pounds /acre higher in the conservation system (956 lbs/acre vs 862 lbs/acre). The net returns were $60/acre higher from the conservation system than the conventional system. Variable costs such as fertilizers, seeds, and herbicidest were $170 per acre for the conservation system and $163 per acre for the conventional system.

Tillman et al. (2004) examined cover crops for their ability to harbor beneficial insects like big-eyed bugs *(Geocoris punctipes),* minute pirate bugs *(Orius insidiosus),* and fire ants during the cotton growing season. They strip killed several cover crops including balansa clover, crimson clover, hairy vetch, rye, combinations of the three legumes, and the three legumes combined with rye. Into the killed strips, cotton was strip-till planted by cooperating farmers involved in the study. The remaining cover crop herbage was allowed to grow after cotton planting

with the idea that this herbage would harbor beneficial insects that would later move onto the cotton. Four pest insects were monitored using sweep nets during the growing season in both cotton and the remaining cover crops: 1) aphids, 2) tarnished plant bugs, 3) stink bugs, and 4) Heliothine (budworms and bollworms) moth larvae. A no-cover crop treatment was included in the study as a control.

More stink bugs were found in cover crops than in cotton both years of the study, with crimson clover and the mixed legume holding the highest numbers of stink bugs (Tillman et al., 2004). Stinkbugs levels were not significantly different among the cover crops or control, nor did stinkbugs reach economic thresholds in either year of the study. Tarnished plant bug numbers were higher in legume cover crops than in rye alone or rye with a legume during both years of the study, indicating that they preferred the legumes to rye (**Table 23**).

Tarnished plant bug numbers were much lower in cotton than they were in the cover crops. Their levels were either similar to or lower than the control level. No sprays were necessary to control tarnished plant bugs in either of the two years of the study.

Heliothine (budworm and bollworm) numbers were not significantly different in cotton during 2001, but the number of times the economic threshold (ET) was exceeded was quite variable (**Table 24**). An economic threshold is arrived at by considering more than just the number of pest insects. It also takes into account the number of beneficials and the size (instar) of the pest insects. Consequently, even though there may be the same number of pests on a sample date, other factors may change the economic threshold for that field at the sample time. As shown in **Table 24,** cover crops reduced the number of times when Heliothine levels exceeded their economic threshold levels and required spraying. In another study, Ruberson et al. (1995) reported that conventionally-tilled cotton without a cover crop required four insecticide treatments for Heliothines, while a comparative reduced-till field with crimson clover required only one spray. The potential savings in money, pesticides, and equipment use are substantial in this case.

In an earlier study, Tillman et al. (2002) examined predator and pest insects on cotton growing in cover-crop strips but grouped all the pest species then all the predator species and reported them as such. Those results and cotton yields are shown in **Table 25.** The no-cover-crop treatment had the highest numbers of pest insects and the lowest numbers of beneficials. Predators were most abundant in crimson clover and the legume blend + rye mixture. Cotton yields were not statistically different among any of the treatments, but the number of insecticide sprays needed was. Cotton grown under the pure rye stand required no sprays, while the legume blend + rye, the blend, and no-cover-crop cotton required between 1.3 and 1.8 sprays for insects, and cotton growing after crimson clover required only 0.3 sprays. The crimson clover or pure rye stands benefitted growers by reducing the number of sprays required.

Table 23. Tarnished Plant Bug Sweep Counts in Cover Crops During the Cotton Growing Season.

Cover Crop	Tarnished Plant Bugs, 2001	Tarnished Plant Bugs, 2002
Legume mixture	1.68 a*	1.26 a
Crimson clover	1.39 b	1.22 a
Rye + legume	0.70 c	0.55 b
Rye alone	0.55 d	0.51 c

** Within the columns, numbers followed by the same letter are not significantly different at the 0.05 level.*

Trap Cropping for Pests and Conserving Beneficial Insects

A trap crop is one grown near the main crop to lure pest insects into it and away from the main crop. The main crop is protected simply by allowing the pests to remain

Table 24. Heliothine (Budworm and Bollworm) Levels and Economic threshold (ET) Occurrences in Cotton Over Two Years (Tillman et al., 2004).

Cover Crop	Worms 2001	Number of Times over ET	Worms 2002	Number of Times over ET
Control	.51a*	2.0 ± .41a	.52a	3.3 ± .63a
Legumes + rye	.51a	1.3 ± .33ab	.51a	2.3 ± .48 ab
Legumes alone	.51a	1.0 ± .41ab	.40c	2.0 ± .41ab
Crimson clover	.50a	0.75 ± .25b	.49b	1.7 ± .33b
Rye	.51a	0.30 ± .33b	.49b	1.0 ± .33b

** Within the columns, numbers followed by the same letter are not significantly different at the 0.05 level.*

Table 25. Insect Numbers, Yield, and Insecticide Sprays Needed for Cotton (Tillman et al,. 2002).				
Cover Crop	Pest Insects/20 Sweeps	Predator Insects/20 Sweeps	Yield Bales/ac	Sprays Needed
None	2.1c*	1.1d	1.9a	1.8a
Blend + rye	2.3c	3.4ab	2.4a	1.7a
Blend	1.9c	3.1c	2.1a	1.3ab
Crim-son clover	10.4a	4.6a	2.1a	0.3bc
Rye	6.4b	4.4bc	2.4a	0.0ct
** Within the columns, numbers followed by the same letter are not significantly different at the 0.05 level.*				

in the trap crop or by killing them there before they move onto the main crop. Savings in pesticide costs are usually substantial. Trap crops are also used to attract and maintain high populations of beneficial insects that then move onto the main crop. Trap crops work because the pest insects prefer them over the main crop. As with intercropping, trap crops fit into the larger concept of increasing farm diversity in order to increase the overall natural enemy population.

In a Georgia study, sorghum was grown as a trap crop to reduce the number of bollworms *(Heliothis [=Helicoverpa] zea)* in adjacent cotton. The researchers found sorghum to be highly attractive and preferred over cotton by bollworm in both years of their study. Bollworm females deposited more eggs on sorghum than on adjacent cotton. In cotton fields without sorghum trap crops,

Sorghum trap crop planted between cotton (far left) and peanuts (far right). Stinkbugs migrating from harvested peanuts are intercepted by the sorghum trap crop instead of moving to the cotton. Photo: Kristie Graham, USDA/ARS

Southern Green Stink Bug 5th instar in sorghum trap crop at hard dough stage. Notice* Trichopoda pennipes *egg, a fly parasite of stinkbugs, on left "shoulder" of stinkbug exoskeleton. Photo: Kristie Graham, USDA/ARS

more bollworm eggs were found than were found on cotton with trap crops, indicating that the sorghum was not the source of bolltworms invading cotton. The number of times when insecticide sprays were needed was much higher for cotton without trap crops than for cotton with a sorghum trap crop (**Table 26**).

Sorghum can also hold abundant numbers of beneficial insects such as pirate bugs, lady beetles, and spiders. Prasifka et al. (1999) documented the movement of these and other predators out of sorghum fields into adjacent cotton fields growing side-by-side in Texas. Using capture and recapture methods, these researches found pirate bugs, lady beetles, and spiders could move from 72 to 105 feet per day in and around cotton/sorghum field interfaces. They concluded that this degree of mobility would allow the planting of larger blocks of cotton and sorghum rather than having to strip-crop each within a single field. Additionally cotton saw predator increases

Brown stink bug in sorghum at hard dough stage. Photo: Kristie Graham, USDA/ARS

Leaf-footed bug in sorghum at hard dough stage. Photo: Kristie Graham, USDA/ARS

from adjacent sorghum crops during the critical boll formation period in both years of their study (Prasifka et al., 1999).

Though more commonly used in the western cotton belt, alfalfa trap cropping has been used in the Southeast for management of tarnished plant bug and spider mites in cotton. Alfalfa trap-crop programs for control of boll weevil in the South and lygus bug (closely related to the tarnished plant bug) in California were developed toward the end of the 1960s (Hokkanen, 1991). Cotton is one of four crops where trap cropping has been reasonably successful (Hokkanen, 1991). Tarnished plant bugs/lygus prefer lush alfalfa over cotton and thus will remain in alfalfa growing beside cotton. Additionally, alfalfa provides excellent habitat for many beneficial insects that attack caterpillars, aphids, and spider mites. Typically these alfalfa-cotton planting arrangements have a ratio around 1:14, alfalfa to cotton, across the field.

In one study, alfalfa was planted in 20-foot-wide strips into 320- to 480-foot-wide cotton strips (Hokkanen, 1991). The alfalfa was sprayed four to six times for plant bugs. Some of the alfalfa strips were harvested for seed. The alfalfa must be managed to keep it physiologically "young"—that is, parts of a strip need to be mowed on alternate dates to spur new growth. Once the tarnished plant bugs/lygus detect that the alfalfa is becoming "old," and thus less palatable, they will migrate to cotton.

Table 26. Number of Dates When an Economic Threshold was Exceeded for Bollworms in Cotton with or without a Sorghum Trap Crop (Tillman and Mullinix, 2004).

Year	No trap crop	With trap crop	Significant difference?
2001	0.143	0.0213	Yes
2002	0.196	0.059	Yes

Sorghum can act as a trap crop for stinkbugs, as well as a reservoir for beneficial insects such as green lacewings, that lay their eggs on leaves as shown here. Photo: Rex Dufour, NCAT

Alfalfa is one of the best crops for attracting and retaining beneficial insects, and this characteristic can be enhanced further. Strip-cutting alfalfa (i.e., cutting only half of the crop at any one time, in alternating strips) maintains two growth stages in the crop; consequently, some beneficial habitat is available at all times. In somecases, alfalfa is mixed with another legume and a grass.

In another study (Godfrey and Leigh, 1994), researchers planted alfalfa strips in a cotton field at a ratio of 1:14, alfalfa to cotton. The alfalfa strips were 7.7 feet wide and the cotton 107 feet wide. After the first hay harvest in late April, the following cutting treatments were used: 1) half of each strip was cut at 28-days and the other half cut 14 to 17-days later, 2) uncut; and 3) a grower-managed crop where the entire field was cut every 28 days. Averaged over the entire growing season, plant bug levels were highest in the uncut field, lowest in the grower field, and intermediate in the staggered-cut field. Beneficials (pirate bugs, big-eyed bugs, and damsel bugs) were more abundant in the staggered-cut field with 2.5 beneficial insects/square foot in the new growth and 3.2 beneficial insects/square foot in the old growth. Beneficial insect numbers were generally low in the grower-managed field. In the uncut field, beneficial insects were highest of all the treatments with 9.2 of them per square foot.

