Using Winter Annual Cover Crops in a Virginia No-till Cotton Production System

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Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in
Crop and Soil Environmental Sciences

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December 1, 1997
Blacksburg, Virginia

Key words: cotton, no-till, cover crop, biomass, ground cover, soil moisture, yield, quality.

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(ABSTRACT)

Cotton (Gossypium hirsutum L.) is a low residue crop, that may not provide sufficient surface residue to reduce erosion and protect the soil. A winter annual cover crop could alleviate erosion between cotton crops. Field experiments were conducted to evaluate selected winter annual cover crops for biomass production, ground cover, and N assimilation. The cover crop treatments were monitored under no-till and conventional tillage systems for the effects on soil moisture, cotton yield and quality. Six cover crop treatments, crimson clover (Trifolium incarnatum L.), hairy vetch (Vicia vilosa L.), hairy vetch and rye (Secale cereale L.), rye, wheat (Triticum aestivum L. amend. Thell.), and white lupin (Lupinus albus L.), and two tillage systems (conventional and no-till) were arranged in a split-plot design with four replications. Cover crop biomass production depended on climate conditions. Ground cover percent and N assimilation by cover crops were directly correlated with the amount of biomass produced within cover crop treatments. Within a range of near average winter temperatures, all cover crops except lupin provided enough ground cover to comply with federal conservation tillage standards. More ground cover remained on the soil surface further into the cotton growing season following the small grain treatments compared to the legume cover crop treatments. Soil moisture was higher (P < 0.05) under no-till compared to conventional tillage during the periods of drought in 1997. Tillage system had no effect on cotton yield and quality in 1995 and 1996. High cover crop biomass production coupled with an extended cotton growing season in 1995 resulted in higher lint yield for cotton grown following the hairy vetch + rye treatment compared with cotton grown following the wheat treatment. High heat unit accumulation in October 1995 led to the over maturity of cotton fiber and high micronaire values for cotton grown following all cover crop treatments. The high micronaire values (5.0 - 5.2) for cotton grown in all cover crop
treatments except hairy vetch + rye (4.9), resulted in a market price deduction of 1.4 cents per kilogram of lint in 1995. All cover crops used in this experiment, with the exception of lupin, provided enough ground cover within a range of average winter temperatures to meet federal conservation requirements. The winter annual cover crops in a no-till cotton production system provided greater soil moisture conservation during periods of drought, and produced cotton yields and quality comparable to conventional tillage.
ACKNOWLEDGMENTS

I wish to express my deepest appreciation to my advisor Dr. A. Ozzie Abaye, for her continuous support, guidance, understanding, and patience throughout my graduate study. I will always be grateful to her for the time she invested into my development as a graduate student, and her promptness in reviewing this manuscript. I would also like to thank Dr. Marcus M. Alley and Dr. James C. Baker for their guidance, input, and encouragement as members of my graduate committee.

A special thanks is extended to Wesley Adcock for his continuous assistance with the field and office work related to my research project. I am grateful to Rajiv Khosla for his help calibrating the soil moisture probe and to Dr. Lee Daniels for the use of his Troxler Sentry 200-AP soil moisture probe. I would like to thank Nicole Fomchenko for her continuous support during the preparation of this thesis.

I am grateful to James C. Maitland (cotton extension specialist), Bill Wilkinson (farm manager), and the farm staff at the Southern Piedmont Agricultural Research and Extension Center for the management, scouting, and data collection during the various stages of this study.

I am grateful to my parents and family, whom I love and respect, for their support throughout the extent of my education. With their encouragement and blessings I was able to successfully accomplish my educational goals.

The financial support of the Virginia Agricultural Council is greatly appreciated. Completion of this study would not have been possible without this assistance.
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Chapter I

INTRODUCTION

The production of cotton (*Gossypium hirsutum* L.) in Virginia has greatly increased over the past eight years. In 1988 approximately 1,377 hectares of cotton were planted in Virginia; in 1995 that figure had risen to more than 43,000 hectares (Virginia Cooperative Extension, 1996). Currently, cotton is mostly grown in the southeastern coastal plain region of Virginia. The expansion of cotton production in Virginia stems from high cotton prices, cotton’s ability to tolerate drought stress, and improved varieties well suited to Virginia’s climate.

The increase in cotton production has provided a new cash crop for producers in this region of Virginia. When a new crop enters a region, a suitable cropping system must be developed. As the acreage expands in Virginia, some of the land used for the production of cotton is not suitable for conventional tillage. The use of no-till practices complimented with a winter cover crop, allows for row crop production of cotton while complying with Virginia’s Code 329, conservation tillage program (Bauer and Busscher, 1996; NRCS, 1992). A no-till system can produce cotton yields comparable to conventional tillage while providing many environmental benefits protecting soil and maintaining water quality (Smart and Bradford, 1996; Meisinger et al., 1991). Increased organic matter improves soil tilth, cation exchange capacity, and increases water holding capacity while winter cover crops also reduce leaching of residual soil N into the ground water (Bradley, 1995). For a better understanding of no-till cotton production in Virginia, a study was conducted at the Southern Piedmont Agricultural Research and Extension Center in Blackstone, Virginia. The overall objective was to examine the influence of various cover crops and tillage practices (conventional vs. no-till) on the yield and quality of cotton. The specific objectives were:

1. To evaluate winter annual cover crops for percent ground cover and biomass production.
2. To assess N assimilation by selected winter annual cover crops.
3. To measure the effects of cover crops and tillage systems on soil moisture content.
4. To measure the influence of cover crops and tillage systems on cotton yield and quality.
Chapter II

LITERATURE REVIEW

Cotton

Modern, commercially-cultivated varieties of upland cotton (*Gossypium hirsutum* L.) originated from southern Mexico, Guatemala, northern South America, and the West Indies (McWhorter and Abernathy, 1992; Elliot et al. 1968). Many species of *Gossypium* are found growing wild in the native habitat, varying in morphology from bushy shrubs to woody trees exceeding 6 m in height (Smart and Simmonds, 1995). Perennial by nature, with an indeterminate growth habit, cotton is managed agriculturally as an annual crop. Through genetic selection, breeders have developed varieties with determinate growth habits resulting in early crop maturity (Eaton, 1955). These short season varieties are important to the northernmost cotton producing areas which are limited by the length of the growing season.

Cotton Production in Virginia

Cotton production in Virginia has fluctuated tremendously over the past 100 years. The most cotton ever planted in one year in Virginia was 45,765 hectares in 1924 (VASS, 1997). In 1978 the state cotton crop was only 40.5 hectares. Virginia is located in the far northern part of the cotton belt which limits the length of the growing season, but improvements in short-season cotton varieties provide competitive yields. By 1992 cotton production had risen to 1,377 hectares with the capability of rapid expansion. The decrease in profitability of corn and soybeans and the high market price for cotton influenced many farmers in southeastern Virginia to start producing cotton. Cotton’s drought tolerant capability adapted well in this region with hot summer temperatures and sandy soils. With four cotton gins built in the region, Virginia’s cotton acreage dramatically increased to over 43,335 hectares by 1995 (Virginia Cooperative Extension, 1996).
Currently, over 40,500 hectares of cotton are produced annually in Virginia. The rapid expansion of agricultural land in cotton production in the southeastern part of the state came with changes. Some of the land used for corn and soybean production is now planted in cotton. The strong increase in state cotton production initiated cotton management and production research for this northern edge of the cotton belt. Profitable production of cotton also attracted the interest of producers in the southern piedmont region of Virginia.

Southern piedmont topography confines agricultural production to smaller fields with significant slopes which are not well suited for cotton production. The cultivation techniques associated with conventional tillage cotton coupled with the sloping topography, potentially results in erosion rates detrimental to soil productivity. Federal government soil conservation requirements often do not allow agricultural row crop production, using conventional tillage methods, on these highly erodible fields.

**Federal Conservation Requirements**

The Food Security Act of 1985 established law to promote the conservation of soil on crop land classified as highly erodible (United States, 1985). Revisions to further define and help enforce the conservation regulations were made in the Food Security Act of 1990 and 1995. The Natural Resource Conservation Service (NRCS) was the federal agency tasked to enforce the conservation standards on agricultural producers on the state and local level. The NRCS defined and published conservation tillage standards in conservation tillage Code 329. NRCS standards require 60% ground cover remaining on the soil surface after cotton planting for no-till practices and 30% ground coverage after cotton planting for minimum tillage practices (NRCS, 1992).

In many cases a change from conventional tillage to no-till is necessary to continue row crop production on these sloping piedmont soils, to decrease erosion for compliance with federal conservation requirements (McGregor et al., 1975). Research indicates the use of winter annual cover crops in a no-till cotton production system as an
economically feasible approach to control soil erosion problems (Bloodworth and Johnson, 1995; Denton and Tyler, 1994; Holderbaum et al., 1990). Additionally, Bauer and Busscher (1996) found that winter annual cover crops can provide the required surface residue to comply with the NRCS conservation tillage Code 329 standards. The movement toward conservation of agricultural resources led to advances in conservation tillage equipment, and the development of herbicides to further control weeds in conservation tillage and no-till systems (Banks, 1992). These advances led to the increase in conservation tillage cotton production in many areas of the United States.

