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

Summary

Cotton is grown on over 11.6 million acres in the Southeastern USA each year. But less than 25% of this cotton is grown using conservation tillage. Improvements in adoption have been hard to achieve for a number of reasons. This project's aim was to improve a system for cotton production and to increase producer understanding of sustainable production practices including conservation tillage and cover crops. In on-farm studies we investigated effects of cover crops in conservation tillage cotton production systems on crop production. Insect dynamics, soil microarthropods and plant parasitic nematodes were used to evaluate impacts of cover crop management. Companion studies on station and in the greenhouse were used to identify cover crops with the most potential to produce biomass, enhance biological diversity and reduce threats of plant parasitic nematodes. Our results showed a positive impact of a blend of legumes (balansa clover, crimson clover, and hairy vetch) plus rye on above and below ground biological populations. Addition of cover crops increased soil biological diversity and microbial activity and in one year reduced the number of pesticide applications needed to control cotton insect pests. Plant parasitic nematode populations were supported by some of the cover crops in our system and trials with other cover crops indicated that alternative cover crops would be better choices where plant parasitic nematode populations exist. Through partnerships with the Georgia Conservation Tillage Alliance, Seven Rivers RC&D, and Sunbelt Farm Expo we provided information to several thousand farmers on use of cover crops in conservation tillage systems and impacts cover crops can have on nutrients, soil C, pest insects, nematodes and crop yields. Research results were presented at on-farm field days, conservation tillage meetings, the Sun Belt Agricultural Exposition, professional scientific society meetings and in scientific and nonscientific publications. Our outreach efforts were effective and successful in promoting sustainable farming practices in the Southeast.

Introduction

The southeastern USA produces over 11.6 million acres of cotton each year. But in 2000, only 13% of the cotton grown in the region used some form of conservation tillage. Research results from the past 20 years showing the benefits of conservation tillage for reducing costs in the long-term through improved soil water relationships and improved soil productivity (Reeves, 1994) have apparently been ignored by most producers in the region. Many factors may be contributing to limited adoption of conservation tillage systems for cotton. Unwillingness of farmers to adopt the practices implies that conservation tillage is either perceived to be unprofitable or that other significant constraints to adoption exist. The constraints can be classified into biological, institutional and social categories. Grower groups, University and NRCS personnel and farm service providers, conservation programs administered through the United States Department of Agriculture's Natural Resources Conservation Service and Farm Services Agency and activities of local grower groups are designed to overcome these obstacles however, national goals of widespread adoption of conservation tillage systems have not been met.

Our project was conceived to improve production practices and increase adoption of conservation tillage systems. It focused on development of management practices that could potentially reduce costs of insecticide applications and also improve soil physical, chemical and biological properties thereby improving crop and soil productivity. A significant amount of research has been conducted on cover crops in conservation tillage systems in the south (Reeves, 1994) but little has focused on use of cover crops with conservation tillage to enhance beneficial insects (Ruberson et al. 1997, Lewis et al. 1997). Most studies have focused on comparisons among single species of legumes and non-legumes (Reeves, 1994). Only a few have addressed mixtures of cover crops even though they can provide a more diverse biological

Coordinator

Harry Schomberg, Ecologist
USDA ARS
J. Phil Campbell, Sr., Nat. Res. Cons. Center
1420 Experiment Station Rd.
Watkinsville, GA 30677-2373
Phone: 706-7695631 222
Fax: 706-769-8962
E-mail: hhs1@uga.edu

Participants

Lamar Black, President:
Georgia Conservation Tillage Alliance
Irvin Branch, Owner/Manager:
Branch Farms
Fred Evans, Owner/Manager:
Bryant's Inc.
J. H. Harrison, Owner:
Harrison Farms
Sharon Lachnicht Weyers , Ecologist:
USDA ARS
Marshall Lamb, Ag. Economist:
USDA ARS
Dawn Olson, Entomologist:
USDA ARS
Sharad Phatak, Professor:
University of GA - Horticulture Dept
Brian Ponder, Owner/Manager:
Ponder Farms
Tim Ross, Producer:
Ross Farms
Upendra Sainju, Soil Scientist:
Fort Valley State University
Bharat Singh, Professor of Agronomy:
Fort Valley State University
Grady Thompson, Owner/Manager:
Thompson Farm
Glynn Tillman, Entomologist:
USDA ARS
Patricia Timper, Entomologist:
USDA ARS
Scott Utley, Georgia Cooperative Extension Agent - Turner Count:
University of Georgia Extension
Wayne Whitehead, Crop Physiologist:
Fort Valley State University
Joe Williams, Owner/Manager:
Williams Cotton Farms

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habitat by extending availability of nectar and other food sources (Altieri, 1995) and improve nutrient management because of complimentary differences in chemical composition between legumes and grasses that influence decomposition and N mineralization rates (Rannells and Wagger, 1996; Creamer et al., 1996).

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Objectives/Performance Targets

Our first objective was to investigate how cover crop management might be used to enhance insect habitat (to increase the number of beneficial insects present) and how different cover crops influence interactions among aboveground insects (predator/prey relationships). We also evaluated how these practices influenced soil biology and other soil quality indicators.

Our second objective was to educate producers about environmental and economic benefits of soil quality in sustainable agriculture systems and expand the network of area producers who provide leadership for further adoption and dissemination of information on sustainable production practices.

Materials and Methods

Both on-farm and research center field and laboratory studies were used for the first objective.

