EFFECT OF RYE RESIDUE ON SOIL PROPERTIES AND NITROGEN FERTILIZATION OF COTTON

Except where reference is made to the work of others, the work described in this thesis is my own or was done in collaboration with my advisory committee. This thesis does not include proprietary or classified information.

Fernando Ducamp Rodriguez

Certificate of Approval:

Kipling S. Balkcom
Affiliate Assistant Professor
Agronomy and Soils

Francisco J. Arriaga, Chair
Affiliate Assistant Professor
Agronomy and Soils

Charles C. Mitchell
Extension Specialist & Professor
Agronomy and Soils

George T. Flowers
Interim Dean
Graduate School

EFFECT OF RYE RESIDUE ON SOIL PROPERTIES AND NITROGEN FERTILIZATION OF COTTON

Fernando Ducamp Rodriguez

A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
August 9, 2008

EFFECT OF RYE RESIDUE ON SOIL PROPERTIES AND NITROGEN FERTILIZATION OF COTTON

Fernando Ducamp Rodriguez

Signature of Author

Date of Graduation

VITA

Fernando Ducamp Rodriguez, son of Luis Angel Ducamp Dure and Nely Rodriguez Ferreira was born August 11, 1971 in Tacuarembo, Uruguay. He graduated from High School (Liceo No. 1 de Young, Uruguay) in 1990. He entered Facultad de Agronomía, Universidad de la Republica, Uruguay, and graduated in 1998 with a Bachelor of Science degree in Agronomy. After graduation, he worked as a contractor at the “Mario A. Cassinoni” Experimental Station of Facultad de Agronomia, Uruguay. He enrolled in the Auburn University Graduate School in January 2006 and completed a degree of Master of Science in Agronomy and Soils in August 2008.

THESIS ABSTRACT

EFFECT OF RYE RESIDUE ON SOIL PROPERTIES AND NITROGEN FERTILIZATION OF COTTON

Fernando Ducamp Rodriguez

Master of Science, August 9, 2008
(B.S., Facultad de Agronomia, Universidad de la Republica, Uruguay, 1998)

149 Typed Pages

Directed by Francisco J. Arriaga

Conservation tillage systems that use rye (*Secale cereale* L.) as a cover crop have many benefits on soils properties and crop productivity. However, rye biomass could be harvested for alternative uses, which could jeopardize the long-term sustainability of cropping systems. The objective of this study was to determine: (i) the effect of rye residue management on selected soil properties, and (ii) the impact of rye residue management and cotton (*Gossypium hirsutum* L.) nitrogen (N) fertilization rates on cotton growth parameters and yield, in a Marvyn loamy sand (fine-loamy, kaolinitic, thermic Typic Kanhapludult) of central Alabama, United States. Three rye residue managements (no winter cover crop, rye residue removed and rye residue retained) and four N fertilization rates for cotton (0, 50, 100 and 140 kg ha^{-1}) were evaluated.

Treatment arrangement was a split-plot in a randomized complete block design with four replications. After two growing seasons, total soil organic carbon (C), particulate organic matter C, mineral-associated + water-soluble C and total soil N were significantly higher in rye residue retained than in other treatments, to a depth of 5-cm. The soil water retention across matric potentials was reduced by 7 % and bulk density was increased by 5 % for rye residue removed compared to rye residue retained. Rye residue removal decreased the soil water content early in the cotton season compared to rye residue retained. There were no significant differences between rye residue retained and removed for the other measured soil properties. The highest values of soil penetration resistance were observed with no winter cover crop. In one of the two years, cotton population, leaf and plant nitrogen concentration, cotton biomass and N uptake at first square, and cotton biomass production between first square and cutout were higher in rye residue retained followed by rye residue removed and no winter cover crop. Nonetheless, leaf N concentration at early bloom and cotton biomass N concentration between first square and cutout were higher for no winter cover crop, followed by rye residue removed and retained. The highest seed cotton yield was recorded in rye residue retained with either 125 kg N ha^{-1} or 140 kg N ha^{-1}. Short-term rye residue removal appears to have negative effects on some surface soil properties of these Coastal Plain soils. This could negatively affect cotton growth, seed cotton yield and the cotton response to N fertilization.

ACKNOWLEDGEMENTS

The author would like to express his gratitude to Dr. Francisco J. Arriaga, Major Professor of the advisory committee, for his support and guidance during the development of this research. The author very much appreciates the advice and assistance throughout this study of committee members Dr. Kipling S. Balkcom and Dr. Charles C. Mitchell.

Special thanks are due to Mr. Jason Ward for his assistance with data collection and multiple procedures, to Dr. J. Rodriguez and Dr. S. Prior for their help with laboratory analysis and procedures, to Dr. E. Van Santen for his support with the statistical analysis, and to Mr. Bobby Durbin and the crew at the E.V. Smith Field Crops Research Unit for managing the experiment.

The author appreciates the contribution of Dr. R. Raper, Dr. J. Bergtold, Dr. A. Price, J. Walker, D. LaGrand, K. Holloway, B. Dorman, T. Dorman and others from Auburn University and the National Soil Dynamics Laboratory.

The author would like to thank to Dr. H. Causarano, Dr. D. Watts, A. Biscaro, P. Simoes, M. Anand, M. Saini and A. Rocatelli for their friendship during all this time.

Thanks also go to O. Ernst, Dr. G. Siri, C. Castiglioni, Natalia and Santiago.

Finally, the author wishes to express his love and appreciation to his parents, Luis and Nely for their unconditional support and guidance during all his life.

Style manual or journal used Publication Handbook and Style Manual of the American Society of Agronomy.

Computer software used Microsoft Word 2007, Microsoft Excel 2007, SAS v. 9.1.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. LITERATURE REVIEW

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is one of the important crops grown in the United States (US). It is planted in 4,382,000 ha with a yearly production value of about 5.2 billion dollar (NASS, 2007). The long-term use of conventional tillage practices together with the soil susceptibility to degradation have been responsible for the high levels of physical and chemical soil degradation (Causarano et al., 2008). It is for these reasons that conservation management practices for crop production became more popular in the 1970's (Gallaher, 2002). Conservation systems for cotton production in the southeastern US have increased in adoption to approximately 50 % of the 2.9 million ha planted in this area (Schomberg et al., 2006).

Advantages of reduced rainfall runoff, less wind and water erosion, better soil moisture retention, improved soil quality, lower production costs, more intense crop rotation and high levels of carbon (C) sequestration are among some reasons why conservation tillage is a popular practice for crop production (Phillips and Young, 1973; Unger and McCalla, 1980; Tsuji et al., 2006). Amounts and quality of residue left on the soil surface under conservation tillage are key determiners of system sustainability.

Those systems based on one summer crop a year, such as cotton in the southeastern US, have the disadvantage of leaving the soil with little or no cover during the winter. This practice is detrimental not only due to lower residue deposition in the soil but also because the soil is exposed to erosion during winter months, which has negative effects on soil productivity and quality (Kuo and Jellum, 2002). For these reasons, winter cover crops (WCC) began to be used in different production systems. Many crops can be used as WCC, from grasses to legumes or their combination, depending on the objective of the production system. Residue of leguminous crops is of higher quality than grasses because of the lower C to nitrogen (N) ratio. They decompose quicker and add more N to the soil than grasses (Ranells and Wagger, 1996). However, grasses add larger quantities of residue and C to the soil making a better contribution to a system's sustainability (Kuo et al., 1997). An additional advantage of grass cover crops over legumes is that they are less likely to be host of parasitic nematodes, a significant problem for cotton production in the southeastern US (McSorley, 2008).