**Cover Crop Biomass Production**

The use of winter cover crops in a no-till cotton production system can enhance soil productivity (Meisinger et al., 1991). Beneficial effects on soil and water in an agricultural system depends on the amount of biomass produced by the cover crop and the management of this residue on the soil surface (Munawar et al., 1990). Using cover crops in a no-till system leaves the soil surface relatively undisturbed allowing for slow residue decomposition which adds organic matter to the soil (Boquet et al., 1994). Utomo et al. (1987) reported a significant increase of total organic matter in the top three inches of soil in a no-till system compared to a conventional tillage system. After many years of conservation tillage research in Tennessee, Bradley (1995) reported that additions in organic matter improve soil tilth, moisture holding capacity, and cation exchange capacity. Other researchers agree that the additions of organic matter to the soil system improves the soil physical properties such as aeration and drainage, water infiltration and retention, and the ability of the soil to retain and supply nutrients to crops (Breitenbeck and Hutchinson, 1994; Hargrove and Frye, 1987). In addition, reduced tillage systems provide more timely field operations in the early cotton season helping to ensure the timely planting of cotton (Boquet and Coco, 1991). Cover crop residue also provides protection by insulating the cotton seedlings and lowering wind speeds in the plant canopy during early season cool temperatures (Stevens et al., 1996).
Soil Moisture Conservation

Cover crops and tillage systems can be managed to conserve soil moisture for crop use throughout the growing season. Organic matter inputs to the soil influence soil aggregate properties increasing the ability of the soil to store moisture for crop extraction (Bordovsky et al., 1994). Sullivan et al. (1991) found that no-till resulted in higher levels of soil moisture when compared to conventional tillage, and the more biomass produced by the cover crops the greater the soil moisture retention throughout the soil profile. The increased organic matter at the soil surface reduces crusting which aids in water infiltration, enabling the soil profile to be more effectively used for water storage (Baumhardt et al., 1993; Busscher and Bauer, 1993; Mosely et al., 1996; Reeves et al., 1996).

The pattern of water withdrawal changes when comparing a conventional tillage system to a no-till system (Blevins et al., 1971). Decreased soil water evaporation in a conservation tillage system, increases the amount of soil water available for crop transpiration (Lascano et al., 1994). Moisture conservation benefits from a no-till system are greatest in the early growing season and last until full cotton canopy (Hill and Blevins, 1973). Evaporation of soil moisture is directly affected by surface mulch. Brun et al. (1986) reported that initial evaporation from a bare soil is 25% greater than that from a stubble-covered surface. However, Bond and Willis (1969) reported after the continuous drying of soil following a rainfall event, the cumulative evaporation of moisture was nearly equal regardless of surface residue. The drying time varied from 5 to 30 days depending on the amount of straw residue (0 to 6,720 kg/ha) left on the soil surface (Bond and Willis, 1969). Unger and Parker (1976) conducted a study comparing water evaporation from the soil under wheat, sorghum, and cotton residues. They concluded that 16 metric tons/ha of sorghum residue and 32 metric tons/ha of cotton residue was needed to reduce soil water evaporation equivalent to that of 8 metric tons/ha of wheat residues. Cumulative evaporation was strongly influenced by residue thickness, but residue surface coverage and specific gravity also had an effect (Unger and Parker, 1976).
Ground Cover Provided By Cover Crop Residue

The amount of cover crop biomass produced and the management of this residue on the soil surface determines the percent ground cover. Cotton is considered a low residue crop, that may not provide sufficient surface residue to reduce erosion and protect the soil. Surface residue is the critical factor in controlling erosion on agricultural land (Hofmann et al., 1983). Soil is subject to water erosion by soil particle detachment by runoff water, or by particle detachment from direct and indirect rainfall splash (Singer et al., 1981). Edwards and Burney (1991) found that cover crop residue remaining on the soil surface intercepts falling rain drops decreasing the disruption and erosion of soil particles. Singer et al. (1981) concluded that the transport of soil particles by surface flow decreases as the amount of surface residue increases from 0 to 96%. Jones et al. (1969) reported that ground cover residue provides soil water conservation. Surface residue slows the velocity of runoff and allows for greater infiltration of water into the soil surface by 25 to 50% compared to a conventional tillage system (Naderman, 1991). These benefits of cover crops and no-till can protect the soil against erosion and allow row crop production on sloping upland soils (McGregor et al., 1975).

Ground cover associated with cover crop residue provides benefits to the large, flat, open fields in the coastal plain. The soils of southeastern Virginia are composed of coarse textured, sandy loam and loamy sand surface horizons. The large, flat, open production areas are susceptible to wind erosion. Blowing sands in early season wind storms physically damage the cotton seedlings and is known as “sand-blasting.” By planting cotton into surface residue the cotton is given protection from blowing sands which can damage and sometimes kill the young seedlings (Banks, 1992; Barker et al., 1989; Stevens et al., 1996).

Cover Crop Selection and Management

Selecting the best crop species for use as a cover crop depends on the needs of the agricultural system. A cover crop must be adaptable to location, soil type, and climate for optimum growth and production of biomass. If the cover is just used for soil
conservation and nutrient cycling then a grass species may be best (Shipley et al., 1992). To decrease the cost of inorganic fertilizer-N a legume can be planted to provide N for the following summer annual crop (Thompson and Varco, 1996). In terms of costs for establishment and management, legumes are much more expensive to establish and sometimes more difficult to chemically kill compared to small grains (O’Brien-Wray, 1995; Stevens et al., 1992). Regardless of the cover crop used, careful planning is needed in selecting and managing a cover crop for maximum beneficial effects.

Three factors affecting residue management are cover crop growth rate, stage of growth, and the length of the growing season (Power and Koerner, 1994). It is very important to seed the cover crop during the recommended planting period to help insure good stand establishment and growth before the onset of cold winter temperatures. Sometimes cotton harvest stretches into November and it is necessary to inter-seed the cover crop into standing cotton to ensure time for establishment and growth before winter. Keeling et al. (1996) researched selected cover crops for fall inter-seeding into standing cotton and found wheat, rye, Austrian winter pea, and hairy vetch to be the most dependable for providing good ground cover. The length of the growing period and the cover crop growth stage is important because this affects the C:N ratio, and the amount of N assimilated in the biomass at the time of desiccation. Legumes usually have a low C:N ratio which results in rapid biomass decomposition and release of N to the soil system (Hargrove, 1986). Small grain cover crops however, have higher C:N ratios leading to persistent surface residues which potentially immobilize soil N (Sullivan et al., 1991). Ranells and Wagger (1997) researched the use of a small grain/legume (rye/hairy vetch) combination for a cover crop with a seeding rate of 56/22 kg/ha. During cover crop decomposition the relatively low small grain/legume C:N ratio of < 30 allowed for N additions to the following summer annual crop.

Cover crops are used to increase moisture throughout the soil profile after cotton planting, but before the cover crops are desiccated they can deplete the soil of moisture and cause early season droughty conditions for cotton seedlings. Extending the growing
period allows for greater biomass yield, but this benefit is usually offset by soil moisture depletion (Munawar et al., 1990). It is recommended to kill cover crops two to three weeks prior to cotton planting to allow for soil water accumulation and guard against competition for water and nutrients. Early cover crop desiccation may be necessary to control biomass growth. If cover crop residue is too dense at cotton planting, the residue could disrupt soil to seed contact and decrease stand establishment. Cover crops can be a valuable tool used in conservation tillage, but without proper planning and management cover crops can cause problems in cotton production.

**Nitrogen Assimilation**

Cover crops are also used for better N management in agricultural production systems. Fall-seeded legumes, such as hairy vetch or crimson clover, can supply large amounts of N for the following summer annual crop (Blevins et al., 1990; Sullivan et al., 1991). Legume N inputs can reduce the amount of fertilizer N needed by the following cotton crop, therefore decreasing input costs of inorganic fertilizers (Boquet et al., 1994; Holderbaum et al., 1990). The N assimilated in the legume biomass is derived from residual soil N (NO$_3^-$ + NH$_4^+$), and N$_2$ fixed by rhizobia associated with the legume. Munawar et al. (1990) reported the decomposition of legume cover crop biomass and the release of assimilated N is faster compared with small grains due to legumes having a lower C:N ratio (depending on plant growth stage). Although legume N may decrease the amount of fertilizer N needed by the cotton crop, untimely mineralization and release of legume N may not match the needs of the cotton crop. This random N supply could lead to delayed maturity and excessive late-season cotton growth.

In addition to legumes being used to supply N to the cotton crop, small grains are used to assimilate residual soil N in cover crop biomass (Shipley et al., 1992). The effectiveness of a cover crop species on N assimilation can be based on characteristics such as rooting depth, persistency throughout the winter, N accumulation by the plant, and depletion of the soil N pool in the spring (Thorup-Kristensen, 1994). Small grains, such as wheat and rye, are more effective scavengers for soil NO$_3^-$ than legume cover
crops (Groffman et al., 1987). Breitenbeck and Hutchenson (1994) reported an increase in N content of wheat cover crop biomass with an increase in the amount of N fertilizer previously applied to cotton. The N in these non-leguminous small grain cover crops is strictly from residual soil N ($\text{NO}_3^- + \text{NH}_4^+$) supplies. The accumulation of N in the small grain biomass effectively protects water quality by decreasing the amount of soil N susceptible to leaching from the soil and contaminating surface and ground waters during winter and spring months (Clark et al., 1994). Grasses are two to three times more efficient in reducing N leaching compared to legumes (Meisinger et al., 1991). Small grain cover crop residues act as a N sink more than a N source for the cotton (Azevedo et al., 1996). After the cover crop is killed in the spring the stalky, straw residue of small grains is very persistent and decomposes slowly. The high C:N ratio of small grains, slows decomposition of surface residue and potentially immobilizes soil N (Sullivan et al., 1991).