I. On-Farm Field Studies

On-farm studies were conducted near Louisville, GA and Tifton, GA in 2001, and 2002. We compared traditional cover crop practices (rye or crimson clover) to two diverse cover crop mixtures (legume blend and legume blend plus rye) and to a no cover crop treatment. The blend was designed to improve availability of food sources to beneficial insects and to increase cover crop biomass for improving soil organic matter. The three legumes in the blend (balansa clover, crimson clover, and hairy vetch) had early, midseason, and late blooming characteristics. Each treatment was planted on 4 ha (10 acre) fields at each farm (total of 40 acres). Large field sizes were used specifically for evaluating aboveground insect dynamics (pests and beneficial). Although it was not always possible for the cooperators to provide enough land to establish one complete set of treatments on adjacent fields, most were within close proximity so that farm location was used as replicates in the statistical analyses. The locations of treatments within fields were chosen to ensure similar soil types across farms at each location (Tifton and Louisville).

The cover crops were planted in the fall directly into mowed cotton stubble using a no-till grain drill. For the blend plus rye treatment, the blend and rye were planted in alternating strips of approximately 46 cm (18 inches) wide to accommodate planting of the spring cotton into the area where the rye had grown. The cover crops were killed 3 weeks prior to cotton planting with an herbicide (paraquat or glyphosate). For the legume blend, legume blend plus rye and the crimson clover treatments, glyphosate was applied in 46 cm (18 inch) wide bands leaving 46 cm (18 inch) wide strips of cover crop that continued to grow to maturity to provide insect habitat. All of the rye in the rye treatment was killed i.e. it was not killed in strips.

Cotton was planted into strip-tilled rows (producer owned KMC strip-till rigs) at 11.2 kg/ha (10.1 lb/ac) by the producers using John Deere planters either during or after strip-tilling. Planting dates of cotton ranged from 1 May to 30 May in 2001 and from 26 April to 11 May in 2002. Cotton planting dates varied due to differences in strip-killing dates and the ability of the producers to plant the cotton. Cotton varieties varied due to decisions by the producers and included DP 458, DP 5415, DP 5690, and Delta Pearl (Delta and Pine Land, Co., Scott, MS). In 2001, one legume blend plus rye field was not planted in cotton because the producer harrowed the cover crop prior to planting and one rye field was not planted because the cotton producer decided not to plant cotton.

Cotton was harvested from mid October to late December in 2001 and 2002. Cotton yield was determined in by harvesting one or two 120 to 150 m by four-row areas using four-row or six-row John Deere cotton pickers. In 2002, producers in Tifton were willing to collect data on one blend plus rye field, two blend fields, one rye field, and all control fields because they were behind in harvesting cotton. No cotton harvest occurred in Louisville because the drought that limited yield below the economic level for harvest. Cotton was weighed in the field using a weigh wagon (Tifton) or cotton wagon on highway scales (Louisville) immediately after machine harvest, to determine seed-cotton yields.

Above ground insect dynamics --Procedures for determining insect pests and predators are presented in detail in Tillman et al., 2004. Plants were sampled weekly in the spring for cover crop treatments and in the summer cotton by collecting twenty sweep samples from each plot (6.1-m length using sweep nets 38 cm in diameter). Whole plant sampling was done in cotton weekly to monitor heliothine species before the heliothines Heliothis virescens (F.) and Helicoverpa zea (Boddie) occurred and biweekly thereafter. Insect diversity and population density were determined for pests, predators, hymenopteran parasitoids, and entomopathogenic fungi. Three main groups or species of pests were collected in cover crops and cotton: 1) the heliothines Heliothis virescens (F.) and Helicoverpa zea (Boddie); 2) the tarnished plant bug, Lygus lineolaris (Palisot de Beauvois); and 3) stink bugs. The main stink bugs collected were the southern green stink bug, Nezara viridula (L.); the brown stink bug, Euschistus servus (Say); and the green stink bug, Acrosternum hilare (Say). Cotton aphids, Aphis gossypii Glover, were collected only on cotton.

Soil biological diversity – Microarthropods were sampled three times a year in the cotton plots near Tifton planted with blend plus rye, and blend cover crop treatments to evaluate diversity of groups of soil meso and micro fauna important to nutrient cycling. The samplings occurred during the summer growing season at pre-plant, mid-season and after harvest periods, during 2001 and 2002. Microarthropods were extracted from soil cores using modified Tullegren extractors (Mallow and Crossley, 1984) and sorted to the mite suborders Mesostigmata, Oribatida, and Prostigmata, and the insect order Collembola (other organisms were noted) and converted to biomass.

Cover crop effects on soil C dynamics were determined by assessing microbial biomass C and N, potential C and N mineralization, particulate organic C and N, and water stables aggregates. Four soil cores (5 cm diameter) were collected from four locations in each field and segmented into 0 to 2.5, 2.5 to 7.5, 7.5 to 15, 15 to 30 and 30 to 60 cm depths. Soils were collected before cotton planting and after cotton harvest. They were composited within areas and depths, air-dried, and passed through a 5-mm sieve.

Crop growth and nutrients dynamics (C, N) -- Cover crop biomass samples were collected from four 1 m2 areas in each field to evaluate nutrient C and N by dry combustion LECO CNS2000, and resource quality (carbohydrate, cellulose, and lignin content by near infrared reflectance; Marten, et al., 1985). Cotton emergence and stand counts were monitored to determine cover crop effects on cotton establishment. Early season and late season cotton biomass samples were collected from four areas in each field to evaluate cover crop effects on growth.