Decreasing profits of cotton producers is a reason to consider alternative uses of the WCC biomass, e.g., feeding animals or as energy source. However, this management practice could affect soil properties because of lower amounts of C added to the system, and the soil surface is left with low residue coverage. However, managing N fertilization can be important in these situations by increasing the potential harvestable aboveground biomass and also, the below-ground biomass. The later can become an important source of C and N to the soil, maintaining soil organic matter levels when residue is removed (Sainju et al., 2005).

Winter cover crop management that includes biomass removal can influence N dynamics in soil particularly during the summer season. When a residue with a high C/N ratio is left on the soil surface, N immobilization occurs, and the residue competes with the summer cash crop for the inorganic N present in the soil. As a result of this competition, summer cash crops in rotation with small grain cover crops would require higher levels of N fertilization (Mitchell, 1996; Reiter et al., 2002). This effect could be minimized when the residue is removed from the soil surface, increasing the amount of inorganic N potentially available for the summer crop.

Understanding how cover crop residue management affects soil properties and N dynamics is important to determine the sustainability of systems with WCC and also to develop appropriate N management strategies for cotton in conservation tillage systems (Schomberg and Endale, 2004).

WINTER COVER CROPS AND BIOMASS REMOVAL

Cover crops play a strategic role in agricultural systems, particularly in those based on one crop a year. Winter cover crops are used in rotation with summer crops, particularly cotton, in the southeastern US. About 23 % of the cotton area in Alabama, Georgia and Tennessee is managed in rotation with WCC (ERS, 1997). There are many benefits of cover crops such as protecting the soil against kinetic energy of rainfall, reducing velocity and amount of runoff, increasing soil organic carbon (SOC) content, improving physical, chemical and biological soil properties, and sequestering C from the atmosphere which reduces the greenhouse effect (Dabney et al., 2001). Frequently, the residue is left on the soil surface after killing the cover crop with herbicide prior to cotton planting, but alternative uses for the WCC biomass have been proposed (Blanco-Canqui et al., 2006). However, SOC dynamics and its related soil properties are highly dependant on residue management practices. The absence of a mulch of residue could have negative effects on physical, chemical and biological soil properties because of the lower C inputs to the soil (Blanco-Canqui et al., 2006). Additionally, crop biomass removal implies transference of nutrients out of the system, increasing long term fertilizer requirements (Larson et al., 1972; Gallagher et al., 2003). However, the practice of WCC biomass removal does not imply harvest of the total biomass or a permanent condition of bare soil as well, because only part of the aboveground biomass is removed by the end of the cover crop season.

The literature is rich in references about crop residue removal, its effects on soil properties and systems productivity, but most studies have focused on removing residue from the main crop in a rotation. The crop rotation used should be also considered. Cover crop residue inputs on soil quality and productivity are more important in rotations with low-residue crops such as cotton, peanut (*Arachis hypogaea* L.) and soybean [*Glicine max* (L.) Merr.] when compared with rotations including high-residue crops such as corn and sorghum. Corn and sorghum are characterized not only by their high biomass production but also by slow residue decomposition. This type of residue represents relevant C inputs to the soil and longer soil surface coverage. Other management practices that could influence the effect of residue removal in the soil system are removal rates and frequency. Worse situations would be those combining total residue removal every year.

BIOMASS REMOVAL, SOIL ORGANIC CARBON AND SOIL PROPERTIES

Soil properties response to soil management depends on climatic conditions, soil type, crop rotation and time (Singh and Malhi, 2006). The practice of residue removal has direct and indirect effects on soil properties. It directly affects the soil because the residue acts as a barrier protecting the soil surface against the impact of rain-drops, decreasing the kinetic energy of rain before it reaches the soil and reducing particle dislodgement and transportation (Nelson, 2002). The crust forming process occurs when rain-drops impact the soil surface, detaching soil particles and dispersing aggregates (Blanco-Canqui et al., 2006). Soil crusts are responsible for low infiltration rates, poor crop emergence, reduced soil-air gas exchange and high surface runoff, with an overall negative effect on plant growth and production (Baumhardt et al., 2004; Wells et al., 2003). This represents an initial point for the soil degradation process (Thierfelder et al., 2005). The amount of residue left on the soil surface, soil type, climate and period of time with bare soil surface are factors influencing crust formation (Karlen et al., 1994; Salinas-Garcia et al., 2001). Thierfelder et al. (2005) found that soils with vegetative cover did not develop soil crusts, while bare soil did. Similar results were reported by Blanco-Canqui et al. (2006) who observed a negative effect of corn stover removal on soil surface sealing and crusting.

Residue removal indirectly affects soil properties by decreasing the amount of C inputs. Stored SOC depends on the balance between C additions (residue inputs and organic matter amendments) and losses (respiration and leaching), and is influenced by climatic conditions, nutrient availability in soil, soil water status and soil management (Mann et al., 2002; Salinas-Garcia et al., 2001). After managing a soil for a long period of time under a particular climate and residue management, SOC is expected to achieve an equilibrium level, which would have a tendency to change if we modify residue inputs (Paustian et al., 1998). Jenkinson and Rayner (1977) reported that at Rothamsted (England) the amount of annual carbon inputs required from wheat (*Triticum aestivum* L.) to maintain organic carbon levels were about 1,200 kg ha^{-1}. However, required annual inputs of C from cornstalks to keep levels of SOC were 2,700 and 4,000 kg ha^{-1} in Iowa and Indiana, respectively (Barber, 1979; Larson et al., 1972). Residue removal has the potential to reduce SOC since it decreases C entering the soil (Wilhelm et al., 2004; Larson et al., 1972). A negative effect of residue removal on SOC was observed by Clapp et al. (2000), who found a decrease in SOC and corn-derived SOC in the 0 – 15-cm soil layer after 13 yr of corn stover removal in a no-till system. Carbon inputs from crown, roots and roots exudates are not enough to avoid soil C losses in systems including residue removal (Campbell et al., 1998; Salinas-Garcia et al., 2001; Rasmussen et al., 1998; Roldan et al., 2003; Dick et al., 1998). However, it has been suggested that management practices such as crop rotations and rotation length, and rates of fertilizer could potentially improve C inputs, minimizing the negative effect of residue removal (Malhi et al., 2006). Additionally, researchers have argued that although above ground inputs of C can be higher than below ground, the latter supplies more organic C to the soil (Bolinder et al., 1999; Gale and Cambardella, 2000; Wilhelm et al., 2004). A slower root decomposition rate relative to aboveground residue could be a factor responsible for increasing the time of residence of C from roots in the soil, because roots have higher lignin content and less soluble C compared to the aboveground residue (Puget and Drinkwater, 2001; Balasdent and Balabane, 1996).