**Cotton Yield and Quality**

The effect of a conventional tillage system compared to a conservation tillage system on cotton yield and quality varies by location, yearly climate, management, and the type of cover crop species used. Certain benefits associated with a no-till production system, such as conservation of soil moisture, generally has positive effects on cotton yield (Burnett and Fisher, 1954). Although cotton is taprooted and is considered drought tolerant, a certain amount of moisture is critical for producing high yielding, good quality cotton. Stored soil moisture is often a limiting factor in dryland cotton production (Azevedo et al., 1996). Drought stress on cotton has been linked to yield decreases due to reduced size and production of sympodial leaves (leaves on branches opposite the boll), in addition to reduced photosynthetic rates. These plant reactions during drought stress limit the amount of photosynthetic assimilate available for growth each day (Krieg, 1997). By using a no-till system, surface residue conserves soil water resources for greater use efficiency by the cotton plant (Hill and Blevins, 1973).
Burnett and Fisher (1954) reported that moisture in the top 30 cm of soil is important for crop establishment, but cotton yields are more directly correlated with moisture stored between 30 and 90 cm below the soil surface. From the beginning of the growing season until the cotton canopy shades the middle of the rows, the soil surface is unprotected and vulnerable to moisture evaporation. Water availability between pinhead square (PHS) and first flower (FF) affects the maximum boll load capacity of the cotton crop (Lawlor et al., 1992). If drought stress develops during the fruiting period, a disruption of carbohydrate flow in the cotton plant occurs, reducing the potential fruiting capacity of the crop (Riney et al., 1997). By using cover crops for ground cover, soil water evaporation decreases and allows for greater crop transpiration (Lascano et al., 1994). With increased soil moisture reserve cotton may endure short-term low rainfall conditions without detrimental effects (Blevins et al., 1971). Lawlor et al. (1992) found a 50% increase in square development and higher fruit retention during the early cotton season under reduced tillage systems compared to conventional tillage systems. Previous research studies conclude that using cover crops in a reduced tillage cotton production system increased available soil water and led to higher cotton lint yields compared to conventional tillage systems (Bordovsky et al., 1994; Hill and Blevins, 1973; Moseley et al., 1996). Planting cotton into dense cover crop residue has also been shown to protect young cotton plants from high winds and blowing sand and to result in higher yields (Barker et al., 1989; Stevens et al., 1996). Regardless of moisture conservation other researchers have continuously found that using cover crops in a conservation tillage system successfully maintains or increases cotton yields compared to conventional tillage (Bloodworth and Johnson, 1995; Boquet et al., 1994; Bradley, 1995; Smart and Bradford, 1996). In addition, Bauer and Busscher (1996) found that cotton lint quality was not affected by tillage system or winter cover, but a 0.1 decrease in micronaire was observed in cotton behind rye compared to legumes.

**Tillage System Expense Comparison**

The use of cover crops in a no-till cotton production system improves soil productivity, decreases erosion, and helps prevent ground and surface water
contamination, but if profits decrease agricultural producers would be reluctant to adopt these practices. Sources of expense differ between conventional and conservation tillage systems. Producers fear the additional expenses associated with cover crop establishment and increased chemical usage for pest control in no-till systems. Paxton et al. (1993) conducted a complete economic analysis on the costs associated with production and management practices associated with conventional tillage and no-till cotton production using winter wheat as a cover crop. Total production costs were increased $12.15/ha for no-till compared to the conventional tillage system. The largest difference was a $10.13/ha increase in herbicide expense for weed control in no-till cotton. On the other hand, Bloodworth and Johnson (1995) and Barnett and Stevens (1996) found that no-tillage decreased production costs compared to conventional tillage by $5.08 and $13.73/ha, respectively. Researchers emphasize that by adopting a conservation tillage production system, time and labor expenses decrease by eliminating seedbed preparation and the need for large, high-powered cultivation equipment (Bloodworth and Johnson, 1995; Smart and Bradford, 1996). Burt et al. (1994) reported a 50 % reduction in energy use when planting cotton strip-till (in-row subsoiling and planting) into desiccated cover crop residue compared to conventional tillage (disking, field cultivating, in-row subsoiling, and planting).
REFERENCES


Chapter III

Using Winter Annual Cover Crops in a Virginia No-till Cotton Production System: Biomass Production, Percent Ground Cover, and Nitrogen Assimilation

ABSTRACT

Cotton (Gossypium hirsutum L.) is a low residue crop that may not provide sufficient surface residue to reduce erosion and protect the soil. A winter annual cover crop could alleviate erosion between cotton crops. This experiment was conducted to evaluate selected winter annual cover crops for biomass production, percent ground cover, and N assimilation. Six cover crop treatments, crimson clover (Trifolium incarnatum L.), hairy vetch (Vicia vilosa L.), hairy vetch and rye (Secale cereale L.), rye, wheat (Triticum aestivum L. emend. Thell.), and white lupin (Lupinus albus L.), and two tillage systems (conventional and no-till) were arranged in a split plot design with four replications. Percent ground cover estimation measurements were taken in spring before cover crop desiccation, immediately after cotton planting, and 50 days after cotton planting. Hairy vetch + rye, rye, and wheat consistently provided the most ground cover after cotton planting, while lupin consistently provided the least ground cover. All cover crop treatments, with the exception of lupin, provided enough ground cover (>30%) after cotton planting to comply with Natural Resource Conservation Service conservation standards, except during years with below normal winter temperatures. Fifty days after cotton planting the small grain residues provided more (P < 0.05) ground cover compared to the legume residues. Averaged over the three experimental years, biomass production from the different cover crop treatments ranged from 946 to 3,047 kg/ha. The average amount of N assimilated by cover crops ranged from 32 to 78 kg N/ha, and was closely related to the amount of cover crop biomass produced. Growth and biomass production of cover crops was greatly affected by the climate conditions during each season.
INTRODUCTION

Cotton is grown on approximately 42 thousand hectares annually in Virginia. The production area has increased four fold since 1993. Although most of the cotton is grown in the coastal plain, cotton acreage is increasing in the southern piedmont region. The southern piedmont topography confines agricultural production to smaller fields with significant slopes which are not well suited for cotton production. Cotton is considered a low residue crop that may not provide sufficient surface residue to reduce erosion and protect the soil. Denton and Tyler (1994) reported the use of winter annual cover crops in a no-till cotton production system as an economically feasible approach to control soil erosion problems. Winter annual cover crops can provide the required surface residue to comply with the Natural Resource Conservation Service (NRCS) conservation tillage Code 329 standards (Bauer and Busscher, 1996). NRCS standards require 60 % ground cover remaining on the soil surface after cotton planting for no-till practices and 30 % ground coverage after cotton planting for minimum tillage practices (NRCS, 1992(a)).

In addition to erosion control, cover crops can enhance soil productivity and sustain water quality. After many years of conservation tillage research in Tennessee, Bradley (1995) states that cover crops supply significant amounts of organic matter to the soil and over time improve soil tilth, moisture holding capacity, cation exchange capacity, and overall productivity of the soil. Surface residues slow the velocity of runoff water and enhance infiltration and percolation of water via improved soil structure (Moseley et al., 1996). Cover crops assimilate N into plant biomass reducing the potential leaching of nutrients and contamination of surface and ground water (Meisinger et al., 1991). Thompson and Varco (1996) reported that leguminous cover crops can biologically fix N needed for the following cotton crop, decreasing fertilizer expenses. Small grain cover crops recycle residual soil nutrients from the previous growing season (Breitenbeck and Hutchinson, 1994). Smart and Bradford (1996) found in addition to protecting the soil and water by using a conservation tillage system, fuel, labor, equipment expenses, and
time are saved by eliminating seedbed preparation and the need for large, high-powered cultivation equipment.

The magnitude of the beneficial effects from the cover crops depends on the amount of biomass produced by the cover crop (Holderbaum et al., 1990). Munawar et al., (1990) reported that the amount of biomass (kg/ha) produced by cover crops and the distribution of the residue remaining on the soil surface is important to the effectiveness of the conservation tillage system. Biomass production directly affects soil properties and water quality in an agricultural system. If the amount of cover crop biomass is too thick it may interfere with proper seed to soil contact at cotton planting. Without proper equipment adjustments this can result in decreased emergence and poor stand establishment. Smart and Bradford (1996) found that planting cotton into surface residue decreases wind speeds and gives protection from blowing sands which can damage and sometimes kill the seedlings. Cover crop residue also provides protection by insulating the cotton seedlings from cool temperatures of the early growing season (Stevens et al., 1996). The objectives of this study include evaluation of different winter annual cover crops for biomass production, percent ground cover, and N assimilation under central Virginia piedmont soil and climate conditions.
METHODS AND MATERIALS

A field study was conducted during 1995, 1996, and 1997 at the Southern Piedmont Agricultural Research and Extension Center, in Blackstone, Virginia. The soil type at the site was a Mayodan, sandy loam (clayey, kaolinitic, thermic Typic Hapludult) for 1995 and 1996, and a Dothan-Norfolk, sandy loam (fine, loamy, siliceous, thermic Plinthic and Typic Paleudults) for 1997. The experimental design used was a split plot with four replications. The main plot treatments were cover crops and the sub-plots consisted of two tillage practices (conventional and no-till). Plots were 4.27 m wide and 7.63 m long with 4 rows and 1.1 m between the rows. The cover crop treatments were crimson clover (*Trifolium incarnatum* L.), hairy vetch (*Vicia vilosa* L.), hairy vetch and rye (*Secale cereale* L.), rye, wheat (*Triticum aestivum* L. emend. Thell.), and white lupin (*Lupinus albus* L.). Seeding rates were 56 kg/ha for crimson clover and hairy vetch, 28 and 112 kg/ha for the hairy vetch/rye mixture, and 224 kg/ha for wheat, rye, and lupin. The recommended seeding rates were doubled to ensure stand establishment. The cover crops were planted in the fall on 3 Oct. 1994, 11 Oct. 1995, and 29 Oct. 1996. In the fall of 1994 and 1995 the field was plowed, the no-till plots were bedded, the cover crop treatments were broadcast, and all plots were rolled with the culti-packer. In 1996 cover crops were planted the same except all plots were planted on flat ground.