Seedcotton yield data were analyzed by PROC MIXED followed by least significant difference (LSD) separation of means (SAS Institute 1999) where appropriate. Fixed effects were cover crop treatments and random effects were cotton producers' fields and residual error. In 2001, one crimson clover field was not included in this analysis because 25% of the ground cover in this field was volunteer wheat and rye. In 2002, one blend plus rye field was not included in the yield analyses because the cotton producer harvested this field together with several other fields, and so a yield could not be obtained for this field.

Plant parasitic nematodes were evaluated during 2001 and from soil sampled prior to planting, at midseason, and at cotton harvest from the furrow or root zone (Tifton). Thirty soil cores per plot were collected from a depth of 0-20 cm and pooled in the field. The samples were transported from the field in coolers and stored at 10 C until processed. Plant-parasitic

nematodes were extracted from a 150-cm3 homogenized subsample by centrifugal flotation (Jenkins, 1964). All plant-parasitic nematodes were identified to genus and counted.

Cover crop mixture improvement study (year 1 and 2)

Small plot studies were established at Watkinsville and Fort Valley to determine if other cover crops would be better components of the blend treatment. These studies used small plots (3 m by 30 m) to determine early, mid, and late season growth and to measure insect population dynamics. We had planned to use the best mixtures identified from these evaluations in an on farm comparison against our original mixtures in the third year of the study.

Cover crops as potential hosts for root-knot nematodes

Cover crops could potentially serve as hosts of the southern root-knot nematode, the most wide-spread nematode pathogen of cotton in the southeast. We evaluated the reproduction of this nematode on rye and various legume cover crops in the greenhouse, and determined whether the presence of winter cover crops increase densities of this nematode and subsequent damage to cotton in the field. The following crops were tested in replicated greenhouse and field studies: Wrens Abruzzi rye, AU Sunrise crimson clover, Early hairy vetch, Cahaba vetch, and Hairy vetch.

II. Expand producer knowledge of sustainable systems

Outreach results from the project are described elsewhere however our approach was to work with The Georgia Conservation Tillage Alliance to conduct a field day each year. At those field days we surveyed the producers about their use of cover crops, conservation tillage, and sustainable practices such as integrated pest management. We expanded the outreach for the project to the Sustainable Agriculture/Conservation Tillage School in Douglas, GA in 2004 and the Sun Belt Farm Exposition in 2003 and 2004 by participating in grower education workshops and field day demonstrations.

I. Management to enhance biological function

LOUISVILLE 2001 AND 2002

Cover crop biomass

In April of 2001 in Louisville, the blend plus rye treatment produced around 20% more biomass than rye or crimson clover alone while the no-cover (weeds) plots had very little biomass (Table 1). In 2002 the cover crop biomass was sampled two to three weeks earlier than in 2001 to avoid delaying producers from planting cotton which resulted in slightly lower biomass amounts compared to 2001. Rye and legume blend plus rye averaged around 1750 kg ha-1 of biomass which was nearly 2 times greater than the blend and no cover treatments. Nitrogen content of the cover crops ranged from 12.0 to 48 kg ha-1 for the two years. The greatest amount of N was in the legume blend plus rye treatment which averaged 50 kg N ha-1. The lowest amount was in the no cover plot which averaged 14 kg N ha-1.

Cotton biomass

Cotton biomass was determined early and late in the cotton growing season (Table 1). In 2001 at the early season sampling, cotton biomass and N content was greater in the rye and no cover treatments compared to the blend and blend plus rye treatments. Near the end of the growing season differences due to cover crop treatment had practically disappeared for cotton biomass while N contents were greater for the blend plus rye treatments compared to the rye treatment. No significant differences were found for C to N ratio of the cotton due to the cover crop. In 2002 variability in the data was much greater than in 2001. Much of this was due to the low rainfall in the region which severely limited plant growth and cotton development. This

resulted in no differences being determined for cotton biomass or N content even though differences among the means for the cover crop treatments were greater than in the previous year.

Table 1. Cover crop and cotton biomass for Louisville farms in 2001 and 2002.

	Cover crop			Cotton Early			Cotton Late		
	mass	N	C:N	mass	N	C:N	mass	N	C:N
2001	kg ha-1			kg ha-1		kg ha-1			
No Cover	930	15	27.9	2885	81	15.1	6548	147	20.5
Blend	2118	43	20.8	1982	63	13.6	7369	163	21.1
Rye	2082	26	35.0	2501	72	14.9	6460	131	23.2
Blend + Rye	3373	48	31.5	1566	50	13.2	7684	170	20.8
2002									
No Cover	718	13	21.5	597	22	9.9	6278	164	15.0
Blend	948	30	12.0	119	6	8.9	2200	71	12.0
Rye	1895	44	17.1	465	17	10.2	5439	153	14.5
Blend + Rye	1959	51	14.4	62	3	8.6	2534	79	12.1

Early season sampling was in early July for 2001 and late June for 2002.
Late season sampling was in early September for 2001 and late August for 2002.

Cotton Yield

Cotton yields in Louisville were not different among the cover crops in 2001. Yields as seed cotton were 1306, 1528, 1670, and 1710 kg ha-1 for the no cover, blend, rye and blend plus rye treatments respectively. In 2002, due to the severity of the drought, the producers did not harvest their cotton. Yields were estimated to be less than 350 kg ha-1 based on visual observation of crop consultants working with this project. Poor growing conditions for 2002 are reflected in the cotton biomass data referenced above.