Soil organic C is a soil component that affects many physical, chemical and biological soil properties, such as soil aggregation and stability, soil penetration resistance, water holding and movement, bulk density, nutrients cycling and availability, microorganism development and soil temperature (Mann et al., 2002; Loveland and Webb, 2003; Ding et al., 2006). If residue removal decreases SOC levels, a deterioration in soil properties in response to the reduction in soil C soil should be expected. A study by Govaerts et al. (2007) reported lower infiltration and soil moisture content in a wheat-corn rotation with residue removed compared to residue retained, resulting in crop yield reduction. Research by Malhi et al. (2006) and Singh and Malhi (2006) showed that straw removal from winter crops resulted in a tendency to have a higher percentage of wind-erodible aggregates compared to straw retained. They also found a greater amount of aggregates with large weight diameter when straw was retained. According to Wilhelm et al. (2004), removal of corn stover can increase soil compaction because of the lower residue inputs to the soil and the increase in machinery traffic in the field when removing the residue. Singh and Malhi (2006) found that residue removal in a no-till barley (*Hordeum vulgare* L.) monoculture system resulted in a higher penetration resistance to a depth of 10-cm compared to residue retention. Tsuji et al. (2006) reported that levels of inorganic N and N mineralization after summer cropping in no-till conditions were lower when aboveground residue was removed, which explained why yields of winter crop were lower under residue removal conditions. Salinas-Garcia et al. (2001) found similar results with corn. They indicated there was a significant decrease in potential mineralizable N, inorganic N, soil microbial biomass C and N, and extractable phosphorus (P) with increasing levels of stover removal. With residue removal, the decrease in soil microbial biomass C and N has been associated with the decrease of labile fractions of C (water soluble C and water soluble carbohydrates) that represent sources of energy for microbial activity (Roldan et al., 2003). An increase in soil bulk density and a reduction in soil water content in response to corn stover removal were reported by Blanco-Canqui et al. (2006). However, differences between treatments with stover retained and 25 % of stover removed were not significant, hinting that a partial removal of stover may not have negative effects on soil properties. An increase in soil bulk density to a depth of 17.5-cm in response to stover removal was also indicated by Clapp et al. (2000) in a long-term corn monoculture system.

GRASS RESIDUE DECOMPOSITION AND NITROGEN DYNAMICS IN SOIL

Grass residue in no-tillage systems can cause reductions in inorganic soil N due to N immobilization (Ebelhar et al., 1984). Nitrogen immobilization is an important factor to consider for N fertilization in summer crop systems that include a rotation with grass cover crops. Immobilization occurs because N is required for residue decomposition which initially is characterized by a quick microbial growth and N assimilation (Aulakh et al., 1991; Jensen, 1997). As a result, microbes compete with the summer crop for available inorganic N in the soil during the first weeks of residue decomposition. Kuo and Sainju (1998) reported from an incubation study at 25^{o} C that rye (*Secale cereale* L.) and ryegrass (*Lolium multiflorum* L.) residue required at least 140 days for net N mineralization to occur. Similar results were summarized by Quemada and Cabrera (1995) from another incubation study in which N immobilization in a soil amended with stems of rye, wheat and oat (*Avena sativa* L.) occurred until the end of the incubation study (160 days). Henriksen and Breland (1999) and Aulakh et al. (1991) had similar results in incubation studies with barley straw and wheat, respectively. All these studies show that when there is grass residue present on the soil surface soil N immobilization occurs until several weeks after residue input. This can create a potential problem for summer crops because their peak N demand occurs before N mineralization begins. This would help explain why N fertilization requirements are higher in conservation systems that include high levels of residue with a large C/N ratio (Rice and Smith, 1984).

COTTON NITROGEN FERTILIZATION

Proper N fertilization is key when growing cotton, because of its influence in vegetative and reproductive plant growth. Nitrogen is applied in 82 % of the cotton area in US (The Fertilizer Institute, 2003). Optimal N rates are required to maximize cotton yield, while low or excessive rates can reduce crop productivity (Boquet and Breitenbeck, 2000). Most common effects of N deficiency are reductions in vegetative growth, boll production and set, and yield (McConnell et al., 1993). Over application of N can lead to excessive vegetative growth, delay in maturity and harvest, promotion of boll shedding, reduction of fiber quality and yield, and increased water pollution (Harris and Smith, 1980; Boquet and Breitenbeck, 2000). Optimum N rates for cotton depend on the potential yield, tillage method, N sources, type of soil, method of N application, water availability, cover crop use and cover crop species used (Howard et al., 2001; Boquet et al., 2004).

Cotton requires about 70 kg N ha^{-1} to produce one bale of lint (Hodges, 1995). Mitchell (1996) stated that the recommended N rate for fine-textured soils in the

Tennessee Valley is 67 kg ha^{-1} and 100 kg ha^{-1} for coarser soils. The same author suggests increasing N rates by about 34 kg ha^{-1} for cotton growing in conservation tillage systems with small grain cover crop residue. Boquet et al. (2004) indicated that 118 kg N ha^{-1} as required to maximize cotton yields after no-legume cover crops, a rate higher than that commonly used for cotton planted over native cover on loess soils. According to Howard et al. (2001) maximum cotton lint yields were obtained with applications of 67 kg N ha^{-1} to cotton following winter wheat and 101 kg N ha^{-1} to cotton planted into corn stover. Wiatrak et al. (1999) found a response of cotton lint yield up to 120 kg N ha^{-1} averaged over tillages and winter cover crops. Results reported by Reiter et al. (2002) suggest that 134 kg N ha^{-1} could be required to optimize cotton yields in a high rye residue conservation system. However, a study by Bronson et al. (2001) revealed that the optimum N rate for irrigated conservation tillage cotton with lint yields of 1,100 kg ha^{-1} was 61 kg ha^{-1}, a N rate lower than most of those mentioned for cotton following non-legume cover crop in conservation systems.

The increase in N fertilizer requirements for cotton under conservation tillage compared to conventional tillage can be explained by N immobilization and ammonia volatilization processes occurring as consequence of having high levels of residue on the soil surface with a high C/N ratio (Reiter et al., 2002). However, N fertilizer requirements in long term conservation tillage systems may decrease with time, since build up SOC is accompanied by an increase in organic N levels. This can potentially increase the amount of N mineralized annually from organic sources (Dinnes et al., 2007). In those systems when aboveground biomass of small grain cover crop is removed a decrease of N immobilization would be expected because there is a substantial reduction in the amount of high C/N residue left over the soil. In this situation, we could anticipate lower optimum N rates for cotton than those reported for cotton growing in a high residue conservation tillage system with residue retained.

Tissue tests are sometimes used to measure the N status in cotton plants and to establish a relationship with management practices. Petiole nitrate test is a common method utilized to examine N status in cotton plants but it is highly sensitive to changes in soil moisture, providing variable results when used in non-irrigated cotton (Bell et al., 2003). On the other hand, N concentration in the leaf blade can be a good indicator of the N status in cotton plants (Gerik et al., 1994). It is also less sensitive to soil moisture variability compared to the petiole nitrate test and results can be had in a short period of time (Bell et al., 2003). The main disadvantage of this methodology is its high cost (Gerik et al., 1994). As summarized by Sabbe et al., (1972) and Mills and Jones (1996), sufficient levels of leaf N at first match head square and mid-bloom are indicated by leaf N contents between 30 and 45 kg N kg^{-1}. Values lower and higher than this range are considered as deficient and excessive, respectively. Similar sufficiency levels were reported by Mitchell and Baker (2000). However, research by Bell et al. (2003) established leaf blade N critical values of 54 and 41 g N kg^{-1} for the southeastern US, at first pinhead square and mid-bloom, respectively, considering relative cotton yields of 90 %. These sufficiency levels can provide some information on the N status of a particular cotton crop, but the N management (rates, method of application and application time) to achieve the sufficiency N levels in tissues should be done based on recommendations developed for each specific region in which cotton is being grown.