In the spring, shortly before chemical desiccation of cover crops, percent ground cover was estimated, and cover crop biomass samples were taken from conventional and no-till plots. Percent ground cover estimation for each cover crop treatment was determined using the NRCS line transect method (NRCS, 1992(b)) modified for the size of experimental plots. Ground cover measurements were taken each year immediately after cotton planting, and in 1997 additional measurements were taken prior to chemical desiccation and fifty days after cotton planting. Biomass samples were obtained at ground level (2.5 cm height) within a 0.25 m² quadrat to measure cover crop biomass yield (kg/ha). The samples were dried in a forced air oven at 60 °C, ground, sieved (1
mm screen), and analyzed for total N. Approximately 3 weeks prior to the estimated cotton planting date, the conventional tillage plots were mowed and disked while the no-till plots were desiccated with glyphosate (2.24 kg/ha). The no-till plots received an additional burndown herbicide application when it was needed (Table 1). One week after the second burndown application the cotton (cultivar DLP 50) crop was planted at the rate of 16.4 seeds per m of row (Table 1). Cotton was planted using a 4 row no-till planter equipped with a fluted coulter to cut through surface residue followed by a double disk opener to make a furrow for the seed, and press wheels to firmly cover the seed with soil. At planting, aldicarb (granular insecticide) and metalaxyl (granular fungicide) were applied in-furrow at 5.6 and 11.2 kg/ha, respectively. Fertilizer N, P, K and B according to soil test recommendations was broadcast on no-till plots and disked into conventional tillage plots.

**Data analysis**

Analysis of variance was calculated using the SAS software package (SAS Institute, 1993). Effects of treatment (cover crops and tillage), field block, date (when needed), year, and all two and three-way interactions were tested. Mean separations were performed by Duncan’s Multiple Range Test (DMRT), if the ANOVA F-statistic indicated significant effects at the 0.05 probability level (SAS Institute, 1993).
RESULTS AND DISCUSSION

Cover crop biomass production

Data from the three experimental years is shown separately due to year by cover crop treatment interaction, and the tillage treatment had no effect on cover crop growth (P < 0.05). Cover crop biomass yield was highest in 1995, lowest in 1996, and intermediate in 1997 (Fig. 1). Within each year biomass production varied with type of cover crop (treatment effect P < 0.05). In 1995, rye produced the most biomass with 4,600 kg/ha and lupin produced the least with 1,900 kg/ha. Temperature averaged 2.3 °C above normal from November through January with sufficient rainfall, providing for good establishment and growth of cover crops in late fall and early winter (Fig. 2 and 3). After February, the temperature again exceeded the average leading to the high biomass yields in the spring of 1995.

The 1995/1996 growing conditions contrasted greatly to the conditions in 1994/1995. The temperature averaged 1.8 °C below normal from November through March, with January being the coldest month averaging 1.1 °C. Excessive rainfall in October, January, and March (Fig. 3) coupled with below average winter temperatures (Fig. 2) led to unusually low biomass yields for all cover crop treatments in 1996 (Fig. 1). The cover crop biomass yield ranged from highest with crimson clover (968 kg/ha) to the lowest with lupin (319 kg/ha). In 1997 hairy vetch + rye and rye yielded higher while lupin yielded lower than all other cover crop treatments (P < 0.05). Biomass production ranged from 4,015 kg/ha of rye to 619 kg/ha of lupin, slightly lower than 1995 and higher (P < 0.05) than 1996.

Winter temperatures during 1994/1995 and 1996/1997 (Fig. 2) were near or above average resulting in high biomass yields (Fig. 1). In contrast, the winter temperatures for 1995/1996 (Fig. 2) were below average from November through March leading to
extremely low biomass yields (Fig. 1). Over the three-year experimental period rainfall from October through April was sufficient ranging from 451 mm to 664 mm, compared to the 30 year average of 545 mm. Although rainfall for the entire spring of 1995 was below normal, biomass yield was not affected. Therefore the rainfall / temperature interaction had a greater effect on cover crop growth than rainfall alone. The rainfall in January 1995 and 1996 was 108 mm and 131 mm respectively, well above normal (72 mm) (Fig. 3). In January 1995 the average monthly temperature was 4.5 °C (1.0 °C above normal), while in January 1996 the average monthly temperature was 1.1 °C (2.4 °C below normal). The effect of excess rainfall on cover crop biomass was positive in 1995 under warm temperatures, but in 1996 the interaction of high rainfall and below normal temperatures led to low biomass yields (Fig. 1). Biomass yields in 1996 compared to the other years varied by 300 to 4,072 kg/ha for the cover crop treatments (Fig. 1). The differences in climate during the month of January for 1995 and 1996 illustrates the combined effect of rainfall and temperature on cover crop growth and development. Similarly, Power and Koerner (1994) reported a direct correlation between cover crop growth and environmental conditions, mainly rainfall and temperature. On average biomass production added between 946 and 3,047 kg/ha of organic material to the soil each year for the lowest and highest producing cover crop treatments, respectively. Low biomass production in the lupin treatments can be partially attributed to difficulty in stand establishment because of large seed and poor soil to seed contact at planting.

**Percent ground cover**

All percent ground cover measurements after cotton planting were taken only from no-till plots because conventional tillage plots were disked for seedbed preparation. Percent ground cover provided by cover crop treatments after cotton planting for 1995, 1996, and 1997 is shown in Fig. 4. In 1995 all cover crop treatments with the exception of lupin averaged greater than 60 % ground cover after cotton planting, qualifying for no-till under NRCS guidelines. Lupin was lower (P < 0.05) than all other treatments, but
still qualified as minimum tillage with 35 % ground cover. Hairy vetch + rye (89%), and rye (91%), provided more (P < 0.05) ground cover than crimson clover (66 %) and hairy vetch (74%).

Percent ground cover was considerably lower in 1996 compared with 1995 (Fig. 4). Hairy vetch + rye, rye, and wheat provided the most ground cover and met minimum tillage requirements with 35, 32, and 30 %, respectively. Lupin provided 6 % ground cover which was less (P < 0.05) than all other cover crop treatments. Crimson clover and hairy vetch provided 29 and 26 % ground cover, which does not comply with NRCS minimum tillage requirements.

In 1997 all cover crop treatments except lupin averaged greater than 60 % ground cover after cotton planting (Fig. 4). Hairy vetch + rye, rye, and wheat resulted in 96, 94, and 92 % ground cover, respectively. These treatment percentages were higher (P < 0.05) than crimson clover and hairy vetch, both having 73 % ground cover. Lupin at 24 % ground cover was lower (P < 0.05) than all other ground cover treatments.

Percent ground cover is closely related to the amount of biomass produced by the cover crop treatments. Hairy vetch + rye, rye, and wheat consistently produced the most ground cover and lupin produced the least ground cover among cover crop treatments during the three seasons. All cover crop treatments except lupin were able to provide enough ground cover to comply with NRCS conservation regulations except during the below average winter temperatures of 1995/1996. Similar results were obtained by Bauer and Busscher (1996) who reported that cover crops and conservation tillage practices can be used in cotton production to control soil erosion and meet federal conservation requirements.
Cover crops were observed for percent ground cover over time in the 1997 growing season (Fig. 5). Percent ground cover measurements obtained prior to the desiccation date indicated 88, 88, and 54 % surface residue for crimson clover, hairy vetch, and lupin, respectively. However, a decline in ground cover by 15 % for crimson clover and hairy vetch and 30 % for lupin was observed the day of cotton planting. Fifty days after cotton planting crimson clover, hairy vetch, and lupin ground cover residues had further declined to 28, 22, and 9 %, respectively. While the hairy vetch + rye, rye, and wheat residue had weathered slightly, now laying flat on the soil surface and still providing on average a minimum of 85 % ground cover. The legume cover crops decomposed significantly over time and were not as resistant to weathering compared to the small grain crops. Previous research by Munawar et al. (1990) supports the findings of this research project, as these researchers report that rye and wheat produce a persistent residue resisting rapid decomposition due to higher C:N ratios compared to legumes.

**Nitrogen assimilation by cover crops**

Total N assimilated by the cover crops was calculated by multiplying the average biomass yield (kg/ha) times the average percent N concentration of the cover crop treatments (Table 2). Differences in percent N concentration between cover crop treatments for 1995, 1996, and 1997 are shown in Table 2. Although hairy vetch consistently had the highest percent N concentration, it did not assimilate the most N (kg N/ha) compared to the other cover crop treatments. The average amount of N assimilated by cover crop treatments proves that crimson clover is the highest N assimilating legume and rye is the highest N assimilating small grain with 78 and 74 kg N/ha, respectively. Nitrogen in the legume cover crops is derived from residual soil N (NO$_3^-$ + NH$_4^+$), and N$_2$ fixed by rhizobia associated with the legume. Nitrogen in the non-legume cover crops is from residual soil N supplies. The N assimilated by the cover crops will be retained in the plant material instead of being lost by the soil through leaching and runoff, possibly contaminating ground and surface waters.
(Clark et al. 1994; Moseley et al., 1996). Furthermore, once the cover crops are killed in the spring, decomposition of the biomass releases N for potential uptake by the summer annual crop.
CONCLUSIONS

Cover crops produce large amounts of biomass providing surface residue and N assimilation for a no-till cotton production system. Cover crop biomass production varied by year and treatment ($P < 0.05$). Yearly differences in biomass production was dependent on temperature and rainfall conditions during the growing seasons. Near or above average monthly temperatures resulted in high biomass yields for 1995 and 1997. Lower than normal average monthly temperatures for the 1995/1996 winter, and the low temperature, high rainfall interaction in January 1996 resulted in extremely low biomass yields. Percent ground cover and N assimilated by cover crops was positively correlated with the amount of biomass produced. Results indicated that within a range of near average winter temperatures all cover crop treatments with the exception of lupin did provide enough surface residue after cotton planting, to meet NRCS conservation tillage standards. Additional observations of surface residue showed that small grain cover crops decomposed slower and provided erosion control further into the cotton growing season compared to the legumes used in this study.