TIFTON 2001 and 2002

Cover crop and Cotton Biomass

Table 2. Cover crop and cotton biomass for Tifton farms in 2001 and 2002

	Cover crop			Cotton Early			Cotton Late		
	mass	N	C:N	mass	N	C:N	mass	N	C:N
2001	kg ha-1			kg ha-1		kg ha-1			
Blend	2787	79	14.1	3598	120	12.6	12825	231	26.2
Crimson Clover		2637	82	13.9	2783	97	12.1	13559	267
23.6									
Rye	5354	94	25.0	3329	105	13.5	12053	259	26.1
Blend + Rye	8891	128	28.9	2210	72	13.1	14481	261	25.8
2002									
Blend	1542	45	12.5	350	17	8.4	4596	167	11.5
Crimson Clover		1664	56	12.3	538	24	8.9	5807	192
13.2									
Rye	2787	55	21.8	671	29	9.1	7858	273	12.9
Blend + Rye	1792	46	14.7	693	29	9.5	6498	197	14.7

Early season sampling was in early July for 2001 and late June for 2002.
Late season sampling was in early September for 2001 and late August for 2002.

Cover crops

In 2001 the rye and blend plus rye produced two times more biomass than the blend or the crimson clover treatments (Table 2). Nitrogen contents of the blend plus rye was about 60 % greater than that of the blend and crimson clover treatments. There were no statistically significant differences between rye, crimson clover and blend. The C:N ratio of rye and blend plus rye was about 27 while that of the blend and crimson clover was significantly lower averaging 14. In 2002, cover crops were sampled earlier (March) to avoid delaying producer

operations therefore the amount of biomass measured was less than in the previous year. There were no differences for biomass or n content among the cover crops. Biomass averaged 2000 kg ha-1 and N content averaged 50 kg ha-1. The C:N ratio of the rye was 22 while the C:N ratio for the other cover crops averaged 13.2.

Cotton biomass

In 2001, the cover crop treatments had no effect on cotton biomass at ether the early or late sampling periods. In early July cotton biomass averaged 2960 kg ha-1 while at the late season sampling in September, biomass averaged 13300 kg ha-1. The C:N ratio of the biomass was 12.7 at the early sampling date and 25.3 at the late sampling date. Results in 2002 were similar to those in 2001 but the amount of biomass measured was lower partially due to early sampling and partially due to the sever drought experienced in the region. Plots in Tifton were irrigated however due to the severity of the drought the amount of water in surface ponds limited the amount of water the producers could apply. Averaged across cover crop treatments, biomass was 587 and 6184 kg ha-1, N content was 25.4 and 205 kg ha-1 and C:N ratio was 9.0 and 13.2 for the early and late sampling periods respectively.

Cotton Yields

Table 3. Least squares means for seed cotton yields in 2001 and 2002

Treatment	Seed cotton (kg ha-1) 2001		2002				
	n	Yield	SE	Yield	SE		
Crimson clover	3	3778.2	a	249.6	2026.2	a	235.8
Blend + rye	3	3586.0	ab	249.6	2161.3	a	164.1
Rye	3	3304.2	abc	249.6	1390.4	b	222.8
Blend	4	3045.4	bc	222.8	2031.0	a	244.4
Control	4	2822.2	c	222.8	1072.4	b	57.3

Least square means within a column followed by the same letter are not significantly different between treatments (PROC MIXED, LSD, P = 0.05).

a Refers to the number of fields for each cover crop treatment.

b Blend is balansa clover, crimson clover, and hairy vetch.

Seed cotton yields were significantly different among treatments for 2001 and 2002 (Table 3). In the first year of the test, seed cotton yields were 27 and 34 % greater for cotton with blend plus rye and crimson clover, respectively compared to cotton without cover crops. Yields for cotton with the blend and rye treatments were not significantly different from those for the control. In 2002, the legume cover crop treatments seed cotton yields were 89 to 100% greater than control fields while yields following rye averaged 29 % greater but this was not statistically significant. Our cover crops and planting pattern never resulted in yields that were lower than those of the conventional tillage no cover crop fields therefore we concluded that planting cotton in strip-killed and strip-tilled cover crops did not adversely affect cotton production. Similarly, Scott et al.(1990) reported that cotton grown after rye, hairy vetch, rye + vetch, and rye + crimson clover had higher yields than control fields with no winter cover crop over a 10-yr period. In contrast, both Gaylor et al.(1984) and Ruberson et al.(1997) reported that cotton yields were reduced in crimson clover cotton fields, but similar in rye fields, compared with control fields without a cover crop. Availability of new strip-tilling technology may account for the better cotton yields that we obtained for crimson clover fields compared with control fields.

Aboveground Insects (predators and beneficials)

For both years of the study, the heliothines were the only pests that exceeded their economic threshold in cotton, and the number of times this threshold was exceeded in cotton was higher in control cotton than in crimson clover and rye cotton. Heliothine predators and aphidophagous lady beetles occurred in cover crops and cotton during both years of the experiment. Geocoris punctipes (Say), Orius insidiosus (Say), and red imported fire ant, Solenopsis invicta Buren were relatively the most abundant heliothine predators observed. Lady

beetles included the convergent lady beetle, Hippodamia convergens Gue´rin-Me´neville; the seven spotted lady beetle, Coccinella septempunctata L.; spotted lady beetle, Coleomegilla maculata (De-Geer); and the multicolored Asian lady beetle, Harmonia axyridis (Pallas). Density of G. punctipes was greater in cotton fields previously planted in crimson clover compared with control cotton fields for all combined sampling dates in 2001. Intercropping cotton in live strips of cover crop was probably responsible for the relay of G. punctipes onto cotton in these crimson clover fields. Density of O. insidiosus was not significantly different between cover crop and control cotton fields. Lady beetles seemed to relay from cover crops into cotton. Conservation of the habitat of fire ants using conservation tillage during planting increased the density of red imported fire ants relative to control cotton fields. Reduction in the number of times in which economic thresholds for heliothines were exceeded in crimson clover and rye compared with control fields indicated that the buildup of predaceous fire ants and G. punctipes in these cover crops subsequently resulted in reduction in the level of heliothines in conservation tillage cotton with these cover crops compared with conventional tillage cotton without cover crops. (Complete results in Tillman et al., 2004)