The authors, Godfrey and Leigh, offered some guidelines for using alfalfa trap crops to manage tarnished plant bug/lygus. 1) Populations of tarnished plant bugs/lygus should not be allowed to reach excessive levels. 2) Also, it is important to minimize the development of these pests into mobile adults that could easily fly to

Alfalfa rows planted as beneficial insect habitat in cotton field at Windfall Farms, California, 2007. Three rows on left more recently mowed to keep physiologically "young". Photo: Rex Dufour, NCAT

Early planting of insect habitat allows beneficials to build up early in the season. In this picture, insect habitat is (left to right) corn, sunflower, mustard, and buckwheat. Cotton is emerging in the field to the right. Photo: Luis Gallegos, 2006, Sustainable Cotton Project.

the cotton crop. 3) High levels of nymphs are of less concern because they are much less mobile. The highest levels of beneficial insects were consistently found in the uncut treatment, but the levels of tarnished plant bugs/lygus were also the highest and above a tolerable level for managing this pest in cotton (Godfrey and Leigh, 1994). They suspected this high pest level came from the usual mortality to tarnished plant bugs/lygus from cutting the alfalfa. They concluded that 28-day strip cutting optimized tarnished plant bug/lygus management in this cotton/alfalfa system. A 35-day cutting schedule could also benefit cotton pest management by holding healthy numbers of beneficial insects (Godfrey and Leigh, 1994).

In general, beneficial insects will be present when there is adequate food for them. Consequently, the levels of pest insects have to rise before beneficial insects aggregate in adequate numbers unless the beneficials have an alternative food source until enough prey insects become available. This difference in population levels between pest and beneficial insects means a lag time before any meaningful impact from the beneficial insects is realized. One of the primary benefits of relay-intercropping, trap cropping, strip intercropping, and other techniques to enhance beneficial insect habitat is that they build up a population of beneficials before a pest outbreak.

Although trap crops have been used in some areas, they have not been widely adopted. This situation will evolve according to the ease of establishing the trap crop or intercrop, the effectiveness of these practices in reducing pest insects, and the economic value of the trap crops. A trap crop with no economic value, other than pest reduction, is not likely to be adopted unless it is highly effective or no other control methods are available.

Insectary Plants for Conserving Beneficial Insects

Insectary plants attract and hold beneficial insects. Plantings of them act as reservoirs or refuges for beneficials by providing alternative foods such as nectar, pollen, and honeydew, providing shelter for reproduction and overwintering, and protection from pesticides. In annual crops like cotton, insectary plants are typically grown in strips within the field and at the field borders. Like trap crops and intercrops, insectary plants add overall diversity to the farm and increase the total population of pests' natural enemies.

Extrafloral nectar from cow peas, fava beans, and even some cotton varieties provides a valuable food source for certain parasites of pest insects. Nectar within flowers also serves as valuable food for many beneficials, as does pollen. Some plants that have been used to provide food for beneficials include Phacelia *(Phacelia tanacetifolia),* dill *(Anethum graveolens),* and coriander *(Coriandrum sativum).*

Unsprayed habitat of (left to right) corn, sorghum and mustard provides habitat for beneficials, as well as a dust barrier from the farm road on the left, reducing the likelihood of a spider mite outbreak. Photo: Rex Dufour, NCAT, 2007.

Beetle banks can be placed along the edge of a field or within a field. Ideal grasses are native annual or perennial grasses that are non-aggressive. Photo: Rex Dufour, NCAT.

Although the idea of beetle banks has not been tried in cotton, the principle behind it is sound, and some farmers may wish to experiment with the idea, which has worked in many other crops in many locations. In England, Scotland, Washington, and Oregon, "beetle banks" are established in crop fields as habitat for ground beetles (Carabids) and spiders, primarily, but also for other beneficials and some ground-nesting birds. They are typically grass strips planted about six feet wide across the field on a slight bed. They don't have to run to the edge of the field, so the whole field can still be farmed as a single unit. Orchard grass, perennial ryegrass, and various native perennial and annual grasses have been used for beetle banks.

Intercropping to Conserve Beneficial Insects

Strip intercropping cotton with crops such as sorghum, corn, pearl millet, alfalfa, and peanuts can be done using conventional field machinery. For example, if someone wanted 6-row strips of cotton interplanted with sorghum, a 12-row planter could be filled with 9 sequential hoppers of cotton seed and 3 sequential hoppers of sorghum seed. When the planter reaches the end of the field and turns 180 degrees to go back across it, the next pass plants the inverse number of rows of each crop. The result would be 18-rows of cotton (three 6-row strips to match the picker) and 6 rows of sorghum to match a 6-row all-crop combine header. Another possibility would be to fill the 12-row planter with each 6-hopper halves of cotton or sorghum resulting in 12-rows of cotton then 12-rows of sorghum. A 6-row picker could easily harvest the cotton, and a 24-foot combine head could easily harvest the sorghum, assuming each was planted on 24-inch rows. Many other combinations are possible to match existing equipment.

Innovative farmers are paving the way with intercrops and realizing pest management benefits as a result. Georgia cotton farmers Wayne Parramore and sons reduced their insecticide and fertilizer use by growing a lupine cover crop ahead of their spring-planted cotton (Dirnerger,1995). They started experimenting with lupines on 100 acres in 1993, and by 1995 were growing 1,100 acres of lupines. Ground preparation for cotton planting is begun about 10 days prior to planting by tilling 14-inch wide strips into the lupines. Herbicides are applied to the strips at that time, and row middles remain untouched. The remaining lupines provide a beneficial insect habitat and also serve as a smother crop to curtail weeds and grasses. The lupines in the row middles can be tilled in with the cultivator later in the season to release more legume nitrogen.

The Parramores estimate that improved yields, combined with cost reductions, are netting them $184 more per acre with the strip-tillage lupine system than with conventional management.

In the Parramores' system, all the nitrogen needs of the cotton crop are met with cover crops except for 10 units per acre of starter nitrogen and another 15 units applied while spraying herbicides. Petiole samples taken each week to monitor plant nitrogen show that cotton grown with lupines maintains a normal range of tissue nitrogen throughout the growing season. The nitrogen level in cotton grown solely with fertilizer is very high initially, then falls back to a lower level. In one representative year, the cotton grown following lupine produced 96 more pounds of lint per acre, with only 25 units of commercial nitrogen, compared to a field with 125 units of nitrogen and no lupines. Additionally, the lupine field required less spraying for insects—only twice compared to five sprays for the commercial nitrogen field. This reduction saved 60% on insecticides, amounting to $35 per acre.

The reduced need for pesticides is attributable to the large population of beneficial insects generated and sustained in this system. The lupines provide food for aphids and thrips, which attract ladybugs, big-eyed bugs, and fire ants as predators. When the cotton gets big enough to shade out the lupines, the beneficial insects move to the

Lace wing larva on cotton square. Lace wing larvae are voracious predators of aphids and other cotton pests. Adult lacewings feed only on pollen and nectar. Photo: http://cottoninsectcorner.org/albums/Beneficial/index.htm

Spiders prey on a wide range of pests, including aphids, moths, and worms (moth larvae). Spiders have a wide range of hunting strategies—ambush, jumping, and web-spinning, to name a few. No-till, mulches and unsprayed areas encourage spider populations. Photo: Texas A&M University, Lubbock Cotton DVD

cotton rather than migrating from the field. The Parramores estimate that improved yields, combined with cost reductions, are netting them $184 more per acre with the strip-tillage lupine system than with conventional management.

Dr. Sharad Phatak of the University of Georgia has been working with cotton growers in Georgia to test a strip-cropping method using winter-annual cover crops (Yancey, 1994). In a test-plot, farmer Benny Johnson planted cotton into strip-killed crimson clover which improves soil health, cuts tillage costs, and allows him to grow cotton with no insecticides and only 30 pounds of nitrogen fertilizer. Benny Johnson reportedly saved at least $120/acre on his 16-acre test plot with the clover system. There were no insect problems in the test plot, while beet armyworms and whiteflies were infesting nearby cotton and required 8 to 12 sprayings to control.

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Cotton intercropped with crimson clover yielded more than three bales of lint per acre compared to 1.2 bales per acre in the rest of the field (Yancey, 1994). Boll counts were 30 per plant with crimson clover and 11 without it. Phatak identified up to 15 different kinds of beneficial insects in these strip-planted plots. Phatak finds that planting crimson clover seed at 15 pounds per acre in the fall produces around 60 pounds of nitrogen per acre by spring.

By late spring, beneficial insects are active in the clover. At that time, 6- to 12-inch planting strips of clover are killed with Roundup™ herbicide. Fifteen to 20 days later, the strips are lightly tilled and planted with cotton. The clover in the row middles is left growing to maintain beneficial insect habitat. When the clover is past the bloom stage and less desirable for beneficials, they move readily onto the cotton. Even early-season thrips, which can be a problem following cover crops, are limited or prevented by beneficial insects in this system. The timing coincides with a period when cotton is most vulnerable to insect pests. Following cotton defoliation, the beneficials hibernate in adjacent non-crop areas. Phatak points out that switching to a whole-farm focus while reducing off-farm inputs is not simple. It requires planning, management, and several years to implement on a large scale.

In a scientific study, Mississippi researchers interplanted 24 rows of cotton with 4 rows of sesame to study the intercrop effect on tobacco budworms and bollworms (Heliothis spp.). Throughout the growing season, until late August, larvae numbers were much higher in the

Table 27. Aphid Predators/Row-Meter in Wheat, Canola and Sorghum (Parajuilee et al, 1997)			
Year	Wheat	Canola	Sorghum
1992	2.0	2.3	7.9
1993	1.7	6.1	12.4
1994	1.3	14.1	4.5
Average	1.7	7.5	8.3

sesame than on the cotton, indicating the worm's preference for sesame. Following a heavy summer rain when the sesame was reaching maturity, the Heliothis adults became more attracted to the cotton. The researchers noted that sesame's attractiveness to Heliothis and sesame's ability to harbor high numbers of beneficial insects made it useful in a cotton pest management program (Laster and Furr, 1972).

Relay intercropping (a pattern that allows planting of one crop before the harvest of an earlier-planted crop growing in the same field) holds promise by allowing the buildup of beneficial insects on the early crop that then move onto the later-planted crop. For example, simple two-crop relay intercrops have been used in China where wheat is planted in the fall with an open row width left within the wheat for cotton to be planted the following spring (Xiao et al., 2006). There develops a beneficial-insect reservoir in the adjacent wheat by the time aphids show up on the interplanted cotton seedlings. More complex planting arrangements are possible involving three or more crops planted across the field for harvest at different times.

In a Texas study, Parajuilee et al. (1997) created a relay-intercrop system by planting strips of wheat next to strips

Table 28. Number of Aphids and Predators in Two Cotton Systems (Parajuilee et al, 1997)		
Year	Isolated cotton	Relay cotton
Average Number of Aphids/leaf August to September		
1992	409	117
1993	187	1
1994	527	235
Average	374	118
Average Number of Predators July to August		
1992	7.4	40.4
1993	7.6	10.3
1994	0.4	1.4
Average	5.1	17.3

The flowering sorghum at right was planted several weeks prior to the sorghum in the center, and demonstrates the principles of relay cropping to allow build-up and maintenance of beneficial insect populations. The sorghum also acts as a trap crop for stinkbugs migrating from peanuts (far right) during harvest to cotton, which is to the left of the sorghum rows. Photo: Kristie Graham, USDA/ARS

of canola in the fall, then in the spring, planting 4 rows of sorghum adjacent to the wheat and 16 rows of cotton adjacent to the sorghum. They used an isolated pure stand of 16 rows of cotton for comparison. No pesticides were used in this study. The researchers wanted to determine seasonal numbers of aphids and their predators on these two cotton crops with the expectation that predator numbers would build up in the relay-intercrop and move from the wheat to the canola to the sorghum then to the cotton.