Based on our research in cover crop biomass production, ground cover percent, and N assimilation, rye performed best compared to the other cover crop treatments used in this study. Rye was established in October, persisted throughout cold winter temperatures, and grew rapidly in the spring. Rye produced large amounts of biomass, provided the highest percent ground cover after cotton planting, and assimilated on average 74 kg N/ha. Rye was less expensive to establish, easier to chemically desiccate, and provided surface residue further into the cotton growing season compared to leguminous cover crops. Overall rye worked well as a cover crop in a no-till cotton production system under the soil and climate conditions in the southern piedmont region of central Virginia.
Although rye performed best, the hairy vetch + rye and the wheat treatments were comparable to rye for biomass production, percent ground cover, and N assimilation. The additional cost involved with planting the hairy vetch + rye mixture may not provide any benefit over the rye cover crop treatment alone. Crimson clover and hairy vetch were more expensive to establish, produced less biomass, provided less ground cover, were more difficult to kill, but assimilated comparable amounts of N in relation to rye. The legume cover crop residue breaks down quickly after it is killed in the spring, potentially releasing the assimilated N to the summer annual crop. The unpredictable amount and timing of N release from the legumes risks late season rank growth in cotton, but it can work well with a different summer annual crop. Lupin performed poorly for each year of the study and is not recommended for use as a winter annual cover crop in this region.
<table>
<thead>
<tr>
<th>Year</th>
<th>Cover crop desiccation date</th>
<th>Cotton planting date</th>
<th>Herbicides used at planting for no-till cotton weed management</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Common Name</td>
</tr>
<tr>
<td>1995</td>
<td>† March 31</td>
<td>§ May 19</td>
<td>Pendimethalin</td>
</tr>
<tr>
<td></td>
<td>† April 14</td>
<td></td>
<td>Fluometuron</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Paraquat</td>
</tr>
<tr>
<td>1996</td>
<td>† April 12</td>
<td>May 15</td>
<td>Fluometuron</td>
</tr>
<tr>
<td></td>
<td>† April 23</td>
<td></td>
<td>Metolachlor</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>Paraquat</td>
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<tr>
<td>1997</td>
<td>† April 15</td>
<td>§ May 29</td>
<td>Pendimethalin</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fluometuron</td>
</tr>
</tbody>
</table>

† First burndown herbicide application  
‡ Second burndown herbicide application  
§ Replant date due to poor cotton stand
Fig. 1. Cover crop biomass yield obtained prior to desiccation for the 1995, 1996, and 1997 growing seasons.

Means for bars within years followed by the same letter are not significantly different P = 0.05 (DMRT).
Fig. 3. Average monthly rainfall from planting through desiccation of cover crops for the 1994/1995, 1995/1996, 1996/1997 growing season and the 30 year average.
Fig. 4. Percent ground cover provided by cover crop treatments after cotton planting for the 1995, 1996, and 1997 growing seasons.

Means for bars within years followed by the same letter are not significantly different P = 0.05 (DMRT).
Fig. 5. Percent ground cover by residue over time for cover crop treatments during 1997.
Table 2. Average cover crop biomass yield, nitrogen concentration, and nitrogen assimilation for 1995, 1996, 1997 and the three year average.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average biomass (kg/ha)</th>
<th>Avg. nitrogen concentration (%)</th>
<th>Change in N conc. over 3 test years</th>
<th>Assimilated nitrogen (kg N/ha)</th>
<th>3 year average Biomass (kg/ha)</th>
<th>Assm. N (kg N/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crimson clover</td>
<td>4270 968 2094</td>
<td>3.04 3.16 3.51</td>
<td>0.47</td>
<td>129.8 30.6 73.5</td>
<td>2444 78</td>
<td></td>
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<tr>
<td>Hairy vetch</td>
<td>2890 738 1631</td>
<td>4.04 3.92 4.36</td>
<td>0.44</td>
<td>116.8 28.9 71.1</td>
<td>1753 72</td>
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<td>Hairy vetch + rye</td>
<td>3650 605 3547</td>
<td>2.78 2.70 2.15</td>
<td>0.63</td>
<td>101.5 16.3 76.3</td>
<td>2600 65</td>
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<tr>
<td>Rye</td>
<td>4600 528 4015</td>
<td>2.78 1.91 2.06</td>
<td>0.87</td>
<td>127.9 10.1 82.7</td>
<td>3047 74</td>
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<tr>
<td>Wheat</td>
<td>4060 451 2766</td>
<td>2.32 1.99 2.37</td>
<td>0.38</td>
<td>94.2 8.9 65.6</td>
<td>2426 56</td>
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<tr>
<td>Lupin</td>
<td>1900 319 619</td>
<td>3.94 2.46 2.16</td>
<td>1.78</td>
<td>74.9 7.9 13.4</td>
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<td>LSD *(0.05)</td>
<td>1701 164 724</td>
<td>0.75 0.41 0.39</td>
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<td>22.3</td>
<td>23.8</td>
<td></td>
</tr>
</tbody>
</table>

*LSD: Least significant difference at the 5% level of probability
REFERENCES


Chapter IV

Using Winter Annual Cover Crops in a Virginia No-till Cotton Production System: Cover Crop and Tillage Effects on Soil Moisture, Cotton Yield, and Cotton Quality

ABSTRACT

Winter annual cover crops could help control soil erosion problems on sloping piedmont soils in a no-till cotton (Gossypium hirsutum L.) production system. Field experiments were conducted from 1995 to 1997 to monitor the effects of winter annual cover crops in a no-till cotton production system on soil moisture, cotton yield, and cotton quality using the variety Deltapine 50. Cover crop treatments, crimson clover (Trifolium incarnatum L.), hairy vetch (Vicia vilosa L.), hairy vetch and rye (Secale cereale L.), rye, wheat (Triticum aestivum L. emend. Thell.), and white lupin (Lupinus albus L.), and two tillage systems (conventional and no-till) were arranged in a split-plot design with four replications. Volumetric soil moisture was measured at 15, 30, 61, and 92 cm depths every 7 to 10 days during the 1996 and 1997 cotton growing seasons. Cotton was hand-picked, weighed, and ginned for lint yield determination. Sub-samples of the ginned cotton from each plot were analyzed for quality (length, uniformity, strength, and micronaire). Soil moisture results indicated that no-till plots had higher soil moisture compared to conventional tillage during periods of drought in 1997. The no-till rye treatment conserved more soil moisture than any other cover crop treatment from pinhead square through the first three weeks of cotton flowering at the 15 cm depth. Cotton yield and quality were not affected by tillage system. However, the hairy vetch + rye cover crop treatment had higher (P < 0.05) cotton lint yields during 1995, compared with the wheat cover crop treatment, probably due to N immobilization by the wheat residue. Although differences occurred between cover crop treatments for the different quality parameters during 1995 and 1996, the market value of lint was only affected by micronaire in the 1995 growing season. High micronaire measurement for cover crop treatments in 1995 resulted from unseasonable heat unit accumulation in October and
over maturity of the cotton fiber. Using winter annual cover crops in a no-till cotton production system provides greater soil moisture conservation during periods of drought, while producing lint fiber of similar yield and quality compared to a conventional tillage system.
INTRODUCTION

Although cotton (*Gossypium hirsutum* L.) is taprooted and considered drought tolerant, a certain amount of moisture is critical for producing high yielding, good quality cotton. Stored soil moisture is often a yield limiting factor in dryland cotton production (Azevedo et al., 1996). Drought stress on cotton has been linked to yield decreases due to reduced size and production of sympodial leaves, in addition to reduced photosynthetic rates. These plant reactions during drought stress limit the amount of photosynthetic assimilate available for growth each day (Krieg, 1997). By using a no-till system, surface residue can be managed to better conserve soil water for greater use efficiency by the cotton plant (Hill and Blevins, 1973).

The pattern of water withdrawal changes when comparing a conventional tillage system to a no-till system (Blevins et al., 1971). Naderman (1991) reported that surface residue potentially increases infiltration of water into the soil by 25 to 50% under no-till compared to a conventional tillage system. In addition, cover crop surface residue decreases the effect of wind and temperature on soil water evaporation and increases water storage in the soil profile (Brun et al., 1986; Smart and Bradford, 1996). Unger and Parker (1976) concluded that wheat straw was four times better (by weight) than cotton residue for decreasing moisture evaporation from the soil. The different physical characteristics including specific gravity, thickness, and surface coverage led to differences in the water conserving ability of the residues (Unger and Parker, 1976).