REFERENCES

Aulakh, M.S., J.W. Doran, D.T. Walters, A.R. Moiser, and D.D. Francis. 1991. Crop residue type and placement effects on denitrification and mineralization. Soil Sci. Soc. Am. J. 55:1020-1025.

Balasdent, J., and M. Balabane. 1996. Major contribution of roots to soil carbon storage inferred from maize cultivated soils. Soil Biol. Biochem. 9:1261-1263.

Barber, S.A. 1979. Corn residue management and soil organic matter. Agron. J. 71:625-627.

Baumhardt, R.L., P.W. Unger, and T.H. Dao. 2004. Seedbed surface geometry effects on soil crusting and seedling emergence. Agron. J. 96:1112-1117.

Bell, P.F., D.J. Boquet, E. Millholln, S. Moore, W. Ebelhar, C.C. Mitchell, J. Varco, E.R. Funderburg, C. Kennedy, G.A. Breitenbeck, C. Craig, M. Homlman, W. Baker, and J.S. McConnell. 2003. Relationship between leaf-blade nitrogen and relative seedcotton yields. Crop Sci. 43:1367-1374.

Blanco-Canqui, H., R. Lal, W.M. Post, R.C. Izaurralde, and L.B. Owens. 2006. Corn stover impacts on near-surface soil properties of no-till corn in Ohio. Soil Sci. Soc. Am. J. 70:266-278.

Bolinder, M.A., D.A. Angers, M. Giroux, and M.R. Laverdiere. 1999. Estimating C inputs retained as soil organic matter from corn (*Zea Mays* L.). Plant and Soil. 215:85-91.

Boquet, D.J., R.L. Hutchinson, and G.A. Breitenbeck. 2004. Long-term tillage, cover crop, and nitrogen rate effects on cotton: yield and fiber properties. Agron. J. 96:1436-1442.

Boquet, D.J., and G.A. Breitenbeck. 2000. Nitrogen rate on partitioning of nitrogen and dry matter by cotton. Crop Sci. 40:1685-1693.

Bronson, K.F., A.B. Onken, J.W. Keeling, J.D. Booker, and H.A. Torbert. 2001. Nitrogen response in cotton as affected by tillage system and irrigation level. Soil Sci. Soc. Am. J. 65:1153-1163.

Campbell, C.A., F. Selles, G.P. Lafond, B.G. McConkey, and D. Hahn. 1998. Effect of crop management on C and N in long-term crop rotations after adopting no-tillage management: comparison of soil sampling strategies. Canadian J. Soil Sci. 78:155-162.

Causarano, H.J., A. J. Franzluebbers, J.N. Shaw, D. W. Reeves, R.L. Raper, and C.W. Wood. 2008. Soil organic carbon fractions and aggregation in the Southern Piedmont and Coastal Plain. Soil Sci. Soc. Am. J. 72:221-230.

Clapp, C.E., R.R. Allmaras, M.F. Layese, and D.R. Linden. 2000. Soil carbon and ^{13}C abundance as related to tillage, crop residue, and nitrogen fertilization under continuous corn management in Minnesota. Soil Till. Res. 55:127-142.

Dabney, S.M., J.A. Delgado, and D.W. Reeves. 2001. Using cover crops to improve soil quality. Commun. Soil Sci. Plant Anal. 32:1221-1250.

Dick, W.A., R.L. Blevins, W.W. Frye, S.E. Peters, D.R. Christensen, F.J. Pierce, and M.L. Vitosh. 1998. Impacts of agricultural management practices on C sequestration in forest-derived soils of the eastern Corn Belt. Soil Till. Res. 47:235-244.

Ding, G., X. Liu, S. Herbert, J. Novak, D. Amarasiriwardena, and B. Xing. 2006. Effect of cover crop management on soil organic matter. Geoderma. 130:229-239.

Dinnes, D., D. Jaynes, T. Kaspar, T. Colvin, C.A. Cambardella and D.L. Karlen. 2007. Plant-soil-microbe N relationships in high residue management systems [Online]. Available at http://www.sdnotill.com/Newsletters/Relationships.pdf (verified 30 April 2008).

Ebelhar, S.A., W.W. Frye, and R.L. Blevins. 1984. Nitrogen from legume cover crops for no-till corn. Agron. J. 76:51-55.

Economic Research Service (ERS). 1997. General crop management practices [Online]. Available at http://www.ers.usda.gov/publications/sb969/sb969e.pdf (verified 25 March 2007).

Gale, W.J., and C.A. Gambardella. 2000. Carbon dynamics of surface residue-and root-derived organic matter under simulated no-till. Soil Sci. Soc. Am. J. 64:190-195.

Gallagher, P.W., M. Dikeman, J. Fritz, E. Wailes, W. Gouthier, and H. Shapourt. 2003. Supply and social cost estimates for biomass from crop residues in the United States. Environ. Res. Eco. 24:335-358.

Gallaher, R.N. 2002. History and future challenges and opportunities in conservation tillage for a sustainable agriculture: research and extension perspective. p. 2-11. *In.* E. van Santen (ed.) Making conservation tillage conventional: building a future on 25 years of research. Proc. Annu. Southern Conservation Tillage Conf. for Sustainable Agric., 25th, Auburn, AL, 24-26 June 2002. Special Report No. 1, Alabama Agricultural Exp. Station and Auburn University.

Gerik, T.J., B.S. Jackson, C.O. Stockle, and W.D. Rosenthal. 1994. Plant nitrogen status and boll load of cotton. Agron. J. 86:514-518.

Govaerts, B., M. Fuentes, M. Mezzalama, J.M. Nicol, J. Deckers, J.D. Etchevers, B. Figueroa-Sandoval, and K.D. Sayre. 2007. Infiltration, soil moisture, root rot and nematode populations after 12 years of different tillage, residue and crop rotation managements. Soil Till. Res. 94:209-219.

Harris, C.H., and C.W. Smith. 1980. Cotton production affected by row profile and N rates. Agron. J. 72:919-922.

Henriksen, T.M., and T.A. Breland. 1999. Evaluation of criteria for describing crop residue degradability in a model of carbon and nitrogen turnover in soil. Soil Biol. Biochem. 31:1135-1149.

Hodges, S.C. 1995. Nitrogen Fertilization [Online]. Available at http://hubcap.clemson. edu/~blpprt /nitrofer. html (verified 14 December 2007).

Howard, D.D., C.O. Gwathmey, M.E. Essington, R.K. Roberts, and M.D. Mullen. 2001. Nitrogen fertilization of no-till cotton on loess-derived soils. Agron. J. 93:157-163.

Jenkinson, D.S., and J.H. Rayner. 1977. The turnover of soil organic matter in some of the Rothamsted classical experiments. Soil Sci. 123:298-305.

Jensen, E.S. 1997. Nitrogen immobilization and mineralization during initial decomposition of ^{15}N-labeled pea and barley residue. Biol Fert. Soils. 24:39-44.

Karlen, D.L., N.C. Wollenhaupt, D.C. Erbach, D.C. Berry, E.C. Swan, J.B. Swan, N.S. Eash, and J.L. Jordahl. 1994. Crop residue effects on soil quality following 10 years of no-till corn. Soil Till. Res. 31:149-167.