During the summer growing season, they collected a number of predators including lady beetles, big-eyed bugs, soft-winged-flower beetles, lacewings, pirate bugs, damsel bugs, assassin bugs, and several species of spiders. Aphid predator numbers increased from the wheat to the canola then to the sorghum in two out of three years of the study. The aphids were increasing in number, then migrating from the wheat to the canola then on to the sorghum as shown in **Table 27**. From the sorghum they could easily move onto the cotton.

Due to higher predation, aphid numbers were drastically lower in the relay-intercrop system than in the isolated pure cotton system (**Table 28**). Though predators reduced the aphid population in the relay-intercrop system, aphid populations did exceed the economic injury level of 50 aphids per leaf for three weeks in both 1992 and 1994. In 1993 aphid numbers stayed well below the economic injury level in the relay treatment while it exceeded this level by four times in the single-crop system (Parajuilee et al., 1997). Typically, the benefit of

Table 29. Average Number of Insect Predators in Strip-Intercropped Cotton.				
	Before 7/15	Before 7/15	After 7/15	After 7/15
Strip Crop Treatment	1996	1997	1996	1997
Fall canola	10c	18ab	8a	14a
Wheat	10c	19a	8a	14a
Vetch	15ab	14abc	9a	14a
Spring canola	14bc	14bc	8a	14a
Grain sorghum	21a	17ab	9a	17a
Forage sorghum	14bc	17ab	8a	8a
Canola/ sorghum	16ab	17ab	9a	14a
Cotton check	9c	10c	9a	14a
Within a column, numbers followed by the same letter are not significantly different at the 10% level.				

natural enemies is lower on annual crops than in more stable perennial systems. Annual crops suffer more disturbance and require beneficials to recolonize the annual crop each year. In perennial systems, beneficial insect levels can build up year after year, assuming shelter and food are available. Within the relay-intercrop, predator insects can arrive earlier than they can in single-crop cotton, increasing their numbers by the time aphids appear on the adjacent cotton.

In a later study near Munday, Texas, Parajulee and Slosser (1999) tested the ability of seven strip crops to increase predatory insects on the adjacent cotton and consequently to reduce pest insects. The strip crops were fall-planted wheat, hairy vetch, and canola. The spring-planted strip crops were canola, grain sorghum, forage sorghum, and a split-strip of canola on the outside and grain sorghum next to the cotton. Cotton strip-planted next to cotton was used as a check plot. Each complete strip-crop set consisted of eight rows of cotton in the middle flanked by four rows of the strip crop on either side. Each plot was 51 feet wide and 90 feet long. A fallow strip was left on all four sides of each complete strip-crop set. The experimental plots were surrounded by a 205-acre commercial cotton field that received normal insecticide sprays as indicated by a scout-spray program. No pesticides were applied to the experimental plots. The study ran for two years.

In the early part of the growing season (before July 15), the cotton growing beside cotton check, wheat, and fall canola strips had the lowest predator numbers compared to the other strip-crops in the first year of the study. During the second year of the study, fewer differences in predator number prior to July 15 were apparent. For consistent, year-to-year ability to increase predator numbers in cotton, spring canola was the best. For year-to-year consistency and a high increase in predators, grain sorghum and the canola-sorghum relay strips were the best (**Table 29**). After July 15, predator numbers were lower overall and similar among all the treatments.

Overall, cover crops suppressed aphid levels in cotton during both years of the study. Wheat and spring canola consistently reduced aphid numbers in cotton both years (Parajulee and Slosser, 1999). Bollworm and budworm levels were statistically similar during both years of the study, ranging from 5.20 to 3.07 per 13 feet of row the first year and 0.73 to 0.27 the second year. In the first year, bollworm-budworm levels exceeded economic threshold at one sample date, yet no pesticides were applied during the entire study, and the pest level declined below the threshold within seven days (Parajulee and Slosser, 1999). On the larger farm, cotton was sprayed three times during this crop season for bollworm-budworms. In the second year, worm levels remained well below the economic threshold in the study plots as a result of predators killing them, while cotton on the nearby larger farm suffered a severe infestation from worms that resulted in a 45% loss of yield compared to the average for the strip-crop plots.

There was no significant difference in lint yields among the different strip-crop treatments. Since no pesticides were used in the study, this was probably because predators were so widely dispersed that they suppressed bollworms and budworms in all of the plots. This may mean that larger plots and buffer areas are needed to prevent migration of predators across the study area. When yields from the strip crops were compared to the cotton on the larger farm, they were not significantly different the first year, but in the second year of the study, lint yields were markedly higher on the test plots than in conventionally raised cotton on a nearby farm. The researchers concluded that using relay-strip cropping is a viable strategy for growing cotton without pesticides.

Managing pests by providing habitat for beneficial insects and reducing the frequency and toxicity of pesti-

Table 30. Effect of Five Insecticides on Beneficial Big-eyed Bugs (BEB) and Pest Tarnished Plant Bugs (TPB)/Lygus.			
Treatment	Rate Pounds AI/acre	BEB % Mortality	TPB % Mortality
Dicrotophos	0.5	89	98
Fipronil	0.05	88	93
Acephate	0.05	86	83
Oxymil	0.31	71	92
Imidacloprid	0.047	45	65
Water=control		0	4.2

cide applications has been proven to work. This approach requires more management and knowledge on the part of the farmer, and can be less predictable than exclusive reliance on chemical pesticides, but in the long run can save the farmer money. It is likely that due to a combination of increased regulation, pest resistance, and higher fossil fuel prices, pesticides will become more expensive, less available, and a less desirable option for pest control in the future.

As noted previously, NRCS has many programs that will help pay farmers part of the cost for innovative pest and soil management practices. In addition, the Conservation Stewardship Program (CSP) will provide payments to farmers who are already implementing good conservation practices. A list of state and county service centers can be found at *http://offices.sc.egov.usda.gov/locator/app?agency=nrcs.*

Table 31. Percent Mortality of First-Instar Assassin Bugs Treated with Various Insecticides at Various Rates in the Laboratory (Grundy, 2007).				
Insecticide	Full Rate	75% Rate	50% rate	25% Rate
Bacillus thuringiensis (Bt)	0	0	0	0
Nucleopolyhedroirus (NPV)	0	0	0	0
Buprofezin	0	0	0	0
Pyriprozifen	2.2	0	0	0
Indoxacarb	7	2	0	0
Spinosad	27	11	12	7
Fipronil	43	25	18	14
Emamectin benzoate	69	47	42	16
Abamectin	84	61	51	41
Diafenthiuron	100	100	91	84
Imidacloprid	100	100	96	94
Omethoate	100	100	100	100

Pesticide Effects on Beneficials Insects

Given that some pesticides will be needed in most cotton-growing years, it is reasonable to select those that pose the least threat to beneficial insects. In a lab study, minute pirate bugs and the parasitic wasp *Cotesia marginiventris* were subjected to four insecticides labeled for cotton: Tracer (spinosyn A and B), Pirate (Chlorfenapyr), Confirm (Tebufenozide), and Karate (L-cyhalothrin). For the minute pirate bug, Karate was the most toxic (greater than 75% mortality) with Pirate being of moderate toxicity (25% to 50% mortality) and Tracer and Confirm being the least toxic (less than 25% mortality). Confirm and Karate were the least toxic (less than 25%) on the Cotesia wasp while Tracer was intermediate, and Pirate was the most toxic (Pietrantonio & Benedict, 1997).

Tillman et al. (2003) tested five insecticides for their impact on the beneficial predator big-eyed bugs (BEB) and on a cotton pest, tarnished plant bugs (TPB), in an effort to determine which insecticides would serve to selectively kill pest insects while conserving the beneficial predator. The five pesticides were sprayed on cotton plants in the field at recommended rates. Insect sampling was done immediately before spraying then one, three, and five days after spraying. The results are shown in **Table 30**.

In general, all the insecticides tested were lethal to both insect species. Oxymil and Imidacloprid had slightly lower impact on big-eyed bugs than on tarnished plant bugs but still took out a large number of the predatory big-eyed bugs.

Grundy (2007) tested several pesticides for their effects on the beneficial assassin bug, *Pristhesancus plagipennis.* First instar (the most vulnerable stage) assassin-bug nymphs were sprayed in a laboratory setting with various pesticides at several rates. Buprofezin, *Bacillus thuringiensis,* NPV virus, and Pyriproxifen were non-toxic to first-instar assassin bugs (**Table 31**). Indoxacarb had little effect on the assassin-bugs. Spinosad, Fiprinol, Emamectin-benzoate, and Abamectin were of low to moderately-high toxicity, depending on dosage rate. Abamectin (at full rate), Diafenthiuron, Imidacloprid, and Omethoate were highly toxic to assassin bugs regardless of rate.

Even some organically approved insecticides can be lethal to certain beneficial insects. Azadirachtin (Aza-Direct™), the active ingredient in neem, acts as a repellant or anti-feedant on some insects and also inhibits egg-laying and interferes with larval molting. Spinosad (Tracer™) is produced by the soil microbe *Saccharopolyspora spinosa* and acts on the nervous system of some insects (Tillman, 2008). Spinosad is used to control moth larvae pests on cotton and is presumed to be tolerated by many beneficial insects. These two organically-approved insecticides were tested along with L-cyhalothrin (Karate™) for their effectiveness on *Trichopoda pennipes,* a parasitic fly of Southern Green Stinkbug *(Nezara viridula)*, and on green stinkbug nymphs and adults. The parasitic flies were exposed to these three insecticides in three different ways: by walking on a sprayed surface (petri dish), by having the insecticide sprayed on their upper side, and by feeding on sugar water that had been treated with the insecticide. Regardless of application method, L-cyhalothrin and Spinosad killed 100% of Trichopoda parasitic flies within 24-hours after exposure. Azadirachtin (neem) killed none of these fly parasites. Tillman (2008) went on to say that Spinosad is generally less toxic to natural enemies than broad-spectrum insecticides such as organophosphates and second-generation pyrethroids. Also, this particular parasitic fly was more susceptible to Spinosad than some other natural enemies (Tillman, 2008).

The frequency and severity of disturbance, either physical or chemical, on a given field determines to some extent the success of natural-enemy conservation efforts. Reduced pesticide use, careful pesticide selection, use of cover crops, intercropping, and no-till cultivation reduce disturbance and encourage beneficials. Practices detrimental to conserving natural enemies include broad-spectrum pesticides, clean tillage, fall tillage, and burning ditch banks—all of which create disturbance and destroy beneficial habitat. Once habitat is provided, it will likely take more than a single season to build up beneficial insect populations to the carrying capacity of the habitat.