Burnett and Fisher (1954) reported that moisture in the top 30 cm of soil is important for crop establishment, but cotton yields are more directly correlated with moisture stored between 30 and 90 cm below the soil surface. Water availability between pin head square (PHS) and first flower (FF) influences the maximum boll load capacity of the cotton crop (Lawlor et al., 1992). From the beginning of the growing season until the cotton canopy closes the rows, the soil surface is unprotected and vulnerable to moisture evaporation. By using cover crops to maximize ground cover, soil water evaporation decreases and crop transpiration increases (Lascano et al., 1994). With increased soil
moisture reserve, cotton may endure short-term low rainfall conditions without detrimental effects (Blevins et al., 1971). Previous research studies conclude that using cover crops in a reduced tillage cotton production system increased available soil water and led to higher lint yields compared to conventional tillage systems (Lawlor et al., 1992). Regardless of moisture conservation other researchers have continuously found that the combined effect of cover crops and conservation tillage maintains or increases cotton yields compared to conventional tillage (Bloodworth and Johnson, 1995; Boquet et al., 1994). In addition, Bauer and Busscher (1996) found that cotton lint quality was not affected by tillage system or winter cover, but a 0.1 decrease in micronare was observed in cotton following rye compared to legumes. The objectives of this study were to determine the effects of cover crops and tillage systems on soil moisture, cotton yield, and cotton quality under central Virginia piedmont soil and climate conditions.
METHODS AND MATERIALS

A field study was conducted during the 1995, 1996, and 1997 growing seasons at the Southern Piedmont Agricultural Research and Extension Center, in Blackstone, Virginia. Due to delayed cotton maturity in 1997, data for yield and quality will be reported only for 1995 and 1996, while soil moisture data will be reported for the 1996 and 1997 growing seasons. The soil type at the site was a Mayodan, sandy loam (clayey, kaolinitic, thermic Typic Hapludult) for 1995 and 1996, and a Dothan-Norfolk, sandy loam (fine, loamy, siliceous, thermic Plinthic and Typic Paleudults) for 1997. The experimental design used was a split plot with four replications. The main plot treatments were cover crops and the sub-plots consisted of two tillage practices (conventional and no-till). Plots were 4.27 m wide and 7.63 m long with 4 rows and 1.1 m between the rows. The cover crop treatments were crimson clover (*Trifolium incarnatum* L.), hairy vetch (*Vicia vilosa* L.), hairy vetch and rye (*Secale cereale* L.), rye, wheat (*Triticum aestivum* L. emend. Thell.), and white lupin (*Lupinus albus* L.). A detailed description of cover crop planting and management, in addition to the sampling technique for biomass production, percent ground cover, and N assimilation was given in chapter III.

Approximately 3 weeks prior to the estimated cotton planting date, the conventional tillage plots were mowed and disked while the no-till plots were desiccated with glyphosate (2.24 kg/ha). The no-till plots received an additional burndown herbicide application when it was needed (Table 1). One week after the second burndown application, the cotton cultivar Deltapine 50 was planted at the rate of 16.4 seeds per m of row (Table 1). Cotton was planted using a 4-row no-till planter equipped with a fluted coulter to cut through surface residue followed by a double disk opener to make a furrow for the seed, and press wheels to firmly cover the seed with soil. At planting, aldicarb (granular insecticide) and metalaxyl (granular fungicide) were applied in-furrow at 5.6 and 11.2 kg/ha, respectively. Fertilizer N, P, K and B according to soil test recommendations was broadcast on no-till plots and disked into conventional tillage.
plots. Each year standard production management practices were conducted throughout the cotton growing season (Table 2, 3, and 4).

Volumetric soil moisture was measured in each plot of the first two experimental replications in 1996 and 1997, to monitor differences in soil moisture under tillage systems (conventional vs. no-till) and cover crop treatments (Appendix A). The measurements were taken with the Troxler Sentry 200-AP soil moisture probe, operated from a permanent access tube (Troxler Electronic Laboratories Inc., 1991). Access tubes were constructed from schedule 40 PVC pipe which had an inside and outside diameter of 5.22 and 6.03 cm, respectively. Access tubes were cut 1.22 m long, and sealed on the bottom with an inside diameter plastic plug and PVC glue. The access tubes were inserted tightly into a newly augured hole, with 15 cm of the tube extending from the soil surface. Once all the access tubes had been installed, volumetric soil moisture measurements were taken at the 15, 30, 61, and 92 cm depths every 7 to 10 days from the day of cotton planting until the middle of the cotton flowering period.

For reliable soil moisture readings the Sentry 200-AP moisture probe was calibrated to the specific soils in the experimental area. The moisture probe calibration procedure was based the technique of Khosla and Persaud (1997). The probe was calibrated to within ±2.56 and ±0.37 % accuracy for 1996 and 1997, respectively. Reproducibility of the instrument was high based on repeated measurements at the same depth that showed little or no drift in the measurement.

Although soil moisture was measured every 7 to 10 days during the growing season, only three measurement dates will be represented in this paper. The three moisture measurement dates were chosen to specifically match critical periods in the growth stage of the cotton plant when moisture availability could affect stand establishment, fruit development, maturity, and overall cotton yield. The moisture measurement dates analyzed were 20 May, 1 July, 5 August, and 27 May, 2 July, and 7 August, for the 1996 and 1997 cotton growing seasons, respectively. Each year the
moisture data was analyzed separately by depth (15, 30, 61, and 92 cm), on each date to
determine the effect of tillage and cover crop treatment on soil moisture.

Each year about 2 weeks prior to the estimated harvest date the cotton was
sprayed for defoliation (Table 3, 4, and 5). On 12 Oct. 1995 and 14 Nov. 1996, a 2.43 m
length of row was harvested by hand from one of the middle rows in each experimental
plot. The number of plants and open bolls were counted in each section of row harvested.
Sub-samples of the harvested cotton were ginned for lint yield determination and
analyzed for quality.

The cotton fiber quality (length, uniformity, strength, and micronaire) was
analyzed by the USDA laboratory in Florence, SC. Fiber length is the average length of
the longer one-half of fibers in a sample (upper half mean length) of cotton. Length is
reported in 100ths and 32nds (of an inch), and usually ranges from 0.80 to 1.36 100ths or
24 to 44 32nds (USDA, 1995). Uniformity is the ratio between the mean length and the
upper mean length of fibers. Uniformity is reported as a percent, and usually ranges
between 77 (very low) and 85 % (very high). Fiber strength is a measure of the amount
of force in grams needed to break a bundle of fibers one tex unit in size. A tex unit is
equivalent to the weight in grams of 1,000 meters of fiber (USDA, 1995). Strength is
reported as g/tex, and usually ranges between 23 and 31 g/tex (weak to very strong).
Micronaire is a measure of fiber maturity and fineness. Micronaire is reported in units,
with an acceptable range between 3.4 and 5.0 units (USDA, 1995).

Data analysis
Analysis of variance was calculated using the SAS software package (SAS
Institute, 1993). Effects of treatment (cover crops and tillage), depth, field block, date
(when needed), year, and all interactions were tested. Mean separations were performed
by Duncan’s Multiple Range Test (DMRT), if the ANOVA F-statistic indicated
significant effects at the 0.05 probability level (SAS Institute, 1993).
RESULTS AND DISCUSSION

Soil Moisture

Data from the two experimental years was reported separately due to differences in the two growing seasons. Results from the 1996 growing season indicated no difference in soil moisture by tillage or cover crop treatment, on any given date or soil depth. Treatment effects may have been minimized by low biomass production of cover crops (319 to 968 kg/ha) in 1996. Also, higher than average rainfall during May, July, and August (Fig. 1) contributed to the minimal soil moisture differences between conventional and no-tillage systems.

The 1997 results indicated that tillage system affected (P < 0.05) soil moisture one week after FF (7 Aug). At the 15, 30, and 61 cm depths soil moisture was higher (P < 0.05) under no-till compared to conventional tillage (Fig. 2). The no-till system had 2.0, 2.4, and 1.9% higher soil moisture compared to conventional tillage at the 15, 30, and 61 cm depths, respectively. Similar results were obtained by Lawlor et al. (1992) who reported higher soil moisture under conservation tillage compared to conventional tillage. The high percent soil moisture reported in this study under the no-till system could be attributed to the presence of a surface residue that probably resulted in higher rainfall infiltration and decreased soil water evaporation.

For the 7 August sample date, which corresponded with the first week of cotton flowering, soil moisture was higher (P < 0.05) by certain cover crop treatments under no-tillage at the 15 cm depth (Fig. 3). The rye treatment (20.1%) had higher soil moisture (P < 0.05) compared to crimson clover, wheat, and lupin (Fig. 3). Furthermore, the no-till rye cover crop treatment had the highest soil moisture of all other cover crop treatments from PHS (2 July) through the first three weeks of the cotton flowering period (19 Aug) at the 15 cm depth (Fig. 4). The greater moisture conserving ability of rye compared to the other cover crop treatments could be due to the amount and physical characteristics of the residue. The rye cover crop treatment produced more (P < 0.05) biomass than all the other cover crop treatments with the exception of hairy vetch + rye. In addition the rye
cover crop treatment reached a mature growth stage which resulted in a high C:N ratio of the straw residue. Unger and Parker (1976) explain that residue specific gravity, thickness, and surface coverage differ by type of residue, which alters the potential moisture evaporation from the soil.

The conserved soil moisture in the no-till system throughout the cotton fruiting and flowering period could have potentially increased cotton yield in 1997. However, due to the late planting date and delayed cotton maturity in 1997, the effects of increased soil moisture under no-till on cotton yield could not be determined.

**Cotton Yield**

Although no year x treatment interaction was observed in the cotton yield data, due to extreme yield differences between the two years, data is shown separately by year. Since no tillage x cover crop treatment interaction was observed for 1995 and 1996, cotton lint yield was averaged over tillage systems. In 1995 cotton lint yield differed among cover crop treatments, however in 1996 no cover crop treatment effects were observed (Fig. 5).

The cotton yield following hairy vetch + rye, a small grain/legume cover crop mixture, was higher (P < 0.05) than the wheat treatment in 1995 (Fig. 5). The increase in cotton lint yield, following a small grain/legume mixture may be attributed to increased N availability to the following cotton crop. For maximum utilization of legume N by the cotton crop, mineralization of legume N must occur at the same time as crop N uptake. The timing of N mineralization by the hairy vetch + rye mixture may differ from the other cover crop treatments, and correspond better to the uptake of N by the cotton crop. Ranells and Wagger (1997) researched the use of a small grain/legume cover crop combination and reported that the C:N ratio of < 30 allowed for N additions to the following summer annual crop. Sullivan et al. (1991) stated that small grain cover crops have higher C:N ratios leading to persistent surface residues potentially immobilizing soil N. These findings by Ranells and Wagger (1997) and Sullivan et al. (1991) may help to
explain the decrease in cotton lint yield under the wheat cover crop treatment compared to the hairy vetch + rye cover crop treatment reported for 1995 cotton yield.