Kuo, S., and E.J. Jellum. 2002. Influence of winter cover crop and residue management on soil nitrogen availability and corn. Agron. J. 94:501-508.

Kuo, S., and U.M Sainju. 1998. Nitrogen mineralization and availability of mixed leguminous and non-leguminous cover crop residues in soil. Biol. Fertil. Soils. 26:346-353.

Kuo, S., U.M. Sainju, and E.J. Jellum. 1997. Winter cover crop effects on soil organic carbon and carbohydrate in soil. Soil Sci. Soc. Am. J. 61:145-152.

Larson, W.E., C.E. Clapp, W.H. Pierre. and Y.B. Morachan. 1972. Effects of increasing amount of organic residues on continuous corn. II. Organic carbon, nitrogen, phosphorus and sulfur. Agron. J. 64:204-208.

Loveland, P., and J. Webb. 2003. Is there a critical level of organic matter in the agricultural soils of temperate regions: a review. Soil Till. Res. 70:1-18.

Malhi, S.S., R. Lemke, Z.H. Wang, and B.S. Chhabra. 2006. Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions. Soil Till. Res. 90:171-183.

Mann, L., V. Tolbert, and J. Cushman. 2002. Potential environmental effects of corn (*Zea mays* L.) stover removal with emphasis on soil organic matter and erosion. Agric. Ecosyst. Environ. 89:149-166.

McConnell, J.S., W.H. Baker, D.M. Miller. B.S. Frizzell, and J.J. Varvil. 1993. Nitrogen fertilization of cotton cultivars of differing maturity. Agron. J. 85:1151-1156.

McSorley, R. 2008. Cultural methods for management of nematodes in Florida [Online]. Available at http://swfrec.ifas.ufl.edu/LIV/groups/cultural/pests/flnema.htm (verified 30 April 2008).

Mills, H.A., and JB. Jones. 1996. Plant analysis handbook II : a practical sampling, preparation, analysis, and interpretation guide. Micro-Macro Pub. Athens, GA, 422 pp.

Mitchell, C.C. 1996. Nitrogen Fertility. P. 7-9. *In* C.D. Monks and M.G. Paterson (ed.) Conservation tillage cotton production guide. ANR-952. Auburn Univ. Agron. And Soils Dep., Auburn, AL, U.S.

Mitchell, C.C., and W.H. Baker. 2000. Reference sufficiency range field crops. *In* C.R. Campbell (ed.) Reference Sufficiency Ranges for Plant Analysis in the Southern Region of the United States [Online]. Available at http://www.agr.state.nc.us /agronomi/saaesd/s394.htm (verified 22 April 2008).

National Agricultural Statistics Service (NASS). 2007. Cotton national statistics [Online]. Available at http://www.nass.usda.gov/QuickStats/index2.jsp#footnotes (verified 15 April 2008).

Nelson, R.G. 2002. Resource assessment and removal analysis for corn stover and wheat straw in the Eastern and Midwestern United States-rainfall and wind-induced soil erosion methodology. Biomass Bio. 22:349-363.

Paustian, K., C.V. Cole, D. Sauerbeck, and N. Sampson. 1998. CO2 mitigation by agriculture: an overwiew. Climatic Change. 40: 135-162.

Phillips, S.H., and H.M. Young. 1973. No-tillage Farming. Reiman Assoc., Milwaukee, WI, 224 pp.

Puget, P., and L.E. Drinkwater. 2001. Short-term dynamics of root-and shoot-derived carbon from a leguminous green manure. Soil Sci. Soc. Am. J. 65:771-779.

Quemada, M., and M.L. Cabrera. 1995. Carbon and nitrogen mineralized from leaves and stems of four cover crops. Soil Sci. Soc. Am. J. 59:471-477.

Ranells, N.N., and M.G. Wagger. 1996. Nitrogen release from grass and legume cover crop monocultures and bicultures. Agron. J. 88:777-782.

Rasmussen, P.E., S.L. Albretch, and R.W. Smiley. 1998. Soil C and N changes under tillage and cropping systems in semi-arid Pacific Northwest agriculture. Soil Till. Res. 47:197-205.

Reiter, M.S., D.W. Reeves, and C.H. Burmester. 2002. Nitrogen management for cotton in a high-residue cover crop conservation tillage system. p. 136-141. *In.* E. van Santen (ed.) Making conservation tillage conventional: building a future on 25 years of research. Proc. Annu. Southern Conservation Tillage Conf. for Sustainable Agric., 25th, Auburn, AL, 24-26 June 2002. Special Report No. 1, Alabama Agricultural Exp. Station and Auburn University.

Rice, C.W., and M.S. Smith. 1984. Short-term immobilization of fertilizer nitrogen at the surface of no-till and plowed soils. Soil Sci. Soc. Am. J. 48:295-297.

Roldan, A., F. Caravaca, M.T. Hernandez, C. Garcia, C. Sanchez-Brito, M. Velasquez, and M. Tiscareño. 2003. No-tillage, crop residue additions, and legume cover cropping effects on soil quality characteristics under maize in Patzcuaro watershed (Mexico). Soil Till. Res. 72:65-73.

Sabbe, W.E., J.L. Keogh, R. Maples, and L.H. Hileman. 1972. Nutrient analysis of Arkansas cotton and soybean leaf tissue. Arkansas Farm Res. 21:2.

Sainju, U.M., B.P. Singh, and W.F. Whitehead. 2005. Tillage, cover crops, and nitrogen fertilization effects on cotton and sorghum root biomass, carbon and nitrogen. Agron. J. 97:1279-1290.

Salinas-Garcia, J.R., A.D. Baez-Gonzalez, M. Tiscarenio-Lopez, and E. Rosales-Robles. 2001. Residue removal and tillage interactions effects on soil properties under rain-fed corn production in central Mexico. Soil Till. Res. 59:67-79.

Schomberg, H.H., R.G. McDaniel, E. Mallard, D.M. Endale, D.S. Fisher and M.L. Cabrera. 2006. Conservation tillage and cover crop influence on cotton production on a Southeastern U.S. Coastal Plain soil. Agron. J. 98:1247-1256.

Schomberg, H.H., and D.M. Endale. 2004. Cover crop effects on nitrogen mineralization and availability in conservation tillage cotton. Biol Fert. Soils. 40:398-405.

Singh, B., and S.S. Malhi. 2006. Response of soil physical properties to tillage and residue management on two soils in a cool temperate environment. Soil Till. Res. 85:143-153.

The Fertilizer Institute. 2003. U.S. fertilizer data [Online]. Available at http://www.tfi.org/mediacenter/stats.cfm (verified 3 April 2008).

Thierfelder, C., E. Amezquita, and K. Starh. 2005. Effects of intensifying organic manuring and tillage practices on penetration resistance and infiltration rate. Soil Till. Res. 82:211-226.

Tsuji, H., H. Yamamoto, K. Matsuo, and K. Usuki. 2006. The effects of long-term conservation tillage, crop residues and P fertilizer on soil conditions and responses of summer and winter crops on an Andosol in Japan. Soil Till. Res. 89:167-176.

Unger, P.W., and T.M. McCalla. Conservation tillage systems. Adv. Agron. 45:1-58.

Wells, R.R., D.A. DiCarlo, T.S. Steenhuis, J.Y. Parlange, M.J.M. Romkens, and S.N. Prasad. 2003. Infiltration and surface geometry features of a swelling soil following successive simulated rainstorms. Soil Sci. Soc. Am. J. 67:1344-1351.