Pest-Management Decision Tools

When it comes to pesticide reduction for cotton-pest insects, the point of impact most often lies in the hands of the IPM scout or the farmer reading the scout's report. Improvements in threshold criteria may need to be made in some scouting protocols to include the impacts of beneficials on the pest population, particularly if the farmer is using trap cropping, intercropping, conservation tillage, or other practices that encourage populations of beneficials.

Several cotton scouting manuals and/or decision assessment tools offer advanced information to improve pest-management decisions. Georgia's Farm*A*Syst Farm Assessment System (see Internet Resources) provides a comprehensive evaluation questionnaire that allows growers to determine the level of IPM being practiced on their farms. The assessment tool asks questions about pesticide use and cultural and biological pest-control practices. Answers to these questions provide a low-medium-high ranking for IPM use on the farm. It has five areas: insect management, weed management, disease and nematode management, nutrient management, and cultural and soil quality management. The assessment easily identifies areas where improvements could be made to lower pesticide costs, lessen insecticide resistance, and reduce the environmental impact of the cotton crop. Completing the assessment requires a modest amount of time, and once it is completed, an action plan can be developed based on the areas needing the most attention.

Texas A&M offers the COTMAN management software package (see **Cotton Information Resources**) that can summarize crop developmental status, detect stress, and assist with in-season and end-of-season management decisions. It was developed by the University of Arkansas with financial support from Cotton Incorporated and in collaboration with Mississippi State University, Louisiana State University, Texas A&M, Virginia Tech, and Arkansas State University. The primary benefits from using COTMAN are the reduction or elimination of late-season insecticides and information about how well the crop is developing. It provides information that can relieve growers' anxiety about pests and provides rationales for NOT spraying. The late-season guides distinguish when the crop is no longer susceptible to pests. In the late season, there is no need even to scout the crop, let alone apply insecticides. It has been tested in commercial cotton fields from Texas to Virginia. The software is divided into two parts. Squareman monitors pre-flower crop development, plant stress, and square retention. Bollman monitors boll-loading stress and assists with crop-termination decisions. Bollman is also available in a non-computer version. The software is distributed to U.S. growers at little or no charge.

To download the Georgia Farm*A*Syst (Farm Assessment System), go to: ***http://pubs.caes.uga.edu/caes-pubs/pubs/PDF/B1152-19.pdf***

To order the COTMAN Cotton Management Software or to learn more about it, go to one of these Web sites:

- ***www.cottoninc.com/Entomology/COTMAN***
- ***http://cotman.tamu.edu/index.htm***

Nematodes

In most cases, nematode problems are symptoms of depleted soil biodiversity. Rotation to non-host crops, nematode-suppressive crops, adding organic matter to the soil, and use of nematode-resistant cotton varieties are all beneficial in reducing nematode populations.

There are many species of nematodes in soils, but only a few of them are harmful to plants. The rest are free-living organisms that either feed on dead plant matter or act as predators on fungi, bacteria, and other soil organisms, including other nematodes. Plant-parasitic nematodes are more common in sandy, well-drained soils and more active in warm weather. Their worst impact on cotton comes when they attack young seedlings as the plants are establishing their root systems. The root injury caused by nematodes invites infections by bacteria and fungi that often cause greater economic damage than the nematodes themselves.

Nematode management starts with knowing which nematodes are in a particular field. This can be done by taking soil samples and sending them to a diagnostic lab for analysis. Your county Extension agent can demonstrate how to take the nematode soil samples and recommend where to send them. The Web site *www.cotton.org/tech/pest/nematode/soil.cfm* also has information about nematode sampling and analysis. Damage from plant-parasitic nematodes typically appears in patches rather than all over the field. This distribution has to be accounted for when sampling for them. The lab results will tell you what species of nematodes are present and in what numbers. If harmful nematodes are present, efforts should be made to keep them from spreading to other fields. One of the best ways to avoid infecting a clean field is to wash equipment used in infected fields before moving it into a clean field. Nematodes can also move from field to field on dirty boots. If nematodes are not present, avoid practices such as continuous planting of one crop species that will allow nematode populations to explode.

Nematodes can be controlled in annual crops with chemicals (typically expensive and toxic to soil organisms that are predators and parasites of nematodes), by planting nematode-resistant varieties (often in short supply), using large additions of compost (cost-prohibitive for most low-value commodity crops), or through crop rotation, which can provide good results depending on the rotation crop and the species of nematodes in the field. Generally, a combination of two or more of these methods will effectively control problem nematodes. Knowing which species of nematodes are present in a field will determine to some extent which rotation crops would be the best choices to reduce the nematode population. Therefore, getting a reliable soil analysis of how many and what kinds of nematodes are in a field is essential.

Crop stunting due to* Rotylenchulus reniformis *damage.
Photo: Charles Overstreet

The best protection against nematode injury is a combination of rotating to crops that are not hosts to the nematodes and practicing good soil management.

Hague and Overstreet (2002) studied 14 crop-rotation sequences using cotton, grain sorghum, corn, and wheat for their effects on three types of nematodes. They found that corn, cotton, and to a lesser extent soybeans and wheat were susceptible to root-knot nematodes, while sorghum was not susceptible. When grain sorghum was used in the rotation on fields where susceptible crops had been grown, root-knot nematodes were reduced from previous levels. That is because both sudangrass and sorghum contain a chemical, dhurrin, that degrades into hydrogen cyanide, a powerful nematicide (Guerena, 2006). But just one year following a susceptible crop (corn, cotton, soybean, wheat), the root-knot nematodes were back to high levels. Cotton and soybeans were found to be susceptible to reniform nematodes. Hague and Overstreet considered corn and grain sorghum good rotation choices for reniform nematode control since these two crops drove reniform nematodes below detectable levels. They found soybean-cyst nematodes only in fields planted in continuous soybeans. Soybeans grown in rotation with any of the other crops had substantially lower levels of cyst nematodes (Hague and Overstreet, 2002).

Farmers in Alabama who added sesame into rotation with cotton, peanuts, and soybeans found nematode levels reduced and yields significantly higher among those crops grown in fields previously planted in sesame. Sesame yields averaged 1500 lbs per acre, well above the world average of 500 to 600 lbs per acre (Anon, 1997). Research shows that sesame may be an effective rotation crop to control peanut root knot nematode *(Meloidogyne arenaria)* and southern root knot nematode *(Meloidogyne incognita)*. Sesame rotation is not effective, however, for the Javanese root knot nematode *(Meloidogyne javanica)* (Starr and Black, 1995). Commercial nematode-control products derived from sesame include Dragonfire™ (oil), Ontrol™ (seed meal)—both manufactured by Poulenger USA—and Nemastop™ (ground-up sesame plant) from Natural Organic Products.

Wang et al., (2002) studied the effects that various cover crops had on nematode populations. They selected a sandy soil in Florida that had a mixture of root-knot, spiral, ring, stubby-root, and lesion nematodes. In this sub-tropical climate, three annual crops could be grown each year. Consequently, warm-season cover crops of sun-hemp, soybeans, cowpeas, and sorghum-sudangrass hybrids were grown as well as cool-season blue lupines and rye.

All the warm-season cover crops suppressed root-knot nematodes below the levels found in the comparative corn crop. Corn and soybean hosted the highest numbers of spiral nematodes, while corn and sorghum-sudangrass hosted the highest numbers of stubby-root and ring nematodes. Corn and cowpeas hosted the highest numbers of lesion nematodes. Fall-planted rye and lupine suppressed root-knot nematodes to undetectable levels by March of the following year. Lupine hosted higher levels of spiral nematodes while rye hosted higher levels of stubby-root nematodes in March.

But four months after corn planting (July), these differences were eliminated, and all nematode levels had increased considerably. Contributing to this increase were warmer soil temperatures and corn, which is a good host to several nematode species. Sunhemp was the most effective cover crop of those tested and resulted in the lowest levels of all nematodes in this sandy Florida field (Wang et al., 2002). Sorghum-sudangrass suppressed root-knot nematodes quite well but was a good host to stubby-root and ring nematodes.

Many clovers and hairy vetch are good hosts to root-knot nematodes. In a Georgia study, however, cahaba white vetch was shown to be highly resistant to root-knot nematodes (Timper et al., 2006). Cherokee red clover was moderately nematode resistant in this study. Crimson clover, berseem clover, and hairy vetch were shown to be quite susceptible to root-knot nematodes. The authors concluded that root-knot nematodes can complete one or two generations on susceptible winter-annual cover crops, and this could reduce cotton yields the following season. In nematode infected fields, rye or a nematode-

New Biological Seed Treatment for Nematodes

Bayer CropScience has developed a new biological treatment for nematodes, VOTiVO, which will be available to select growers and seed companies to test in 2010. It will be registered for use on corn, soybeans and cotton.

VOTiVO is a formulation of bacterial spores, which germinate when the treated seed germinates and creates a living barrier to nematode feeding. Because of this protective mode of action, Bayer CropScience claimes that VOTiVO is effective against all major plant-parasitic nematodes, including lance, lesion, needle, root-knot and soybean cyst nematodes. A three-year data summary shows average yield advantages of 7.1 bu/A in corn, 1.3 bu/A in soybeans and 62 lbs/A in cotton when VOTiVO is added to current leading seed treatment packages.

Table 32. Cover and Rotation Crops to Reduce Various Nematodes.

Nematode	Crops to Reduce These	References
Root knot, *Meloidogyne incognita*	Cahaba vetch, rye, sorghum, peanut, millet, sudangrass, bahiagrass, velvet bean, rice	Temper et al., 2006; Hague and Overstreet, 2002; Rich and Kinlock, No date; Greer et al., No date
Reniform, *Rotylenchus reniformi*	Sorghum, corn, peanut, bahiagrass, sudangrass, millet, rice	Hague and Overstreet, 2002; Kinlock, No date; Greer et al., No date.
Sting, *Belonolaimus longicaudatus*	Tobacco, peanut	Rich and Kinlock, No date

resistant legume such as cahaba white vetch would be better cover-crop choices.

According to the Florida Extension Service (Rich and Kinloch, no date), the best rotation crops for control of root-knot nematodes and reniform nematodes *(Rotylenchulus reniformis)* are bahiagrass, corn, millet, peanut, sorghum, sudangrass, oats, wheat, and rye. The best crops to rotate for control of sting nematodes *(Belonolaimus longicaudatus)* are peanuts and tobacco. Peanuts are not a host for *Meloidogyne areneia* race 1, while cotton is not a host for *Meloidogyne incognita* race 3 (Johnson et al., 1998). Most Extension nematode publications recommend rotation as a viable way to manage nematode populations. And all stress the need to analyze soil samples for nematodes in order to know what species you have and how many of them are in each field.