In 1996 cotton lint yields were not different by cover crop treatment. The cover crop treatment effects were minimized due to low biomass production for all cover crop treatments over the winter of 1995/1996. Furthermore, above average rainfall during May, July, and August (during the periods of cotton planting, fruiting, and flowering) provided abundant moisture for all cover crop treatments and tillage practices.

**Cotton Quality**

Cotton quality data from the 1995 and 1996 growing seasons are reported separately by year due to year x treatment interactions for some of the fiber quality parameters. Since tillage system did not affect cotton quality, the cover crop treatment effects were averaged over tillage systems.

Cover crop treatments did not affect fiber length in 1995 (Fig. 6). However in 1996, the fiber length in the hairy vetch + rye and hairy vetch cover crop treatments were higher (P < 0.05) than the crimson clover treatment. Fiber length for the lupin, wheat, and rye cover crop treatments did not differ.

In 1995, cotton uniformity was higher (P < 0.05) following the rye cover crop treatment compared to the hairy vetch treatment (Fig. 7). Cover crop treatments did not affect uniformity of fiber in 1996. Cotton fiber uniformity for both years graded intermediate to high across cover crop treatments which aids in the efficiency of the spinning process and increases yarn evenness and strength.

Cotton fiber strength was not affected by cover crop treatment in 1995 or 1996 (Fig. 8). However, strength measurements for 1995 were ranked strong (29-30 g/tex) to very strong (> 31 g/tex), while the 1996 fiber strength was average (26-28 g/tex). Higher
cotton fiber strength has greater durability throughout the manufacturing process and results in stronger yarn strength.

Micronaire is a measure of fineness and maturity, which in turn affects processing speeds and dye absorbency. Fiber micronaire measurements of less than 3.5 or more than 5.0 units are discounted in value. In 1995, cotton produced on all cover crop treatments except hairy vetch + rye had micronaire values between 5.0 and 5.2 units (Fig. 9). These high micronaire measurements resulted in a price deduction of 1.4 cents per kilogram of lint ($14.88/bale). In 1996, micronaire was not different across cover crop treatments (Fig. 9) and all micronaire values were in the premium range (3.7 to 4.2 units). The high micronaire values in 1995 resulted from the over maturity of cotton fiber driven by the additional accumulation of heat units in October (Fig. 10).
CONCLUSIONS

Many factors contributed to the effects of cover crop treatments and tillage systems on soil moisture throughout the cotton growing season. Yearly differences in soil moisture were dependent on cover crop growth over the winter and rainfall throughout the cotton growing season. In 1996, cover crops and tillage systems had no effect on soil moisture at any given date or soil depth. Low biomass production of all cover crop treatments and above average rainfall during the cotton growing season, contributed to minimal soil moisture differences between cover crop treatments and tillage systems.

Soil moisture in the no-till system was higher (P < 0.05) compared to the conventional tillage system at the 15, 30, and 61 cm depth one week after FF. As the season progressed and the soil became increasingly droughty, the no-till rye cover crop treatment conserved more soil moisture at the 15 cm depth compared to all the other treatments until 19 August.

Cotton lint yield was not affected by tillage system in 1995 or 1996. However, in 1995 cotton lint yield was affected by certain cover crop treatments. In 1995, cotton grown in the hairy vetch + rye treatment had higher (P < 0.05) lint yield compared with cotton grown in the wheat cover crop treatment. The difference in lint yield was possibly related to the wheat cover crop treatment immobilizing soil N.

Tillage system had no effect on cotton fiber quality in 1995 or 1996. Although differences (P < 0.05) occurred in length and uniformity for certain cover crops, the measured values for each of these parameters did not affect market price. Micronaire measurements in 1995 for cotton grown in crimson clover and wheat residue were higher (P < 0.05) than cotton grown in hairy vetch + rye residue. The hairy vetch, rye, and lupin treatments did not differ. All treatments except hairy vetch + rye had cotton fiber micronaire readings between 5.0 and 5.2, which resulted in a market price reduction of 1.4 cents per kilogram of lint. However, unseasonably high heat unit accumulation in October of 1995 contributed more to the over maturity of cotton fiber and high micronaire measurements, than did the cover crop treatments.
In conclusion the presence of a cover crop residue in a no-till cotton production system provides greater soil moisture conservation during seasons of low rainfall, compared to a conventional tillage system. In addition the no-till rye cover crop treatment conserves more soil moisture, at the 15 cm depth, during periods of short-term drought compared to the other cover crop treatments. Cotton lint yield and quality was not affected by tillage system. Cotton lint yield was affected by cover crop treatment in 1995 when the cover crop treatments produced large amounts of biomass. Cover crop treatments caused minor differences in cotton quality, however the differences were not enough to result in a market price deduction. The market price deduction in micronaire for 1995 was more related to climate than cover crop treatment.
Table 1. Cover crop desiccation and cotton planting dates, and herbicides used at planting for the 1995, 1996, and 1997 cotton growing seasons.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cover crop desiccation date</th>
<th>Cotton planting date</th>
<th>Herbicides used at planting for no-till cotton weed management</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Common Name</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rate</td>
</tr>
<tr>
<td>1995</td>
<td>† March 31  ‡ April 14</td>
<td>§ May 19</td>
<td>P덤말린 (Pendimethalin)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.56 kg/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fluometuron</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.12 kg/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Paraquat</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.69 kg/ha</td>
</tr>
<tr>
<td>1996</td>
<td>† April 12  ‡ April 23</td>
<td>May 15</td>
<td>Fluometuron</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.56 kg/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Metolachlor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.68 kg/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Paraquat</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.52 kg/ha</td>
</tr>
<tr>
<td>1997</td>
<td>† April 15          § May 29</td>
<td></td>
<td>P덤말린 (Pendimethalin)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.74 kg/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fluometuron</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.12 kg/ha</td>
</tr>
</tbody>
</table>

† First burndown herbicide application
‡ Second burndown herbicide application
§ Replant date due to poor cotton stand
<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
<th>Product Used</th>
<th>Rate Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 Jun</td>
<td>fertilization</td>
<td>34-0-0</td>
<td>151 kg/ha</td>
</tr>
<tr>
<td>7 Jul</td>
<td>growth regulator</td>
<td>Mepiquat chloride</td>
<td>0.022 kg/ha</td>
</tr>
<tr>
<td>12 Jul</td>
<td>herbicide</td>
<td>*MSMA</td>
<td>2.24 kg/ha</td>
</tr>
<tr>
<td>17 Jul</td>
<td>growth regulator</td>
<td>Mepiquat chloride</td>
<td>0.037 kg/ha</td>
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<tr>
<td>21 Jul</td>
<td>herbicide</td>
<td>Sethoxydim</td>
<td>0.313 kg/ha</td>
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<tr>
<td>16 Aug</td>
<td>insecticide</td>
<td>Bifenthrin</td>
<td>0.071 kg/ha</td>
</tr>
<tr>
<td>21 Aug</td>
<td>insecticide</td>
<td>Bifenthrin</td>
<td>0.017 kg/ha</td>
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<tr>
<td>28 Sept</td>
<td>defoliant</td>
<td>Tribufos</td>
<td>1.26 kg/ha</td>
</tr>
<tr>
<td>28 Sept</td>
<td>defoliant</td>
<td>Thidiazuron</td>
<td>0.112 kg/ha</td>
</tr>
<tr>
<td>28 Sept</td>
<td>boll opener</td>
<td>Ethephon</td>
<td>1.1 kg/ha</td>
</tr>
</tbody>
</table>

*MSMA: Monosodium Acid Methanearsonate
Table 3. Cotton production management practices during the 1996 growing season.

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
<th>Product Used</th>
<th>Rate Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 Jun</td>
<td>herbicide</td>
<td>Pyrithobac</td>
<td>0.069 kg/ha</td>
</tr>
<tr>
<td>27 Jun</td>
<td>fertilization</td>
<td>13-0-14</td>
<td>448 kg/ha</td>
</tr>
<tr>
<td>12 Jul</td>
<td>growth regulator</td>
<td>Mepiquat chloride</td>
<td>0.0184 kg/ha</td>
</tr>
<tr>
<td>16 Aug</td>
<td>insecticide</td>
<td>Bifenthrin</td>
<td>0.71 kg/ha</td>
</tr>
<tr>
<td>27 Aug</td>
<td>insecticide</td>
<td>Bifenthrin</td>
<td>0.71 kg/ha</td>
</tr>
<tr>
<td>15 Oct</td>
<td>defoliant</td>
<td>Tribufos</td>
<td>0.84 kg/ha</td>
</tr>
<tr>
<td>15 Oct</td>
<td>boll opener</td>
<td>Ethephon</td>
<td>2.1 kg/ha</td>
</tr>
</tbody>
</table>
Table 4. Cotton production management practices during the 1997 growing season.

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
<th>Product Used</th>
<th>Rate Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 Jun</td>
<td>herbicide</td>
<td>Bromoxynil</td>
<td>0.28 kg/ha</td>
</tr>
<tr>
<td>1 Jul</td>
<td>herbicide</td>
<td>Fluazifop-P</td>
<td>0.105 kg/ha</td>
</tr>
<tr>
<td>1 Jul</td>
<td>fertilization</td>
<td>13-0-14</td>
<td>448 kg/ha</td>
</tr>
<tr>
<td>14 Jul</td>
<td>herbicide</td>
<td>*MSMA</td>
<td>2.24 kg/ha</td>
</tr>
<tr>
<td>18 Jul</td>
<td>growth regulator</td>
<td>Mepiquat chloride</td>
<td>0.0123 kg/ha</td>
</tr>
<tr>
<td>29 Jul</td>
<td>growth regulator</td>
<td>Mepiquat chloride</td>
<td>0.0245 kg/ha</td>
</tr>
<tr>
<td>29 Jul</td>
<td>herbicide</td>
<td>Fluazifop-P</td>
<td>0.105 kg/ha</td>
</tr>
<tr>
<td>21 Aug</td>
<td>insecticide</td>
<td>Cyano</td>
<td>0.126 kg/ha</td>
</tr>
<tr>
<td>5 Sept</td>
<td>insecticide</td>
<td>Cyano</td>
<td>0.14 kg/ha</td>
</tr>
</tbody>
</table>

*MSMA: Monosodium Acid Methanearsonate
Fig. 1. Monthly rainfall totals for May through September during the 1996 and 1997 growing seasons, and the 30 year average.
Fig. 2. Soil moisture percent under conventional tillage and no-tillage at the 15, 30, and 61 cm depth one week after first flower (7 Aug) during the 1997 growing season.