Wiatrak, P.J., D.L. Wright, F.M. Rhoads, S. Reed, and J. Pudelko. 1999. Tillage and nitrogen influence on cotton. P. 170-176. *In.* J.E. Hook (ed.) Proceedings of the 22nd Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Tifton, GA. 6-8 July 1999. Georgia Agriculture Experiment Station Special Publication 95. Athens, GA, US.

Wilhelm, W.W., J.M.F. Johnson, J.L. Hatfield, W.B. Voorhees, and D.R. Linden. 2004. Crop and soil productivity response to corn residue removal: a literature review. Agron. J. 96:1-17.

II. EFFECT OF RYE RESIDUE ON SOIL PROPERTIES OF A COASTAL PLAIN SOIL

ABSTRACT

The use of rye (*Secale cereale* L.) biomass as an alternative source for energy production or animal feed can make cover crops a more attractive option, allowing farmers to increase revenue and long-term sustainability of their production systems. The objective of this research was to determine the impact of rye residue management (RM) on soil properties of a Marvyn loamy sand (fine-loamy, kaolinitic, thermic Typic Kanhapludult), in central Alabama, US, managed under conservation tillage. We evaluated the effect of no winter cover crop (NC), rye residue removed (REM) and rye residue retained (RET) on carbon (C) and nitrogen (N) inputs to the soil system from the cover crop residue, total soil organic C (TOC), particulate organic matter C (POMC), mineral-associated + water-soluble C (maC), total soil N (TN), particulate organic matter N (POMN), mineral-associated + water-soluble N (maN), water-stable aggregates, soil bulk density, soil penetration resistance, infiltration rate, hydraulic conductivity of saturated soil, soil water retention, soil water content and soil N mineralization/immobilization, using a randomized complete block design with four replications. Lower residue inputs in REM significantly decreased TOC, POMC, maC and TN by 25, 29, 21 and 29 %, respectively, to a depth of 5-cm, compared to RET. This reduction in the soil C and N concentration in REM compared to RET accounted for a decrease of 7 % of the soil water retention across matric potentials in RET (0.165 m^3 m^{-3}) relative to REM (0.154 m^3 m^{-3}), and for an increase of 5 % of the bulk density in RET (1.57 Mg m^{-3}) relative to REM (1.49 Mg m^{-3}), to a depth of 5-cm. Rye residue removed decreased the soil water content early in the cotton (*Gossypium hirsutum* L.) season by 19 and 7 % in 2006 and 2007, respectively, compared to RET. There were no significant differences between RET and REM in water-stable aggregates, soil penetration resistance, infiltration rate, hydraulic conductivity and amount of soil N mineralized/immobilized. No winter cover crop treatment had the highest values of penetration resistance and bulk density, and in general the lowest values for all others soil properties evaluated. These results show that short-term residue removal can negatively affect C and N accumulation in soil as well as some physical properties in the surface of this Coastal Plain soil.

INTRODUCTION

The use of conservation tillage combined with winter cover crops plays a key role in the sustainability of cotton production systems in the southeastern US. Soils in this area are sandy and usually have sub-surface compacted horizons that restricts root growth (Schomberg et al., 2006b). Many have also been tilled for a long time resulting in a

---

Abbreviations: C, carbon; K, potassium; maC, mineral-associated + water-soluble C; maN, mineral-associated + water-soluble N; NC, no winter cover crop; N, nitrogen; P, phosphorus; POMC, particulate organic matter C; POMN, particulate organic matter N; REM, rye residue removed; RET, rye residue retained; RM, rye residue management; S, sulfur; TN, total soil N; TOC, total soil organic carbon.

depletion of their naturally low levels of soil organic carbon and a deterioration of C dependant soil physical and chemical properties (Causarano et al., 2008). Conservation tillage, in-row subsoiling and use of winter cover crops in rotation with summer crops are commonly recommended management practices to increase crop productivity and long-term sustainability of these Coastal Plain soils (Hunt et al., 2004; Causarano et al., 2008). Grass winter cover crops such as rye can account for large inputs of C to the soil system, increasing soil organic C levels, improving physical and chemical properties and minimizing runoff (Raper et al., 2000; Roselem et al., 2002). Regardless of all the potential long-term benefits of using cover crops, their establishment and management can cost farmers 80 and 130 USD ha^{-1} year^{-1} for rye and crimson clover (*Trifolium incarnatum* L.), respectively (Morton et al., 2006), which has been one of the limiting factors for their adoption in farming systems (McDonald et al., 2008). As an example, only 20 % of the cotton grown in Alabama under conservation tillage is in rotation with cover crops (ERS, 1997).

The accumulated cover crop biomass at the end of the winter season can be removed and utilized as an alternative energy source or for animal feed helping farmers increase their profits and economic sustainability. In this situation, all those soil properties dependent on soil C levels could be seriously affected as a result of the substantial aboveground biomass removal (Blanco-Canqui et al., 2006). There have been reports indicating a negative effect of biomass removal on water infiltration (Govaerts et al., 2007), soil aggregation (Malhi et al., 2006; Singh and Malhi, 2006), soil compaction (Wilhelm et al., 2004; Singh and Malhi, 2006), bulk density (Clapp et al., 2000; Blanco-Canqui et al., 2006), and soil N mineralization (Tsuji et al., 2006; Salinas-Garcia et al., 2001). This negative impact of residue removal on soil properties could be magnified when growing low-residue cash crops such as cotton (Nyakatawa et al., 2001).

Most of the studies involving biomass removal have focused on the effect of complete removal of cash crop biomass on soil properties. In a winter cover crop biomass removal scenario, not all the cover crop biomass needs to be removed allowing the soil to remain partially covered between the end of the winter season until the summer crop canopy develops and covers the inter-row space. Thereby, the cover crop would still protect the soil from erosion during the winter months. In addition, cover crop roots would still contribute to alleviation of sub-surface soil compaction, a common problem in these Coastal Plain soils (Schomberg et al., 2006b). Roots could also add some valuable C to the soil (Balasdent and Balabane, 1996; Puget and Drinkwater, 2001; Gale and Gambardella, 2000; Molina et al., 2001). Carbon inputs from root exudates and dead roots occur directly in the soil, favoring aggregation, porosity, and water retention and movement (Sainju et al., 2005; Williams and Weil, 2004).

The objective of this study was to assess the impact of rye residue removal on physical and chemical soil properties in a conservation monoculture cotton system in the southeastern US.

MATERIALS AND METHODS

A 2-year field experiment under supplemental irrigation was established in November 2005 at the Alabama Agricultural Experiment Station’s E.V. Smith Research Center – Field Crops Unit (32^o 25’ 19” N, 85^o 53’ 7” W), near Shorter, in central Alabama, US. The soil was a Marvyn loamy sand (fine-loamy, kaolinitic, thermic Typic

Kanhapludult) (NRCS, 2007). This area is characterized by a humid subtropical climate, with an average annual precipitation of about 1100 mm (Schomberg et al., 2006b). The experimental site was previously managed with conventional tillage. Three RM strategies were evaluated: NC, REM and RET. The size of the plots was 18-m long by 8-m wide. In April 2006 soil samples were taken at two depths (0-10 and 10-20-cm) in the experimental area for analysis of selected chemical properties (Table 1-1).