Biological Control of Nematodes

Research and development on biological control for nematodes is underway. One of the most promising biocontrol agents comes from the Pasteuria bacteria species. The private company Pasteuria Bioscience received EPA registration for Econem™, a nematicide for control of sting nematodes in turf, on September 15, 2009. In the near future, they will be developing other nematode products for commodity-crop pests, including cotton reniform and root-knot nematodes. Learn more from their Website at *www.pasteuriabio.com/product_development.html.*

The German company ProPhyta manufactures an EPA-registered fungal *(Paecilomyces lilacinus)* product called NemOut™ (Wells, 2007) for control of reniform, root-knot, and lance nematodes (Johnson, 2007). It is marketed in this country by Plato Industries of Houston, Texas. Research has been conducted on its use as an in-furrow spray at planting or as a seed treatment in cotton by Mississippi State University's Delta-Branch Experiment Station near Stoneville, Mississippi.

Successful, long-term nematode management programs based on building nematode-suppressive soil will have many other benefits besides nematode control because they will also increase soil function and fertility. These practices include using cover crops, animal waste, compost, limited tillage, and planned crop rotations to build up nematode-parasitic fungi and beneficial nematodes that prey on plant-parasitic nematodes. Using poultry litter and no-till cultivation could help make a soil more nematode suppressive. Switching to a more sustainable system that integrates organic matter additions, prudent crop rotations, and nematode-resistant cotton varieties would likely require higher initial input costs, but the results will be lower input costs in the future.

Cotton Diseases

Soil health and management are key to successful control of soil-borne and seedling diseases. A soil with adequate organic matter harbors a high number of beneficial organisms that deter harmful disease organisms from attacking plants.

The most effective, low-cost insurance against cotton diseases is a diverse crop rotation and good soil health. In many instances, a disease is a symptom of some other problem with the soil or in crop management. For example, soil compaction creates many problems in the root zone—poor drainage, inhibited root growth, and anaerobic (very low oxygen) conditions—all of which can make plants more susceptible to disease as well as facilitate development of disease. Investing in soil health will help avoid the conditions that favor plant disease.

Seedling diseases can cause major skips in a stand. Most cotton seed comes pretreated with fungicide to minimize damping-off and seed rot. Other general cultural practices to minimize seedling disease include planting when the soil temperature is 65°F or higher, not planting in cool wet weather (or if such weather is predicted soon after planting), and planting at the proper depth. The need for additional fungicides applied to the seed, in the hopper box or in-furrow, will depend on whether the field has a history of seedling disease, cool and wet weather at planting, poor seed quality, or low seeding rate. In some cases, additional seedling fungicide treatments will not result in additional yield increase. A cotton stand can compensate in part for modest skips by bushing out to fill in the voids with branches and leaves.

Fusarium wilt typically occurs during the middle of the growing season and is often associated with nematode damage. The nematodes alone can cause wilting, but wilting plants that die may be infected with fusarium wilt. As with nematodes, fusarium wilt occurs in patches rather than widely across the field. Effective strategies against nematodes, such as crop rotation and planting nematode-resistant varieties, tend to reduce the incidence of fusarium wilt.

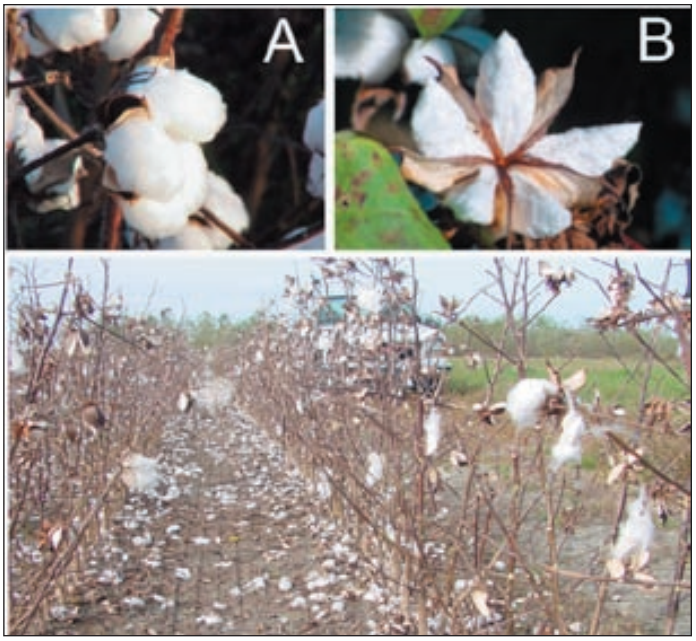
Boll rots are caused by several different types of fungi and bacteria during the late growing season. There is little that can be done to control boll rots during periods of excessive moisture and humidity. Reducing humidity

within the cotton canopy will reduce the incidence and severity of boll rot. Steps to reduce humidity include having low to moderate plant populations, avoiding excessive nitrogen fertilization, proper timing of defoliation and harvest, and using plant-growth regulators to control vegetative growth.

Hardlock or tight lock results when bolls refuse to fluff open and cannot be picked with a spindle picker. Failure to fluff is associated with high nitrogen, high plant populations, insect damage (especially by stinkbugs), high temperature and humidity at boll opening, and immature bolls. Some scientists maintain that the fungus *Fusarium verticillioides* is the cause of some cases of hardlock. Others believe that stinkbugs are the primary culprit.

In a Georgia study (Brown, 2005), both the stinkbug and the Fusarium fungus were addressed by spraying test plots with Bidrin insecticide at eight ounces per acre, or Topsin-M fungicide at one pint per acre, or a tank mix of both Bidrin and Topsin at these rates. An untreated plot was included for comparison. Treatments were started when 50% of the cotton plants reached first bloom and continued at 14-day intervals for a total of four treatments. The study ran for three years. During the first two years of the study, Topsin produced no hardlock reduction and only slight yield increases. Bidrin plus Topsin produced higher yields than Topsin alone, but the mix did not produce higher yields than Bidrin alone. Yield increases from Bidrin provided an economic benefit, but those from Topsin did not. This observation supports the belief that stinkbugs are the primary culprit rather than Fusarium. During the final year of the study, yield with Bidrin stinkbug control was 483 pounds per acre more than the untreated control and 222 pounds per acre more than with Topsin. With Bidrin, income increased $255 per acre over the untreated check and $117 per acre more than with Topsin (Brown, 2005). Conclusions from the study were that stinkbug control was essential for hardlock reduction and yield increases, and any yield benefits provided by Topsin were inferior to those provided by Bidrin.

Florida researchers maintain that *Fusarium verticillioides* (also known as *Fusarium moniliformi)* is the primary cause of hardlock that attacks cotton flowers and that fungicides will control it. Weather conditions on the day of bloom correlate highly with the incidence of hardlock, and the flower is more vulnerable to infection by Fusarium at that time (Hollis, 2004). In their studies, Florida agronomist David Wright and plant pathologist Jim Marois showed considerable yield increases using Topsin-M fungicide to control Fusarium. They used four treatments, one of which was a weekly application starting at first bloom. The second was three applications during boll opening. The third was a combination of the first two treatments for a total of nine sprays, and the fourth was an untreated control. The control plots suffered a 62% hardlock incidence and yielded only 640 pounds of lint per acre. Where the sprays were started at first bloom, yields were nearly twice as high at 1200 pounds per acre. Where only open bolls were treated, yields were 870 pounds per acre, and in the combination treatment, yields were 1220 pounds per acre (Reed, 2003).



A: Typical healthy looking harvestable cotton boll. B: Hardlocked cotton boll that is not mechanically harvestable. Notice that a characteristic fusarium hardlock will exhibit failure to expand fibers from the very first day of boll opening. Frequently bolls do not present any sort of discoloration at this point. Hardlock causes poor harvest practices because the cotton picker is not effective in collecting hardlocked bolls. Photo & caption: Marois, et al., 2007

Foliar Diseases

Bacterial blight caused by *Xanthomonas campestris pv malvacearum* is common in areas with warm, wet growing seasons. It causes defoliation and reduces lint quality. Leaf spots are angular, restricted by leaf veins, water-soaked when fresh, eventually turning brown before defoliation. Boll symptoms are small, round, water-soaked spots that become black. Affected bolls may shed or fail to open and have poor-quality lint. Quick plow-down of crop residues after harvest to give ample time for decomposition will assist in the control of the disease. Crop rotation and using resistant varieties are also effective strategies. Do not cultivate or move equipment through fields when foliage is wet.

Leaf symptoms of bacterial blight. Photo courtesy Texas A&M University, **http://lubbock.tamu.edu/cottondvd/content/cottondvd/Photos/diseasephotos/images/10bacterialblight.jpg**

Alternaria leaf spot caused by *Alternaria macrospore* has historically not been a problem with Acala (upland) types of cotton, compared to Pima types, but some Acala cultivars have shown susceptibility to leaf spot. The disease symptoms start with a tiny circular spot that enlarges to half an inch. Concentric rings form as the spot enlarges, with the center sometimes falling out to form a shothole. Spots can also be found on bolls. High humidity increases incidences of the disease, causing defoliation in severe cases. Controls include using resistant varieties and keeping leaves from prolonged wetness. Reduction of Alternaria leaf spot severity and premature leaf drop of cotton produced on soils low in extractable potassium (K) can be accomplished by applying K to the soil or to the leaves (Howard, et al, 1997).

Some cultivars of Acala cotton are susceptible to Alternaria leaf spot. Photo courtesy Texas A&M University, **http://lubbock.tamu.edu/cottondvd/content/cottondvd/Photos/diseasephotos/images/37alternaria.jpg**

Southwestern cotton rust *(Puccinia cacabata)* first appears as small, yellowish spots on leaves, stems, and bolls, usually after a rain. These spots enlarge, developing orange-reddish to brown centers. Later, large orange spots appear on the lower leaves and discharge orange spores. Rust diseases require more than one host in order to complete their life cycle. For *Puccinia cacabata,* the alternate host is grama grass (Bouteloua spp.), and its proximity to the cotton field may determine the severity of infestation. If there is grama grass near your field, it is best to remove it by burning, plowing, or grazing. A season of heavy rains and high humidity with grama grass close by has the potential for problems with cotton rust.

Creating the Market for Sustainable Cotton

The worldwide demand for sustainably grown cotton is growing, driven both by consumers who want more environmentally-friendly products and by manufacturers and retailers who recognize the marketing advantage of sustainable cotton to reach those customers and align profitability with sustainability.

A 2006 report by the Hartman Group—*www.hartmangroup.com/publications/view/19*—reveals that 50% of U.S. women surveyed want retailers to offer more "green" products, and 43% say they expect to buy increasingly more environmentally friendly products in the future. Greater awareness among consumers globally about cotton's environmental impacts is itself strongly driven by the educational efforts of environmental groups, while the appetite for sustainable cotton among manufacturers and retailers is being whetted by the status it gives them in marketing "green."