Means for bars within depths followed by the same letter are not significantly different P = 0.05 (DMRT).
Fig. 3. Soil moisture percent by cover crop treatment under no-tillage at the 15 cm depth after the first week of cotton flowering (7 Aug) during the 1997 cotton growing season.

Means for bars followed by the same letter are not significantly different $P = 0.05$ (DMRT).
Fig. 4. Soil moisture percent measured between 15 May and 19 August during the 1997 cotton growing season at the 15 cm depth under no-tillage for all cover crop treatments.
Fig. 5. Cotton lint yield by cover crop treatment for the 1995 and 1996 growing seasons.

Means for bars within years followed by the same letter are not significantly different P = 0.05 (DMRT).
Fig. 6. Cotton lint quality (fiber length) by cover crop treatment for the 1995 and 1996 growing seasons.

Means for bars within years followed by the same letter are not significantly different $P = 0.05$ (DMRT).
Fig. 7. Cotton lint quality (length uniformity) by cover crop treatment for the 1995 and 1996 growing seasons.

Means for bars within years followed by the same letter are not significantly different P = 0.05 (DMRT).
Fig. 8. Cotton lint quality (strength of fiber) by cover crop treatment for the 1995 and 1996 growing seasons.

Means for bars within years followed by the same letter are not significantly different $P = 0.05$ (DMRT).
Fig. 9. Cotton lint quality (micronaire) by cover crop treatment for the 1995 and 1996 growing seasons.

Means for bars within years followed by the same letter are not significantly different P = 0.05 (DMRT).
Fig. 10. Heat units accumulated during the cotton flowering and boll maturity period for the 1995 and 1996 cotton growing seasons.

1995 = 1019
1996 = 906
REFERENCES


Chapter 5

Conclusions and Summary

Six winter annual cover crops were evaluated for biomass production, percent ground cover, and N assimilation under central Virginia piedmont soil and climate conditions. In addition the cover crop treatments were evaluated under no-till and conventional tillage systems for their effects on soil moisture, cotton yield, and cotton quality.

Yearly differences in biomass production were dependent on temperature and rainfall conditions throughout the growing season (Oct - Apr). Near or above average monthly temperatures resulted in high biomass yield during the spring of 1995 and 1997. Below average temperatures throughout the winter of 1995/1996, and high rainfall in January, greatly reduced biomass production by all cover crop treatments in 1996. Percent ground cover and the amount of N assimilated by the cover crops was positively correlated with the amount of biomass produced within cover crop treatments. Our results indicated that within a range of near average winter temperatures all cover crop treatments with the exception of lupin provided enough ground cover after cotton planting to comply with federal conservation tillage standards. Additional observation of surface residue showed that small grain cover crop residue decomposed slower and provided erosion control further into the cotton growing season compared to the legume cover crop treatments.

Cover crop biomass production and yearly climate had multiple effects on soil moisture, cotton yield, and cotton quality grown under no-till and conventional tillage systems. The effects of cover crop treatments and tillage systems on soil moisture were minimal in 1996 due to low biomass production by all cover crop treatments and abundant rainfall throughout the cotton growing season. In 1997 the residue covered surface of the no-till system resulted in higher (P < 0.05) soil moisture from 0 to 61 cm,
Cotton lint yield and quality was not affected by tillage system during 1995 or 1996. High cover crop biomass production and an extended cotton growing season, resulted in cotton yield differences between cover crop treatments in 1995. The hairy vetch + rye treatment had a higher (P < 0.05) lint yield compared to the wheat treatment. This yield difference is attributed to N immobilization by the wheat residue. Additional fertilizer N could alleviate the N immobilization by the wheat residue and increase the cotton yield. Although differences occurred between cover crop treatments for the different quality parameters during 1995 and 1996, the market value of lint was only affected by micronaire in the 1995 growing season. All cover crop treatments, with the exception of hairy vetch + rye (4.9), had micronaire values between 5.0 and 5.2 which reduced the market price of lint by 1.4 cents per kilogram. However, the unseasonably high heat unit accumulation in October of 1995 contributed more to the over maturity of cotton fiber and high micronaire measurements, than did the cover crop treatments.

Within a range of average winter temperatures, all the cover crop treatments except lupin produced enough biomass to meet federal conservation tillage requirements while maintaining high-yielding quality cotton in a no-till system compared to conventional tillage. Moisture conservation benefits of the no-till system and certain cover crop treatments were expressed more during periods of drought stress as would be expected. Based on our research, all the cover crops used in this experiment, with the exception of lupin, can be successfully used in a no-till system to produce high yielding and good quality cotton on Virginia’s piedmont soils. However, rye is the recommended cover crop treatment to use in a no-till system. Rye was less expensive to establish and easier to terminate than the legume cover crop treatments. Rye produced large amounts of biomass and provided the highest percent ground cover after cotton planting compared to the other cover crops. Rye assimilated on average 74 kg N/ha from the soil each year,
decreasing the amount of potentially leachable N from the soil system. During periods of
drought, the rye cover crop residue in a no-till system conserved soil moisture longer than
any other cover crop treatment used in our study. Furthermore, cotton grown in the rye
cover crop treatment had similar yield and quality compared to the cotton grown in the
other cover crop treatments.
APPENDIX
Fig. 1. Daily rainfall totals between 20 May and 31 August during the 1996 growing season.
Fig. 2. Soil moisture percent measured between 20 May and 31 Aug during the 1996 cotton growing season at the 15 cm depth under conventional tillage for all cover crop treatments.
Fig. 3. Soil moisture percent measured between 20 May and 31 Aug during the 1996 cotton growing season at the 30 cm depth under conventional tillage for all cover crop treatments.
Fig. 4. Soil moisture percent measured between 20 May and 31 Aug during the 1996 cotton growing season at the 61 cm depth under conventional tillage for all cover crop treatments.
Fig. 5. Soil moisture percent measured between 20 May and 31 Aug during the 1996 cotton growing season at the 92 cm depth under conventional tillage for all cover crop treatments.
Fig. 6. Soil moisture percent measured between 20 May and 31 Aug during the 1996 cotton growing season at the 15 cm depth under no-tillage for all cover crop treatments.
Fig. 7. Soil moisture percent measured between 20 May and 31 Aug during the 1996 cotton growing season at the 30 cm depth under no-tillage for all cover crop treatments.
Fig. 8. Soil moisture percent measured between 20 May and 31 Aug during the 1996 cotton growing season at the 61 cm depth under no-tillage for all cover crop treatments.
Fig. 9. Soil moisture percent measured between 20 May and 31 Aug during the 1996 cotton growing season at the 92 cm depth under no-tillage for all cover crop treatments.

*Soil moisture values for the hairy vetch treatment are not shown due to measurement error.
Fig. 10. Daily rainfall and irrigation totals between 15 May and 19 August during the 1997 growing season.
Fig. 11. Soil moisture percent measured between 15 May and 19 Aug during the 1997 cotton growing season at the 15 cm depth under conventional tillage for all cover crop treatments.
Fig. 12. Soil moisture percent measured between 15 May and 19 Aug during the 1997 cotton growing season at the 30 cm depth under conventional tillage for all cover crop treatments.
Fig. 13. Soil moisture percent measured between 15 May and 19 Aug during the 1997 cotton growing season at the 61 cm depth under conventional tillage for all cover crop treatments.
Fig. 14. Soil moisture percent measured between 15 May and 19 Aug during the 1997 cotton growing season at the 92 cm depth under conventional tillage for all cover crop treatments.
Fig. 15. Soil moisture percent measured between 15 May and 19 Aug during the 1997 cotton growing season at the 15 cm depth under no-tillage for all cover crop treatments.
Fig. 16. Soil moisture percent measured between 15 May and 19 Aug during the 1997 cotton growing season at the 30 cm depth under no-tillage for all cover crop treatments.
Fig. 17. Soil moisture percent measured between 15 May and 19 Aug during the 1997 cotton growing season at the 61 cm depth under no-tillage for all cover crop treatments.
Fig. 18. Soil moisture percent measured between 15 May and 19 Aug during the 1997 cotton growing season at the 92 cm depth under no-tillage for all cover crop treatments.
The author was born on May 19, 1973 in Richmond, Virginia. He is the son of James B. Daniel and Kitty C. Elsaesser and has a brother Edwin G. Daniel, and sisters Courtney D. Jackson and Kelsey F. Daniel. He grew up in Lunenburg County until graduation from Central High School in 1991. He enrolled at Virginia Polytechnic Institute and State University in the fall of 1991, and completed his B. S. in Crop and Soil Environmental Sciences (Environmental Option) in December of 1995. In January of 1996, he began his masters degree under the advisement of Dr. A. Ozzie Abaye. While attending Virginia Tech, J.B. enlisted in the Virginia Army National Guard earning the rank of Sergeant before completion of his enlistment. J.B. also became a member of Gamma Sigma Delta Honor Society and served as President of the CSES Graduate Student Organization.