Soil dwelling insects

Microarthropods were sampled during the cotton growing season at pre plant, mid season and after harvest in the legume blend, and blend plus rye treatments, during 2001 and 2002. We observed the greatest average abundances of soil dwelling microarthropods in 2002 and lowest in pre- and end- season of 2001 (Table 4). Total average abundances were significantly different across producers' fields and the three sampling seasons in 2001 with no significant differences observed in 2002. In 2001, microarthropod communities across fields were mainly comprised of Prostigmatid mites with significant differences in total abundances among seasons (Figure 1a). In 2002, Prostigmata and Collembola (total abundances averaged across fields) evenly dominated communities across seasons; however, only the average total abundances of Mesostigmata were significantly different among seasons (Figure 1b). End season of 2002, Oribatida and Prostigmata equally dominated the community in Branch and Thompson fields whereas Collembola were still dominant in Ponder I &II Blend fields and Ponder II Legume blend plus rye field (Figure 2). There were no significant differences in microarthropod dynamics between the two cover crops because differences were not consistent among producers' fields. However, change in composition of the community from one dominated by a single taxa (Prostigmata) to one dominated by more than one taxa, as well as the increase in average abundances in the second year of strip tillage might indicate a potential change in soil quality with conservation management. Successive years should be evaluated before microarthropod community dynamics can conclusively indicate that conversion to conservation practices improved soil quality.

Cover Crop Affects On Southern Root-Knot Nematode Reproduction

Populations of Meloidogyne incognita were found in several of the fields in the Tifton study during 2001 and 2002. Because of the large plot size (a farm), it was impossible to determine whether the nematode densities are a result of winter cover crop, cropping history, soil texture, etc. Based on analysis of variance, there was no effect of cover crop on densities of M. incognita in 2001 or 2002. Several of the fields had populations of M. incognita that were above the damage threshold for cotton. These fields should be rotated to a non-host (e.g., peanut) to help reduce the nematode populations and reduce the risk of economic loss. Because we felt that our results from the field were inconclusive we conducted greenhouse and field studies to evaluate the potential for various cover crops to serve as hosts for the southern-root knot nematode (See below).

Potentially Mineralizable Carbon and Microbial Biomass

The potential C mineralization (PCM) and microbial biomass C (MBC) in soils were influenced by cover crop treatments, time of soil sampling, and depth. Due to the short duration of the study we did not expect to see major changes in these indicators of microbial activity. At Tifton when the data were averaged across sampling dates, PCM at 0- to 5-cm was greater in blend than in rye but MBC was greater in rye than in crimson clover. In Louisville, the effects of cover crop and cover crop x date of sampling on PCM and MBC were not significant. Averaged across cover crops, PCM at 5- to 15-cm was greater in June 2001 than in June 2003. Similarly, MBC at 0- to 5- and 5- to 15-cm was greater in Jan 2003 than in June 2001.

Table 5. Effects of cover crop species and time of soil sampling on potential C mineralization (PCM) and microbial biomass C (MBC) in soils from Louisville, GA.

	PCM		MBC				
Cover Crop	Date	soil depth (cm)			soil depth (cm)		
		0- to 5-	5- to 15-		0- to 5-	5- to 15-	
Rye	Jun-01	224	102		273	136	
	Jun-02	182	104		327	151	
	Jan-03	176	82		317	185	
Blend		Jun-01	170	110		224	117
	Jun-02	192	98		273	151	
	Jan-03	210	92		361	219	
Blend + rye		Jun-01	212	112		244	117
	Jun-02	214	100		273	137	
	Jan-03	246	80		351	185	
No cover crop			Jun-01	196	108		253	122
	Jun-02	196	102		317	151	
	Jan-03	204	72		370	205	
LSD (0.05)			76	40		146	68
Means							
Rye		194a†	96a		306a	158a	
Blend			191a	100a		286a	162a
Blend + rye			224a	97a		289a	146a
No cover crop				199a	94a		313a	159a
Jun-01			201a	108a		249b	123b
Jun-02			196a	101ab		298ab	148b
Jan-03			209a	82b		350a	199a

† Numbers followed by different letter within a column of a treatment are significantly different at P  0.05 by the least square means test.

The results showed that active fractions of soil organic matter, such as PCM and MBC, were influenced by residue quality, quantity, placement, and soil and environmental conditions. Warming soil temperatures during March and April could have increased soil microbial activities, thereby increasing PCM and MBC. However, increased PCM and MBC in the spring varied by cover crop species, soil depth, and year. Factors, such as quality (C/N ratio), and depth of incorporation of residue and difference in rainfall and temperature in the spring in 2001 and 2002 could have influenced decomposition rate of residue in the soil and influenced labile pools of C. Overall it appeared that the blend cover crop can increase soil microbial activities compared with rye, which thereby should improve soil quality.

Table 6. Effects of cover crop species and time of soil sampling on potential C mineralization (PCM) and microbial biomass C (MBC) in soils from Thompson farm in Tifton, GA.