In the United States, the best organized effort to market sustainable cotton comes from the Sustainable Cotton Project's Cleaner Cotton® Campaign in California, *www.sustainablecotton.org.* The Campaign, ongoing since 1998, has found support for sustainable cotton on college campuses and among fashion designers and clothing makers such as American Apparel. In winter 2007, nearly 100 representatives of the apparel and design industries attended the Sustainable Cotton Project's Cotton Tour, sponsored by the clothing retailer Gap, to see first-hand where their cotton comes from. In fact, "ecofashion" is a hot buzz-word among designers from California to New York, *www.environmentalleader.com/2008/09/11/designers-green-fashion-sustainable.* In 2008, Cleaner Cotton® t-shirts hit the market through Artwear, Inc. (a custom t-shirt company in Los Angeles) and several

other companies are now studying their supply chains to accommodate Cleaner Cotton.®

On the production side, the Project's BASIC (Biological Agriculture Systems In Cotton) program has demonstrated that cotton growers in California's Central Valley can reduce their pesticide use by up to 73% (compared to local county averages) while maintaining yields and profits as high or higher than those of conventional growers. For more information about the BASIC program, see **Cotton Information Resources.**

In Europe, the Better Cotton Initiative (BCI, *http://bettercotton.org/index/140/better_cotton_system.html),* a partnership between major corporations such as Adidas, IKEA, and Gap and non-government organizations such as WWF (formerly World Wildlife Fund), has taken the step of establishing broad criteria to define "sustainable" cotton worldwide. These criteria embrace all phases of cotton production, with an emphasis on sustainable means of production and environmental and economic protection for farmers.

In other parts of the world, activists and agricultural researchers alike are making sure-footed strides toward showing that sustainable cotton production is both an environmental benefit and a profitable means of production. For example, in India, a major cotton producer, researchers in the state of Punjab (Singh and Singh, 2007) found that farms using Integrated Pest Management (IPM) and/or Insect-Resistance Management (IRM) cut costs, reduced farm workers' exposure to toxic farm chemicals, and increased both employment and profits.

All of this is the good news, for it shows a growing acceptance of and broad-based movement toward sustainable cotton that can expand into a demand, even an expectation, among an increasingly large segment of consumers and manufacturers. There remains, especially in the U.S., one major hurdle to overcome. Currently, there is no quantified, universally accepted definition for "sustainable" cotton. Anyone can use the term, regardless of the origin of the cotton. Indeed, in 2008 an advertising effort conducted by Cotton Council International/Cotton USA (a trade association that supports U.S. cotton exports) was banned by the U.K. Advertising Standards Authority (ASA) for using the word "sustainable" in its campaign (Sweney, 2008). The ASA concluded that there is no consensus definition of sustainable cotton and that there is "a significant division of informed opinion as to whether cotton production in the U.S. could be described as sustainable."

BASIC Cotton Manual

This handbook is based on field results from cotton farmers in California's Central Valley. It describes management and marketing options for growers who employ bio-intensive integrated pest management to reduce their use of pesticides.

BASIC (Biological Agricultural Systems In Cotton) growers used about 73% less insecticide and miticide than conventional cotton farmers in the area and had profits and yields equal to or exceeding those of the conventional growers. The manual covers topics such as soil fertility, plant nutrition, crop rotations, managing habitats for beneficial insects, field monitoring, and marketing. It also includes a resource list of production contacts and helpful Web sites. The manual is available to download for free at: *www.caff.org/programs/farmscaping/sust_cotton.shtml*.

Find details about the *BASIC Cotton Manual* under "Production Systems/Pest Control" in the Cotton Information Resources of this publication.

Before any broad-based marketing efforts for sustainable cotton can be viable, there are three essential steps that growers and manufacturers must take.

- Define the product by establishing industry-wide standards for sustainable cotton.
- Ensure the product's integrity through third-party certification (comparable to the National Organic Program).
- Educate consumers (and producers) about the social, environmental, and economic benefits of sustainable cotton.

The first step, establishing standards, is probably the most difficult because sustainability can be measured in different ways under different conditions and must manifest itself in measurable social, environmental, and economic benefits.

One simplified example of the kinds of problems facing standards for sustainable cotton is at a fundamental level, the tillage system. Unlike organic standards that prohibit synthetic herbicides and pesticides and genetically-modified organisms, most approaches to sustainable cotton either accept some use of them or attempt to be "technology neutral" in assessing their role in sustainability. So, if, in response to some extraordinary pest pressure, a given grower has to abandon, say, a no-till scheme for a season, how would standards accommodate this deviation from one of the more widely used practices in sustainable cotton production? What if there

Cotton bales numbered and ready to ship.
Photo: Rex Dufour, NCAT.

is an outbreak of pest insects that beneficials and limited spraying can not control, and a farmer has to use four applications of insecticide instead of two? Would there be biological or economic thresholds to permit the increased spraying?

These and similar uncertainties make establishing standards for sustainable cotton a thorny problem indeed.

Fortunately, we do have the model of the National Organic Program to look to for some guidance. The long and difficult 12 years that it took to arrive at the Final Rule in 2002 provides a perspective on the work that needs to be done to define sustainable cotton.

The NOP also offers a working example of third-party certification. This certification is at the heart of organic products' integrity, and the USDA organic seal has all but eliminated unscrupulous advertising. Initiatives like those of the Sustainable Cotton Project and BCI to establish benchmarks for sustainability in cotton production are laudable and should be encouraged. What is needed is a label and process that consumers and growers recognize, understand, and trust. Implicit in the label and process is the idea that the farmers who grew this cotton took some extra care for our natural resources (soil, water, air, plants, and animals). This is difficult to do without a comprehensive mechanism for third-party certification.

Organic grower cooperatives may have marketing lessons for sustainable cotton. With its stringent certification process and vigorous promotion of organic cotton, the Texas Organic Cotton Marketing Cooperative *(www.texasorganic.com)* has demonstrated success in getting its growers the premium prices they need to offset the greater expense of growing organic cotton.

As noted earlier, consumer demand for "greener" products is growing, in large part due to heightened awareness about the environmental—and, by extension, health—issues surrounding chemicals used in agriculture. With standards and a certification system in place for sustainable cotton, it will be possible to appeal to consumers with the specific benefits that differentiate it from conventionally-grown cotton: limited use of synthetic pesticides and fertilizers, less topsoil erosion, reduced irrigation, and better lives for the farmers who adopt sustainable practices. And for those farmers, there is the opportunity not only to cut production costs but to "get in on the ground floor" of an emerging global market.

Texas Organic Cotton Marketing Cooperative

The Texas Organic Cotton Marketing Cooperative (TOCMC) has proven successful in getting organic cotton to markets that will pay the price premium for organic cotton necessary to offset its higher production costs and ensure a profitable return for its member-growers, who produce most of the organic cotton grown in the United States.

Founded in 1993 and headquartered in Lubbock, Texas, TOCMC has about 30 members farming 8,000 to 10,000 acres of organic cotton, with annual production from these family farms averaging around 8,500 bales. Co-op members are certified organic by the Texas Department of Agriculture under a program that includes soil and plant-tissue testing to monitor compliance. The cotton is classified using USDA standards and pooled and baled according to quality, giving farmers an incentive to grow the highest quality cotton possible. To ensure truth in marketing, each bale of TOCMC is tracked from the field to the consumer, making it possible to trace, say, an organic bath towel back to the very farm where the cotton was grown. See the TOCMC Web site, *www.texasorganic.com.*

U.S. Cotton Production by State in Bales (x 1,000)						
Upland Cotton	**2003-2004***	**2004-2005***	**2005-2006***	**2006-2007***	**2007-2008***	**5-Year Average*+**
Southeast	**4,529**	**4,631**	**5,153**	**5,048**	**3,237**	**4,528**
Alabama	820	814	848	675	416	745
Florida	117	109	135	166	116	125
Georgia	2,110	1,797	2,140	2,334	1,660	1,992
North Carolina	1,037	1,360	1,437	1,285	783	1,185
South Carolina	326	390	410	433	160	338
Virginia	119	161	183	155	102	143
Mid-South	**6,541**	**7,134**	**7,433**	**8,226**	**5,277**	**7,021**
Arkansas	1,804	2,089	2,202	2,525	1,896	2,058
Louisiana	1,027	885	1,098	1,241	699	998
Mississippi	2,120	2,346	2,147	2,107	1,318	2,131
Missouri	700	830	864	985	764	798
Tennessee	890	984	1,112	1,368	600	1,036
Southwest	**4,638**	**8,114**	**8,886**	**6,120**	**8,588**	**6,616**
Kansas	90	71	88	117	57	88
Oklahoma	218	303	358	203	281	258
Texas	4,330	7,740	8,440	5,800	8,250	6,270
West	**2,115**	**2,626**	**1,788**	**1,428**	**1,253**	**2,023**
Arizona	550	723	615	556	514	611
California	1,495	1,790	1,065	779	650	1,318
New Mexico	70	113	108	93	89	94
Total Upland	**17,823**	**22,505**	**23,260**	**20,822**	**18,355**	**20,188**
Extra Long Staple Cotton (ELS)	**2003-2004**	**2004-2005**	**2005-2006**	**2006-2007**	**2007-2008**	**5-Year Average*+**
Arizona	5	6	7	13	5	10
California	371	683	558	687	793	580
New Mexico	13	19	22	20	8	18
Texas	44	38	44	45	46	43
Total ELS	**432**	**746**	**631**	**765**	**852**	**650**
All Cotton	**18,255**	**23,251**	**23,890**	**21,588**	**19,207**	**20,839**

Source: NASS, USDA. Note: Numbers may not add up due to rounding.
** Thousand Bales (480 lb. Bales).*
+ 5-year average is for Crop Years 2002-2006

Checklists of Sustainable Practices for Cotton Producers

For growers interested in increasing the sustainability of their farms, these self-assessment checklists will help identify areas where the soil function and farm performance can be improved. The studies and farmer articles discussed in this publication provide guidance on how to take full advantage of the low-cost services provided by soil organisms, natural enemies of pest insects, and innovative weed control strategies that save money while protecting soil and water resources.

Using the Checklists

The checklists are divided into topics such as soils and pest management. For the most part, the sheets can be completed without going to the field, using farm records or memory.

Each list ranks management practices starting from the lowest and progressing through higher levels of sustainability. With higher levels of sustainability, the numeric value increases. Select the practices that best match yours.

The higher the score, the higher the level of sustainability. An ideal score would be a four in each area. Practices scoring a four need only to be continued. Topic areas with lower scores offer opportunities to take advantage of the low-cost services provided by nature, as mentioned above.

Topics with a score of one or two should be seen as areas of concern. They may require additional technical support from among the many programs offered by NRCS to help farmers meet conservation objectives.

Taking Action

Use the **Summary Sheet** on page 49 to tabulate all the scores from the various topic areas. Once the scores are on one sheet, it will be easier to see which areas need improvement and how efforts might be combined to resolve or improve two or more areas with the same effort. Gather the necessary information, talk to appropriate specialists, read the sections in this publication on topic areas that need attention, then decide what actions to take. Write these action steps on the summary sheet along with a timeline in which they will be accomplished.