Field methods

Soil management

Before planting rye the first year, the entire area was deep-tilled with a non-inversion, bent-leg subsoiler to a depth of 46-cm to remove any soil compaction from previous tillage, after which it was leveled with a field cultivator. In early May each year the experimental area was tilled in-row (1-m between rows) with a narrow-shanked subsoiler to a depth of 40-cm. The in-row tillage was conducted using a tractor with a mounted Trimble AgGPS Autopilot automatic steering system (Trimble, Sunnyvale, CA 94088)[1], with centimeter level precision, to avoid compaction in cotton rows. No cover crop plots were kept free of weeds by applying herbicides when required.

---

[1] Mention of a company does not imply approval or recommendation of the company by Auburn University or USDA-Agricultural Research Service to the exclusion of others that may be suitable.

Table 1-1. Selected soil chemical properties measured in the experimental area at the Field Crops Unit near Shorter, AL in May 2006.

			-----------	Melich-1 extractable		------------
Soil depth	Soil pH	Total soil organic C	P	K	Mg	Ca
cm		--------------------------		g kg $^{-1}$		---------------------------
0-10	6.4	3.53	31	35	28	325
10-20	6.5	3.39	50	55	42	548

Crop management

Rye (cultivar "Elbon") was drilled at 100 kg ha^{-1} in early November each year using a no-till drill. Plots planted with rye received 40 and 30 kg N ha^{-1} as ammonium nitrate applied manually three weeks after planting and in late February, respectively. In the RET treatment, rye was rolled down at the early milk development stage (Zadoks et al., 1974) in late April each year, then sprayed with glyphosate (N-phosphonomethyl glycine) at a rate of 0.9 kg a.i.ha^{-1}. At the same time, rye biomass in the REM treatment was mechanically harvested to a height of 10-cm over the soil surface and removed from the plots.

The entire experimental area received an application of 21, 10, 42 and 6 kg ha^{-1} of N, P, potassium (K) and sulfur (S), respectively, in early May each year, based on the Alabama Cooperative Extension System soil test recommendations (Adams and Mitchell, 2000). Cotton, cultivar DP 454 BG/RR (Delta Pine and Land Co., Scott, MS)[1], was planted during the third week of May each year using a four-row planter John Deere Max Emerge Plus (Deere&Company, Moline, IL)[1] at a rate of 17 seeds m^{-1}. Row spacing was one meter. Herbicides, insecticides and defoliant applied to cotton were based on the Alabama Cooperative Extension System's recommendations (ACES, 2006). The entire research area received supplemental irrigation of 70 and 160 mm during the 2006 and 2007 cotton seasons, respectively, using a linear-movement sprinkler irrigation system. Nitrogen fertilization for cotton was performed by manually broadcasting 72 kg N ha^{-1} as ammonium nitrate at the first pinhead square stage. Before cotton harvest one meter of each end of the plots was cut off with a rotary mower. Cotton was mechanically harvested in the first week of October in 2006 and in the third week of September in

2007, using a spindle picker. After harvesting, cotton stalks were shredded with a rotary mower.

Data Collection

Cover crop

Each year, before cover crop termination in RET and after the biomass removal in REM the amount of aboveground rye biomass was determined by randomly sampling three 0.25 m^2 areas in each plot. No samples were collected from the no winter cover crop plots since they were kept weed free. Rye biomass samples were dried in an air forced oven at 55^o C until constant weight to determine dry matter biomass. Each rye sample was ground to pass a 2 mm screen with a Wiley mill (Thomas Scientific, Swedesboro, NJ)[1] and ground again to pass a 1 mm screen with a cyclone grinder (Thomas Scientific, Swedesboro, NJ)[1]. Total C and N were determined in each sample by dry combustion using a LECO TruSpec analyzer (LECO Corp., St. Joseph, MI)[1]. The potential amount of C and N entering the soil in each plot was calculated considering the rye biomass production and its C and N concentration.

Soil

The percent of water-stable aggregates was determined following the procedure suggested by Nimmo and Perkins (2002). A composite of four sub-samples was taken to a depth of 10-cm from each plot, in May 2006 and October 2007.

Soil penetration resistance from untrafficked interrows was measured using a SC 900 Soil Compaction Meter (Spectrum technologies, Inc., Plainfield, IL)[1] in June 2006, June 2007 and March 2008. Eight measurements per main plot were taken to a depth of 40-cm in June 2006 and March 2008, and to a depth of 35-cm in June 2007. Measurements were taken after the occurrence of a rainfall or irrigation event, when the soil water content was near field capacity. The volumetric water content (0-20-cm) when measuring the penetration resistance was 0.097, 0.095 and 0.134 m^3 m^{-3} in June 2006, 0.11, 0.11 and 0.13 m^3 m^{-3} in June 2007 and 0.13, 0.145 and 0.143 m^3 m^{-3} in March 2008 for NC, REM and RET, respectively. We determined that the soil water content at field capacity (-30 kPa) to a depth of 20-cm in our experimental area was 0.14 m^3 m^{-3}.

Composite soil samples consisting of four cores per plot were taken from un-trafficked interrows at two depths (0-5 and 5-10-cm) using a soil core sampler (7.5-cm diameter) for water retention determination utilizing a pressure plate extractor (Dane and Hopmans, 2002) at four matric potential (0, -30, -50 and -100 kPa). Sampling times were May 2006 and October 2007. The hydraulic conductivity of saturated soil was measured in the same undisturbed soil core samples using the falling-head method (Klute and Dirksen, 1986). Finally, the soil core samples were dried in a convection oven at 105^o C until constant weight was achieved. Oven-dry bulk density was calculated for each depth by calculating soil mass per unit volume.

Water infiltration was measured from untrafficked interrows in June 2006, June 2007 and October 2007 using a double ring infiltrometer following the procedure outlined by Reynolds et al. (2002). Three readings per main plot were collected.

Composite soil samples at four depths (0-2.5, 2.5-5, 5-10 and 10-20-cm) were collected in May 2006 and October 2007, for analysis of TOC and TN. Soil samples were dried in a forced air oven at 55^o C for 72 h, lightly crushed using a soil grinder (Custom

Laboratory Equipment Inc., Orange City, FL)^1 and finely ground using a mortar. Before drying the soil samples, sub-samples were taken from the samples at 0-2.5, 2.5-5 and 5-10-cm depths in May 2006 and from all depths in October 2007, for analysis of POMC, maC, POMN and maN following a methodology similar to the one cited by Cambardella and Elliot (1992). The C and N concentration in each fraction previously described was determined by dry combustion using a LECO TruSpec analyzer (LECO Corp., St. Josepch, MI)^1. Total soil organic carbon and TN stratification ratios were calculated by dividing the soil concentration of each parameter for the 0-5-cm depth by its concentration for the 10-20-cm depth (Franzluebbers, 2002a). All collected soil samples were taken from untrafficked interrows. Surface plant residue was carefully removed from each sampling point before taking the soil sample.

Volumetric soil water content was measured during the cotton growing seasons using a frequency-domain reflectometry device TDR-300 Probe (Spectrum Technologies Inc., Plainfield, IL)^1. Five readings per plot were taken to a depth of 20-cm and 15-cm away from cotton rows in the untrafficked interrows, at 0, 19, 28, 32, 34, 38, 42, 49, 54, 73 and 87 days after planting (DAP) in 2006 and at 0, 15, 22, 37, 43, 48, 55, 69, 76 and 82 DAP in 2007.