	PCM		MBC				
Cover Crop	Date	soil depth (cm)			soil depth (cm)		
	0- to 5-	5- to 15-		0- to 5-	5- to 15-		
Rye Apr-01	197	144		307	219		
Mar-02	255	140		343	183		
Dec-02	158	102		304	212		
Blend	Apr-01	372	213		432	238	
Mar-02	377	186		432	227		
Dec-02	218	147		366	260		
Blend + rye	Apr-01	312	183		344	241	
Mar-02	251	129		315	194		
Dec-02	221	135		337	245		
Crimson clover		Apr-01	273	176		263	169
Mar-02	383	203		337	252		
Dec-02	210	135		336	267		
LSD (0.05)		68	38		88	48	
Means							
Rye	203c†	129b		318b	205b		
Blend		322a	182a		410a	242a	
Blend + rye		261b	149b		332b	227ab	
Crimson clover			289ab	171a		312b	229ab
Apr-01		289a	179a		337a	217b	
Mar-02		316a	164a		357a	214b	
Dec-02		201b	130b		336a	246a	

† Numbers followed by different letter within a column of a treatment are significantly different at P  0.05 by the least square means test.

On Station and Greenhouse Studies

Cover Crop Effect on Southern Root-Knot Nematode Populations

We evaluated whether reproduction of southern root-knot nematode on winter cover crops was great enough to potentially affect cotton yield in replicated greenhouse and field studies using the following cover crops: Wrens Abruzzi rye, AU Sunrise crimson clover, Early hairy vetch, Cahaba vetch, and Hairy vetch. We found that that most of the legumes (clovers and vetches) tested were good hosts for the southern root-knot nematode. In the greenhouse, AU crimson clover, Early hairy vetch, and Hairy vetch were good hosts for nematode reproduction, whereas rye and Cahaba vetch were poor hosts. The number of nematode eggs found in the rye and Cahaba vetch soil was less than 10% of the eggs in the Hairy vetch treatment. In both years of the field experiment (2002 and 2003) in Tifton, temperatures were warm enough during the winter to accumulate sufficient degree days to complete at least two nematode generations. In the field study, cotton grown following Hairy vetch and Early hairy vetch had greater nematode root galling than cotton grown on winter fallow plots. Rye, Cahaba vetch, and AU crimson clover did not increase root galling in cotton. Cotton yields were also reduced following Early hairy vetch and hairy vetch compared to yields following a no cover crop winter fallow. If growers are concerned about the southern root-knot nematode, then winter cover crops of either rye or Cahaba vetch should have a lower risk of building up damaging nematode populations than nematode-susceptible legume crops.

Cover Crop Growth Studies – Searching for alternatives for the blend

Several cover crops (varieties of rye, clover and vetch and several mixtures of legumes) were evaluated for biomass and bloom characteristics at Fort Valley and Watkinsville in 2002

and 2003. At Fort Valley in 2002 and 2003 the rye variety, Wrens Abruzzi, provided highest biomass yield during each harvest date (Table 7). Balansa clover failed to grow at this location. Among legume cover crop mixtures, two clover only treatments provided highest biomass yield in harvest 1, while two different mix treatments of clover and vetch were highest during harvest 2 and 3. Among single legume treatments, highest biomass yield in harvest 1 and 3 was produced by Crimson clover and in harvest 2 Hairy vetch was highest. Lowest biomass yield among rye plots were produced by AC RT 178 in harvest 1 and AC-Rifle in harvest 2 and 3. Also, these two rye cover crops produced lowest plant height. Among single cover crop treatments, percent flowering was best for Crimson clover, Early Crimson, and Wrens Abruzzi, while Cahaba vetch and AC RT 178 produced the worst. Wrens Abruzzi produced highest stand percentage, while Ball clover produced lowest.

At Watkinsville, results were only available for 2003 because of background levels of hairy vetch in the 2002 plots (Table 8). Like the results from Fort Valley, Wrens Abruzzi rye produced the most biomass (3995, 7441, and 8353 kg ha-1 for April, May and June, respectively). Of the legumes early crimson clover and early vetch had the greatest biomass (2705 kg ha-1) in April while biomass of Ball clover had the greatest biomass in June (7720 kg ha-1) with similar results for N contents of the clovers. Nitrogen contents of the legumes were generally greater than 120 lb N ha-1 at the May and June sampling dates. Using the rye N content as an indication of soil available N it appeared that the legumes fixed between 30 and 90 kg N ha-1.

Table 7. Cover Crop Evaluation at Fort Valley, Georgia

	2002			2003		
Cover Crop Treatments	April	May	June	April	May	June
Balansa clover (BC)	nd	nd	nd	3318	5367	732
Ball clover (BLC)	1610	3610	1805	2439	5513	2439
BC + CC + Ball clov	3659	3171	3952	5464	6733	2147
BC + CC + BR	5757	4098	4537	4391	4537	1854
BC + CC + CaV	3220	5123	3805	6147	7904	1512
BC + CC + EV	3513	4440	4732	4537	6977	1854
BC + CC + HV	4098	5464	5757	5952	5367	1415
BC + CC + Rose clov	4147	4391	4244	4391	7123	3220
BC + E.C + EV	3757	6537	9123	7660	7367	2488
Berseem clover (BR)	1951	4244	6196	1854	4537	2293
Cahaba Vetch (Ca. vetch)		2683	6391	7806	6001	5171
Crimson clover (CC)		5952	4732	8050	3171	2781
Early Crimson (EC)	4147	3464	5220	3220	2927	1317
Early Vetch (EV)	5513	7172	4537	6440	8684	1805
Hairy vetch (HV)	2830	6733	6733	3952	7952	1854
No Cover	976	2781	2244	0	2586	1464
Rose clover (RC)	2683	5025	4732	2878	8733	3659
Wrens Abruzzi	7708	7904	11416	7367	15270	6098