Cotton Sustainability Checklists

Soil Testing

No soil testing has been done on my farm. 1 pt ☐

Some soil tests, including for organic matter, were done in the past five years. 2 pts ☐

Soil tests, including for organic matter, are done every two to three years. 3 pts ☐

Soil tests, including for organic matter, are done every year. 4 pts ☐

Most soil-test labs can run an organic matter test if requested. You may also check with your local NRCS office for recommendations on soil testing labs or see the ATTRA publication Alternative Soil Testing Laboratories *at* ***www.attra.ncat.org/attra-pub/soil-lab.html.***

Cotton Sustainability Checklists

Soil Sample Interpretation

No soil samples have been taken. 1 pt ☐

I guess at my fertilizer needs based on past crop performance. 2 pts ☐

I use the soil-test recommendations for two to three years. 3 pts ☐

I or my crop consultant interpret the soil test and develop precise recommendations. 4 pts ☐

Tillage

I practice clean tillage in the spring & fall. 1 pt ☐

I till in the spring but not in the fall. 2 pts ☐

I use conservation or strip-tillage in the spring and do not till in the fall. 3 pts ☐

I use no-till exclusively year round. 4 pts ☐

Crop Rotation

I grow continuous cotton year after year. 1 pt ☐

I rotate cotton with one other crop such as corn, peanuts, or sorghum. 2 pts ☐

I rotate cotton with two other summer crops. 3 pts ☐

I rotate cotton with two or more summer crops and one winter crop such as wheat. 4 pts ☐

Organic Matter Additions

I don't add organic matter to the soil other than what the cotton stalks provide. 1 pt ☐

I grow a winter-annual cover crop each year. 2 pts ☐

I grow winter cover crops and rotate with high residue crops like corn or sorghum. 3 pts ☐

I add manure or compost, and grow cover crops and high-residue crops like corn or sorghum 4 pts ☐

Soil Water Penetration

Water penetration is poor, and I don't know what to do about it. 1 pt ☐

I add gypsum to correct water penetration problems. 2 pts ☐

I add gypsum and compost or manure to correct water penetration problems. 3 pts ☐

I add gypsum, compost or manure, & use killed cover crop mulch for water problems. 4 pts ☐

Cotton Sustainability Checklists

Soil Compaction

I drive equipment across the field no matter how wet the ground is. 1 pt ☐

I never drive my equipment over the fields when the ground is too wet. 2 pts ☐

I select or modify my equipment to minimize compaction (lightest equipment, wider tires). 3 pts ☐

I select or modify equipment to minimize compaction, stay off wet fields, and practice no-till. 4 pts ☐

Soil Erosion

I till to maintain bare ground and don't use cover crops. 1 pt ☐

I till in the spring and grow a cover crop over the winter. 2 pts ☐

I use conservation till or stip till and do not till in the fall. 3 pts ☐

I use no-till year round and grow cover crops over the winter. 4 pts ☐

Pest Monitoring:
Insects, Diseases, Nematodes

My fields are rarely or never scouted for pests. 1 pt ☐

I or my consultant scout the fields periodically. 2 pts ☐

I or my consultant scout the fields weekly. 3 pts ☐

I or my consultant scout the fields weekly, and I keep written records. 4 pts ☐

Beneficial Insect Conservation

I do not consider the effect of pesticides I use on beneficials. 1 pt ☐

I consider effects of pesticides on beneficials and select least toxic pesticides. 2 pts ☐

My field scouting protocols include beneficial insects, and I select least toxic pesticides. 3 pts ☐

I select least toxic pesticides, and use trap crops, insectary plantings, or intercrops for beneficial insect conservation. 4 pts ☐

Pesticide Application

CHECK IF DONE

Target pest level is above economic threshold . ☐

Consider non-chemical alternatives. ☐

Identify beneficial insects that might be harmed by pesticide application. ☐

Select a pesticide that is least toxic to beneficial insects. ☐

Consider the chemical class if pest resistance is an issue. ☐

Identify sensitive areas such as waterways and riparian areas before spraying. ☐

Choose sprayers and application methods that minimize off-site movement of pesticide. ☐

Record application date, rate, product used, and field sprayed after application is done. ☐

Do follow-up inspection to determine whether treatment was effective. ☐

Cotton Sustainability Checklist Summary Sheet and Action Plan		
Topic	**Score**	**Action Steps to Correct and Timeline for Completion**
Soil Testing		
Soil Sample Interpretation		
Tillage		
Crop Rotation		
Organic Matter Addition		
Soil Water Penetration		
Soil Compaction		
Soil Erosion		
Pest Monitoring		
Beneficial Insect Conservation		

Financial Assistance

Conservation Stewardship Program—NRCS/CSP

www.nrcs.usda.gov/programs/new_csp/csp.html

Through this voluntary USDA/NRCS conservation program, farmers who enter into the mandatory five-year contracts to improve, maintain, or manage existing conservation activities on cropland, grassland, prairie, improved pastureland, and non-industrial private forests may be eligible for annual payments up to $40,000, with a maximum of up to $200,000 for the life of the contract. Conservation activities include those that conserve or enhance soil, water, air, and related natural resources. CSP is available on Tribal and private agricultural lands and non-industrial private forest land in all 50 states and the Caribbean and Pacific Island Areas.

Environmental Quality Incentives Program—NRCS/EQIP

www.nrcs.usda.gov/programs/eqip

EQIP is a voluntary USDA/NRCS conservation program that provides financial and technical assistance to farmers and ranchers who contract to implement conservation practices that address environmental natural-resource problems on cropland, grassland, prairie, improved pastureland, and non-industrial private forests. Program payments to a single person or entity are limited to $360,000 for all contracts entered into in any six-year period.

Federal Resources for Sustainable Farming and Ranching

www.attra.org/attra-pub/federal_resources.html

This ATTRA publication offers an overview of the major federal conservation programs that provide resources for farmers and ranchers to enhance and maintain sustainable farming and ranching practices. The level of available conservation resources for this area has dramatically increased since 2002. This guide helps farmers and ranchers make their way through the often complex and difficult application processes. Access to these resources can open new opportunities to preserve agricultural lands, develop sustainable practices, and open new markets. 28 p.

Sustainable Agriculture Research and Education Program (SARE)

www.sare.org/coreinfo/farmers

Information and grants for sustainable production.

Carbon Trading/ Environmental Impact

Fiber Footprint Calculator

www.sustainable-economy.org/main/news/17

This tool from the Center for Sustainable Economy shows how to measure the environmental footprint of conventional, BASIC, and organic cotton production.

Chicago Climate Exchange

www.chicagoclimateexchange.com

The Chicago Climate Exchange (CCX) is North America's only cap-and-trade system for all six greenhouse gasses (GHG). CCX members that emit below their contracted GHG levels may sell or bank their surplus allowances. Those emitting above their targets comply by purchasing CCX Carbon Financial Instrument contracts.

Cotton Marketing

Agricultural Marketing Resource Center

www.agmrc.org/commodities__products/fiber/cotton.cfm

Links to many cotton marketing resources.

Cleaner Cotton Campaign

www.sustainablecotton.org/downloads/Toolkit_2007.pdf

An initiative by the Sustainable Cotton Project and Community Alliance with Family Farmers produced this publication describing the social, environmental, and economic benefits to cotton farmers in California's Central Valley who have adopted Biological Agricultural Systems in Cotton (BASIC). BASIC farmers were able to spray 73% less insecticide and miticide than conventional cotton growers in the region. The publication includes marketing strategies for "cleaner cotton" and a list of contacts for companies wanting to include cleaner cotton in their products. 38 p.

Cleaner, Greener Cotton: Impacts and Better Management Practices

http://assets.panda.org/downloads/cotton_for_printing_long_report.pdf

The global perspective of this report by WWF reflects the worldwide imperative for more sustainable approaches to cotton production. It includes Internet links to other sustainable cotton programs and organizations. 26 p.

Environmental Justice Foundation Cotton Campaign

www.eJfoundation.org/page141.html

Social, environmental, and marketing issues involving "cleaner" cotton.

Fashion Institute of Technology

www.fitnyc.edu/6833.asp

Links to many U.S. and international organizations involved in cotton marketing.

Supply Chain Strategy for Sustainable Cotton

www.icac.org/meetings/plenary/65_goiania/documents/english/os2/os2_de_man.pdf

This presentation by Reinier de Man, an international sustainable-business consultant based in Holland, suggests alternatives to traditional supply-chain strategies for marketing sustainably grown cotton.

Sustainable Cotton on the Shelves: A Handbook for the Mainstream Retail

www.crem.nl/Nieuwsbrief/cotton.pdf

A cooperative project from the Netherlands (Oxfam Novib and WWF among its participants), this handbook focuses on mainstream retailers and helps define sustainable cotton for them. It also plots the supply chain and addresses marketing challenges for sustainable cotton. It includes a resource list and cotton lexicon. 34 p.

USDA Agricultural Marketing Service

www.ams.usda.gov/cotton/mncs

Up-to-date information on cotton markets in *Market News Reports-Cotton Markets*.

Production Systems/ Pest Control

Agricultural Pest Management, Lubbock Research and Extension Center

http://lubbock.tamu.edu/ipm/AgWeb/index.html

Contains a number of pest management articles for cotton and other crops in Texas. Phone: 806-746-6101

Arkansas Agriculture Cotton Newsletter.

www.aragriculture.org/News/cotton/default.

Published weekly during the growing season providing grower information to Arkansas cotton producers. University of Arkansas Division of Agriculture, Cooperative Extension Service, 2301 South University Avenue, Little Rock, Arkansas, 72204, phone: 501-671-2000.

Inspirations for Future Cotton Marketing Campaigns

Marketing efforts for other sustainably grown products—especially timber products—provide possible models for the promotion of cleaner cotton. Below are two forest-product Web sites that illustrate some of these efforts.

Sustainable Forestry Initiative

www.sfiprogram.org

This site focuses on sustainability standards and certification and community outreach and training.

Non-Timber Forest Products Marketing Systems and Market Players in Southwest Virginia: Crafts, Medicinal and Herbal, and Specialty Wood Products

http://scholar.lib.vt.edu/theses/available/etd-1698-13636/unrestricted/ch1_ch4.pdf

This 21-page report provides reviews of marketing studies and outlines of marketing systems.

BASIC Cotton Manual

www.caff.org/programs/farmscaping/Cotton%20Manual.pdf

Based on field results from cotton farmers in California's Central Valley, this manual describes management and marketing options for growers who use bio-intensive integrated pest management to reduce their use of pesticides. BASIC (Biological Agricultural Systems In Cotton) growers used about 73% less insecticide and miticide than conventional growers in the area. It includes a resource list of production contacts and helpful Web sites. 53 p.

California Cotton Growers Workbook—A Self-Assessment Guide of Biointensive Farming Practices

Although developed for California growers by the Sustainable Cotton Project, the workbook outlines practices that are appropriate for most of the cotton belt. It provides some simple checksheets of practices as well as an action plan template to help growers improve the management of their soil, water, vegetation/habitat, pests and human resources. Not available via web. For more information contact Marcia Gibbs, Sustainable Cotton Project, *marcia@caff.org*.

Beetle Banks

Beetle banks are swaths of raised land four- to six-feet wide planted with native bunch grasses to provide shelter for predacious ground beetles in cultivated fields. The following Web sites provide information about creating beetle banks and their benefits in integrated pest management.

- ***http://extension.oregonstate.edu/news/story.php?S_No=390&storyType=news***
- ***www.rsc.org/delivery/_ArticleLinking/DisplayArticleForFree.cfm?doi=b006319n&JournalCode=PO***
- ***http://ofrf.org/funded/reports/snyder_03s27.pdf***
- ***www.sac.ac.uk/mainrep/pdfs/tn513grassbeetles.pdf***
- ***www.rspb.org.uk/ourwork/farming/advice/details.asp?id=204246***
- ***www.rspb.org.uk/Images/beetlebanks_england_tcm9-207516.pdf***

Conservation Tillage Systems for Cotton

http://openlibrary.org/b/OL18161401M/Conservation-tillage_systems_for_cotton

A Review of Research and Demonstration Results from Across the Cotton Belt. Arkansas Agricultural Experiment Station, Division of Agriculture, University of Arkansas Special Report 160. Edited by N.G. Wyatt. July, 1993. 121 p.

COTMAN Cotton Management Software

- ***www.cottoninc.com/Entomology/COTMAN***
- ***http://cotman.tamu.edu/index.htm***

COTMAN uses cotton crop monitoring techniques to summarize crop development, detect stress, and assist with in-season and end-of-season management decisions. It was developed by the University of Arkansas Division of Agriculture with major financial support from Cotton Incorporated and through collaboration with Mississippi State University, Louisiana State University, Texas A&M University**,** Virginia Tech, and Arkansas State University. COTMANs are to promote earliness and plant vigor, and to reduce late-season insecticide applications. The software is distributed to U.S. growers at minimal or no charge. To obtain a copy, contact your Cooperative Extension Service agent or state cotton specialist. E-mail inquiries can be sent to *ddanfort@uark.edu*

Cotton Farming magazine

www.cottonfarming.com

A monthly magazine about all aspects of cotton production. Inquire about subscriptions at Subscription Service Center, Attn: Krystal Decker, 307 Southgate Court, Brentwood, TN 37027. Phone 615-377-3322

Cotton Newsletters

http://commodities.caes.uga.edu/fieldcrops/cotton

Information from the University of Georgia College of Agricultural and Environmental Sciences. Covers a wide variety of topics on cotton production.

Cotton Production in Mississippi

http://msucares.com/crops/cotton/index.html

A comprehensive guide covering many aspects of cotton production from the Mississippi Agricultural and Forestry Experiment Station.

Cotton Production Publications Available from Oklahoma Cooperative Extension Service

www.okstate.edu/ag/oces/cotton_ipm/cotpubs.htm

Cotton Publications from Alabama Extension Cooperative Service

www.ag.auburn.edu/xfer/alabamacotton

Field Guide to Predators, Parasites and Pathogens Attacking Insect and Mite Pests of Cotton: Recognizing the Good Bugs in Cotton

http://lubbock.tamu.edu/cottondvd/content/cottondvd/Insects/Recognizing%20Good%20Bugs%20in%20Cotton.pdf

This extensive, well-illustrated guide from the Texas A&M University Cooperative Extension System, written by Allen Knutson and John Ruberson, looks at 48 beneficial predators, parasites, and pathotgens frequently associated with cotton. It includes chapters on using natural enemies of cotton pests, tables showing which beneficials are effective against specific pests, and sources of entomological supplies. It may also be ordered in print from Texas Cooperative Extension, P.O. Box 1209, Bryan, TX 77806-1209. $5 per copy. Specify publication by title and B-6046. 136 p.

Georgia Farm*A*Syst (Farm Assessment System)

http://pubs.caes.uga.edu/caespubs/pubs/PDF/B1152-19.pdf

Farm*A*Syst is a voluntary program to provide Georgia farmers with assessment tools to evaluate the environmental soundness of their farms and create action plans to address environmental concerns.

Hardlock of Cotton
http://wcrc.confex.com/wcrc/2007/techprogram/P1837.HTM
Historical Review and Perspectives by Dr. Jim J. Marois, Dr. David D. Wright, Dr. Breno Leite, Dr. Daniel Mailhot, and Mr. Enoch Osekre. University of Florida, 155 Research Road, Quincy, FL 32351. Posted online Sept. 12, 2007

Insect Scouting and Management in Bt-Transgenic Cotton
www.msucares.com/pubs/publications/p2108.htm
These guidelines from the Mississippi State University Cooperative Extension System include scouting and management approaches for thrips, aphids, mites, whiteflies, cutworms, tobacco budworms/bollworms, boll weevils, tarnished plant bugs, stink bugs, clouded plant bugs, beet armyworms, and fall armyworms. 7 p.

Integrated Crop & Livestock Systems to Conserve Soil & Water Resources in the Southeastern USA
www.ag.auburn.edu/auxiliary/nsdl/scasc/Proceedings/2006/franzluebbers.pdf

By Alan J. Franzluebbers and Glover B. Triplett, Jr. from the Southern Conservation Systems Conference, Amarillo, Texas, June 2006. The paper details the environmental and economic benefits of integrated crop and livestock systems, with special emphasis on soil conservation and wise water management.

Integrated Pest Management Florida
http://ipm.ifas.ufl.edu/agriculture/field_crops/cotton/index.shtml
Contains publications about pest management for cotton in Florida.

Journal of Cotton Science
www.cotton.org/journal
A quarterly journal containing scientific research articles about cotton production. Published by the Cotton Foundation, P. O. Box 783, Cordova, Tennessee 38088 Phone: (901) 274-9030

North Carolina Integrated Pest Management Information, Crop Production: Cotton
http://ipm.ncsu.edu/TopicResults.cfm?topsubID=33
Provides several publications on a wide variety of cotton production topics.

Organic Cotton: Pest Management
http://ipm.ifas.ufl.edu/agriculture/field_crops/cotton/index.shtml
Provides information about biointensive and organic pest management for cotton.

Project on Sustainable Cotton Production
www.tifton.uga.edu/lewis/Proj.HTM
This ongoing study (since 1995) from the University of Georgia examines the economic benefits of using cover crops, habitat management, improved cotton varieties, pest targeting, and treatment guidelines in sustainable cotton production. Excellent photos of beneficial insects, as well as charts of pests and their predators.

USDA Cotton Project Trials and Studies
www.ars.usda.gov/Research/docs.htm?docid=17717
This Web site provides summaries of recent and ongoing USDA-sponsored research.

Sales/Green Marketing

BusinessGreen.com
www.businessgreen.com/business-green/analysis/2235554/ten-steps-sustainable-marketing
Ten Steps to Sustainable Marketing in an Uncertain Economy

GreenBiz.com
www.greenbiz.com
Web site devoted to all aspects of the "green" economy

Mediacology
http://mediacology.com/2009/05/23/sustainable-marketing
Links to blog posts & articles about sustainable marketing.

Semiosis Communications
www.semiosiscommunications.com/category/sustainable-marketing
Articles and blog links about marketing strategies for sustainably grown products.

Slideshare
www.slideshare.net/group/sustainable-marketing
Free slide shows on aspects of sustainable marketing.

Solutions for Green Marketing
www.solutionsforgreenmarketing.com
Many approaches to green marketing, including "Cause Marketing," "Low Cost Green Marketing," and "Startup Green Marketing."

Sustainable Marketing
www.sustainablemarketing.com
This Web site offers marketing assessments, Web hosting, market research, public relations planning, and other services related to marketing sustainably produced products.

Texas Organic Cotton Marketing Cooperative —TOCMC
www.texasorganic.com
The approximately 30 members of this cooperative, founded in 1993, produce the majority of organic cotton grown in the U.S., about 8500 bales annually. TOCMC has proven very effective at finding the best markets and highest prices for its members.

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Using Bats to Help Manage Pest Insects

Mexican free-tailed bat **(Tadarida brasilensis Mexicana)**
Drawn from a photograph taken by Amanda Lollar, Bat World Sanctuary, Texas

Bats can provide valuable and free pest control services that farmers can augment by providing bat houses. Bats are night-time predators that feed on a wide variety of insects, including the adults (moths) of a whole spectrum of farm pests—armyworms, cutworms, bollworms, and others.

A 2006 study (Cleveland, et al, 2006) found that colonies of Brazilian free-tailed bats in south-central Texas provided pest management against cotton pests in eight counties estimated at $741,000 per year for a crop valued at $6M. Research has shown that some pests can detect bat "sonar" and may avoid locations where bat populations create a high amount of sonar "chatter."

In one season, a typical colony of about 150 big brown bats in the Midwest eats 50,000 leafhoppers, 38,000 cucumber beetles, 16,000 June bugs, and 19,000 stink bugs—not to mention thousands of moths such as adult cornborers, earworms, and cutworms.

Bats also eat insects that are a health nuisance to humans. A small brown bat can devour up to 600 mosquitoes in an hour, reducing risk of West Nile Virus.

Your local NRCS office may be able to provide cost-share money for developing bat habitat on your farm.

Considerations When Locating a Bat House

- Any place that already has bats is best, particularly agricultural areas (vs. urban areas), due to insect abundance and habitat variety.
- Place the bat house near water. Within ¼ mile is ideal.
- Place the bat house near some sort of protective cover like a grove of trees. Don't place houses in a grove of trees, but 20–25 feet away due to predator concerns, and at least 10 ft. above the ground.
- Don't place bat houses near barn owl boxes. The barn owl is a bat predator. Place the two types of boxes a fair distance from each other facing in opposite directions.
- Do not mount bat houses on metal buildings (too hot for bats) or in locations exposed to bright lights.
- Paint the exterior with three coats of outdoor paint. Observations suggest that the color should be black where average high temperatures in July are 80–85° F, dark colors (such as dark brown or gray) where they are 85–95° F, medium or light colors where they are 95–100° F, and white where they exceed 100° F. Much depends upon the amount of sun exposure, Adjust to darker colors for less sun.

Constructing a Place for Bats on Your Farm

The easiest way to construct bat housing is to simply add a sheet of plywood to a barn or house wall with 3/4" spacers between the sheet and wall. Placing the long axis of the plywood vertically will allow for greater temperature variation in the bat space, making it more attractive to bats. Other construction considerations include:

- Use exterior-grade plywood with exterior-grade staples and bolts.
- Minimum bat house dimensions are 32" tall and 14" wide, with a 3–6" wide landing pad below the opening.
- 1 to 4 roosting chambers of parallel sheets of wood separated by 3/4" spacers. Landing pad and roosting chamber should be roughened or have a durable textured surface for the bats to grasp—no sharp points to tear bat wings!
- All seams should be caulked to avoid leaks.• Treating bat houses with diluted bat guano or allowing some weathering of a new bat house may help attract new "renters."

Bat Conservation International provides information about bat natural history and behavior, including designs for bat houses, available online at *www.batcon.org/pdfs/bathouses/SingleChamberBHPlans.pdf*
To learn more about Bat Conservation International, phone 512-327-9721 or visit *www.batcon.org*

Several species of flowers planted adjacent to a cotton field provide season-long nectar and pollen resources for beneficial insects. Photo: Luis Gallegos, CAFF

Habitat for beneficial insects planted adjacent to cotton field include sorghum (next to cotton), sunflower, and corn. Photo: Luis Gallegos, CAFF

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Sustainable Cotton Production for the Humid South

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