Table 8. Cover Crop Evaluation at Watkinsville, Georgia

	April			May			June		
Crop	Biomass	N	C:N	Biomass	N	C:N	Biomass	N	C:N
	kg ha-1			kg ha-1			kg ha-1		
Ball Clover (BLC)	3240	124	11	5703	160	14	7720	166	17
Balansa C (BC)	2425	83	12	4831	138	15	6047	140	19
BC+CC+BLC	2705	93	11	5038	145	14	6280	148	17
BC+CC+BR	2165	73	12	4575	116	16	5233	109	21
BC+CC+CV	2240	81	11	4750	133	15	5635	140	18
BC+CC+EV	2220	77	12	4745	130	15	5620	133	20

BC+CC+HV	2120	73	11	3935	127	15	4810	117	18
BC+CC+RC	1900	62	12	3788	91	16	4200	91	22
BC+EC+EV	2805	98	12	5480	153	15	6650	151	20
Berseem (BR)	1770	61	12	2486	69	16	3800	75	21
Crimson Clover (CC)	2220	74	12	4590	127	15	5380	123	20
Comon Vetch (CV)	2145	71	13	4475	113	16	5180	106	23
Early Crimson (EC)	2705	85	13	5115	139	17	6347	141	25
Early Vetch (EV)	2715	111	10	5462	156	14	6373	163	17
Hairy Vetch (HV)	2440	106	10	5015	156	13	6205	161	15
No Cover	2140	62	13	4090	101	18	5140	99	27
Rose Clover (RC)	2290	78	12	4822	132	15	5760	137	20
Wrens Abruzzi Rye	3995	52	35	7441	68	54	8353	59	64

II. Expand producer knowledge of sustainable systems

Our first Field Day event was held April 4th 2001 at the Jefferson County Extension Office in Louisville, GA. There were only 10 producers and county agents at the meeting most likely due to the need for producers to be working in the field. The following presentations were made:

1. SARE Research Overview
2. Cover Crop Effects on Recruitment and Retention of Beneficial Insects in Cotton Fields
3. Cover crops and nematodes in cotton cropping systems
4. Is your system of production building soil quality?
5. Cover crops and soil fertility: what changes do you need to make?
6. Farm Suite - A whole farm planning system to reduce risk

A field trip to one of the producer sites was also made. Even though the number of participants was not large the producers and consultants present represented more than 5,000 acres of land. A preliminary survey was conducted to assess producer knowledge and interests. Results of the survey indicated 1) top issues of concern for producers were crop yields and pest and weed control, 2) producers desire to learn more about soil quality, and 3) many attendees associate soil organic matter as a major component of conservation tillage management.

In the fall of 2002 demonstration plots were planted at the site of the Sunbelt Agricultural Exposition near Moultrie, GA and on-farm near Hawkinsville, GA. At Hawkinsville, cover crops were planted late due to a wet fall that delayed harvest of the summer crops. This combined with the cold weather in December following cover crop planting resulted in poor establishment so these plots were not used for demonstrations. The Sunbelt Agricultural Exposition plots served as the focus of presentations in July and October where over 3000 farmers were given information about the research.

Demonstration plots were planted in the fall of 2003 in Metter, GA, at the Sun Belt Ag EXPO near Moultrie GA, and on two farm locations in Turner County. The Sun Belt Ag EXPO allowed us to reach a number of producers during the summer and fall of 2004. The Metter, GA location was planted for use as a field day demonstration during the Georgia Conservation Tillage Alliance's annual meeting in February 2004. Rain and cold weather interfered with the field day visit to these plots so a handout and discussion of the research was presented to the 50 to 60 producers attending the meeting. The Turner county locations were used as demonstration plots to show potential benefits from improving insect habitat with cover crops in vegetables and were included in a field day organized by Georgia organics in spring of 2004 that was

attended by over 30 producers, NRCS, and Georgia Extension personnel.

We partnered with the Seven Rivers RC&D to broaden outreach from this project to southeastern producers by developing an educational session for the 3rd annual Conservation tillage Conference. The session used the results of our research to present ideas and approaches for improving sustainability using cover crops in conservation tillage systems. There were over 100 farmers at the conservation tillage school in Douglas, Georgia. The presentations were as follows:

1. Sustainability an Issue for Cotton Production
2. Insect Pests and Predators in Conservation-Tillage Cotton with Cover Crops
3. Reproduction of Meloidogyne incognita on winter cover crops used in cotton production.
4. Cover Crop Alternatives with Conservation Tillage

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Tillman, G., H. Schomberg, S. Phatak, B. Mullinix, S. Lachnicht, P. Timper, and D. Olson. 2004. Influence of cover crops on insect pests and predators in conservation-tillage cotton. J. Econ. Entomol. 97: 1217-1232.

Impact of Results/Outcomes

The results from our on-field research in general support our original hypothesis that adding cover crops and increasing diversity of cover crops increases biological activity in producer fields. We saw trends for this in the aboveground insect populations, soil dwelling microarthropods and in soil microbial activity. It is difficult to state that the trends we observed are significant because of the large amount of variability present in our data and that is inherent

in large scale field studies. The legume blend plus rye mixture of cover crops can serve the dual role of providing biomass and also some additional N. We demonstrated that a diverse cover crop cropping system can reduce pesticide application for the control of certain insects in cotton. Year to year variations in pest insect populations will prevent producers from seeing the same results every year. Our results demonstrate that the potential for cover crops to serve as hosts for plant pathogenic nematodes is variable and that cover crops that are not good hosts should be used in areas where nematodes are a problem.

Through the partnerships formed with the Georgia Conservation Tillage Alliance, Seven Rivers RC&D, and Sunbelt Farm Expo we were able to provided information to several thousand farmers about the use of cover crops and the impacts that cover crops can have on nutrients, soil C, pest insects, nematodes and crop yields. We believe that our outreach efforts were effective and successful in promoting sustainable farming practices in the Southeast.

Field Days and Producer Meetings Presentations

2003 Schomberg H.H. Cover Crops and Conservation Tillage Practices in the South" Ohio No- Till Farmers Conference, Plain City, Ohio December 9, 2003

2003 Schomberg H.H., G. Tillman, S. Lachnicht, P. Timper, D. Olson, S. Phatak. Cover crops, insects, and cotton production in conservation tillage systems. Georgia Conservation Tillage Alliance Meeting, Metter, GA February, 2003.

2003 Tillman G., and H. Schomberg. Influence of cover crops on insect pests and predators in conservation-tillage cotton. Presented to 25 groups of producers at Sunbelt Agriculture Exposition Field Day in Moultrie, GA July 2003.

2003 Tillman G., and H. Schomberg. Influence of cover crops on insect pests and predators in conservation-tillage cotton. Presented to producers at Sunbelt Agriculture Exposition Field Day in Moultrie, GA October 2003.

2004 Phatak S. Cover Crop Alternatives with Conservation Tillage. Presented at Sustainable Agriculture/Conservation Tillage: A System Approach Training Conference in Douglas, GA February 10, 2004.

2004 Schomberg, H., S. Lachnicht, G. Tillman, P. Timper, D. Olson, S. Phatak. Sustainability an Issue for Cotton Production. Presented at Sustainable Agriculture/Conservation Tillage: A System Approach Training Conference in Douglas, GA February 10, 2004.

2004 Tillman G., and H. Schomberg. Influence of cover crops on insect pests and predators in conservation-tillage cotton. Presented to 25 groups of producers at Sunbelt Agriculture Exposition Field Day in Moultrie, GA July 2004.

2004 Tillman G., P. Timper, D. Olson, H. Schomberg, S. Lachnicht, S. Phatak. Insect Pests and Predators in Conservation-Tillage Cotton with Cover Crops. Presented at Sustainable Agriculture/Conservation Tillage: A System Approach Training Conference in Douglas, GA February 10, 2004.

2004 Timper. P. Conservation tillage, cover crops, and nematodes. Presented at Sustainable Agriculture and Conservation Tillage: A System Approach Training, Douglas, GA February 10, 2004.

Professional Meetings Presentations

2002 Lachnicht, S.L., H.H. Schomberg, P.G. Tillman. Soil Microarthropods: bioindicators of conservation management practices. IN E. van Santen, ed. Making conservation tillage conventional: building a future on 25 years of research. Proceedings of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture, Auburn, AL, USA, 24-26 June, 2002 p. 255.

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2003 Timper, P., R.F. Davis, and P.G. Tillman. Reproduction of Meloidogyne incognita on winter cover crops used in cotton production. Presented at the Annual Meeting of the Society of Nematologists, Ithaca, NY, July 13-17, 2003. Journal of Nematology 35:367.

2004 Lachnicht, S. L., Schomberg, H. H., Tillman, G. Soil microarthropod community changes under conservation management practices. Agronomy Abstracts. Agronomy Society of America, Soil Science Society of America and Crop Science Society of America Meeting Seattle WA November 2004

2004 Tillman, G., Schomberg, H., Phatak, S., Timper, P., and Olson, D. Influence of cover crops on insect pests and predators in conservation-tillage cotton. Presented at 26th Ann. Southern Conservation Tillage Conf. for Sustainable Agriculture, Raleigh, NC, June 2004.

Journal Publications

2003 Schomberg, H., J. Lewis, G. Tillman, D. Olson, P. Timper, D.Wauchope, S. Phatak and M. Jay. Conceptual model for sustainable cropping systems in the southeast: cotton system. J Crop Production Volume 8, Issue 1-2, 2003, Pages 307-327

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2004 Tillman, G., H. Schomberg, S. Phatak, B. Mullinix, S. Lachnicht, P. Timper, and D. Olson. 2004. Influence of cover crops on insect pests and predators in conservation-tillage cotton. J. Econ. Entomol. 97: 1217-1232.

Farmer Adoption

We have no data on farmer adoption. However one of the producers working with us on the project was so impressed with the performance of his cotton following crimson clover that he planted a substantial number of acres to that cover crop in the fall after the first year of the study. The system that we were working in is an extension of previous work conducted by Dr. Phatak and his colleagues. Their efforts have resulted in a significant amount of conservation tillage with cover crops in the South Georgia area. Our research hopefully has reinvigorated the enthusiasm of producers in the area and will help to sustain the increase in conservation tillage and cover crops in the region.

Areas Needing Additional Study

Many areas of the research raised questions. Longer term studies are needed to determine if population shifts occur in soil and aboveground insects. Longer studies are needed to determine soil improvement effects. Short term, we need to determine, what is the appropriate ratio of legume to rye needed in mixtures to achieve a beneficial effect? What planting pattern might best be used to achieve an effect? Can cover crops and conservation tillage promote a change in the soil biological community that eventually overcomes plant parasitic nematodes? On the sociological side which barriers can be overcome by education of producers about benefits of conservation systems and which barriers remain that have to be addressed through farm programs and subsidy payments?