In situ soil N mineralization was studied using closed-top solid cylinders (Hart et al., 1994). Four PVC cylinders (5-cm inner diameter) per plot were gently inserted to a depth of 20-cm in untrafficked interrows, immediately before cotton N fertilization (37 DAP in 2006 and 2007). The top of the cylinders were covered with a cup to avoid entry of fertilizer, rain or irrigation water, but still allowing gas exchange. Soil from each cylinder was collected at the cotton cutout stage (92 DAP in 2006 and 2007), oven dried at 55° C until constant weight and analyzed for NO_3-N and NH_4-N using the microscale method (Sims, 1995). When installing cylinders, composite soil samples to a depth of 20-cm were taken from the soil around each cylinder, oven dried at 55° C and analyzed for NO_3-N and NH_4-N following the procedure previously mentioned. Amounts of mineral N (kg ha^{-1}) were calculated using data of soil bulk density and soil mineral N concentration for each RM, at each sampling time. The amount of N mineralized/immobilized was calculated by subtracting the amount of N at the beginning of the incubation study from the amount at the end of this period (Hart et al., 1994).

Experimental design and statistical analysis

The experimental design was a randomized complete block with four replications. Data for each variable were analyzed using the MIXED procedure of the Statistical Analysis System (SAS) (Littell et al., 2006). The LSMEANS PDIFF option was used to establish mean differences between treatments. Treatments were considered as fixed and replication as random effects. The statistical analysis for all the soil properties was performed for each sampling time individually. Soil water retention data was analyzed separately for each matric potential. Total soil organic carbon, POMC, maC, TN, POMN, maN, soil bulk density, hydraulic conductivity and water retention data were analyzed considering RM as the main factor (plots) and depth as a subfactor (subplots) (split-plot arrangement in a randomized complete block). No data regarding depth effects will be discussed unless the interaction RM x depth was significant. A significance level of $P \leq 0.05$ was defined *a priori.*

RESULTS AND DISCUSSION

Carbon and nitrogen inputs from rye

Rye residue management treatments influenced the amount of aboveground C and N inputs to the system. Rye residue removal accounted for a decrease of 87 and 93 % of C and N inputs from rye during the experimental period, respectively, when compared to RET (Table 1-2). Rye residue management also affected the quality of the material left in the field. In REM, most of the material removed consisted of leaves and tops of shoots, those plant components higher in N and soluble C. As a result, in both seasons the N content of the remaining residue was very low, with a higher C/N ratio compared to RET.

In 2006, the C/N ratio for the rye residue left in RET was only slightly higher than the 25-30 critical range reported by Jensen (1997) above which N immobilization is expected to occur. In 2007, there was less rye residue than in 2006 and the residue contained 52 % less N and 30 % less C and had a higher C/N ratio.

Table 1-2. Amount of carbon and nitrogen inputs to the system from aboveground rye residue for REM and RET during the experimental period.

	RM [†]	Year		
		2006	2007	Total
		------------------	$kg\ ha^{-1}$	------------------
Carbon	REM[‡]	480	230	710
	RET	3179	2230	5409
Nitrogen	REM	7	3	10
	RET	97	47	144
C/N ratio	REM	69	77	71
	RET	33	47	38

[†] RM = rye residue management

[‡] REM = rye residue removed

RET = rye residue retained

Total soil organic carbon and total soil nitrogen

In May 2006 there was no RM effect on TOC and POMC, but maC was significantly affected by RM (Table 1-3). No winter cover crop and REM treatments had similar values across depths but significantly lower values compared to RET ($P \leq 0.01$ and $P = 0.05$, respectively) (Fig. 1-1). Since soil samples were taken one month after killing the rye, decomposition of readily decomposable soluble sources of C from the rye residue in the RET treatment and its movement into the soil with rain and/or irrigation may account for the differences observed. This association between maC and labile sources of C was previously reported by Laird et al. (2001). There was also a significant RM effect at this sampling time on TN and maN averaged across depths (0-20 and 0-10-cm, respectively) (Fig. 1-2). Total N was significantly higher for RET and REM compared to NC ($P \leq 0.01$ and $P \leq 0.01$, respectively). A similar trend occurred for maN, with REM and RET having significantly higher concentrations than NC ($P \leq 0.01$ and $P \leq 0.01$, respectively). Total N and maN concentrations were similar for REM and RET. These data show that one growing season of rye was enough to produce differences between both treatments including rye relative to NC. The contribution of root exudates to the soil N during the rye season could explain these results. An effect of rye roots on soil N was previously reported by Kavdir and Smucker (2005), who found ^{15}N in the soil only 17 days after labeling rye plants with ^{15}N. They also stated that rhizodeposition's contribution to soil N occurred during all their experimental period.

In October 2007, there was a significant RM x Depth interaction for TOC, POMC and maC (Table 1-3). To a depth of 2.5-cm, RET had significantly higher TOC, POMC and maC concentrations than REM and NC ($P \leq 0.01$ and $P \leq 0.01$, respectively, for each parameter) (Fig. 1-1). Additionally, REM had higher values for the same parameters when compared to NC ($P \leq 0.01$, $P=0.04$ and $P=0.03$, respectively). For the 2.5-5-cm depth, RET had significantly higher TOC, POMC and maC soil concentration values when compared to NC ($P \leq 0.01$, $P \leq 0.01$ and $P \leq 0.01$, respectively) and REM ($P \leq 0.01$, $P=0.04$ and $P=0.02$, respectively). However, differences between NC and REM were not significant. For depths below 5-cm there was not a significant RM effect on the soil C fractions studied. Our findings coincide with results of Salinas-Garcia et al. (2001), who observed reductions in soil organic C to a depth of 5-cm in response to corn stover removal. Similar results were reported by Clapp et al. (2000).

For the 0-2.5-cm depth, the TOC soil concentration for RET was 74 and 45 % higher relative to NC and REM, respectively. The increment in POMC explained 60 and 65 % of the TOC difference for RET vs. NC and for RET vs. REM, respectively. At the same depth, TOC concentration was 20 % higher for REM compared to NC. The increment in POMC accounted for 50 % of these differences. The pattern observed for TOC concentration and its fractions for each RM followed a similar pattern to the C inputs during the 2006-2007 seasons (Table 1-2).

Within the 2.5-5-cm depth, RET had 32 and 21 % higher TOC concentration compared to NC and REM, respectively. However, at this depth 55 % of the TOC difference for RET vs. NC and RET vs. REM was attributed to an increase of the maC fraction. As depth increases, we expect more abundance of C fractions with a small molecular size as a result of soil microbial activity. These small size fractions of C can form stable complexes with silt and clay fractions, being protected from microbial degradation (Carter et al., 1998; Gonzales and Laird, 2003; Buyanovsky et al., 1994; Baldock and Skjemstad, 2000).

In October 2007 there was C stratification in the shallower layer of soil, which was more evident for the RET treatment (Fig. 1-1). Total soil organic C stratification ratios (0-5/10-20-cm) were 1.06, 1.3 and 1.5, for NC, REM and RET, respectively. Soil organic C stratification is common in conservation tillage systems, since the soil is kept undisturbed and the aboveground crop residue is left on the soil surface without incorporation (Zibilske et al., 2002; Dick, 1983). However, after long-term conservation tillage this tendency can be reverted (Wright and Hons, 2004). Soil organic C stratification is considered by Franzluebbers (2002a) as a better indicator of soil quality than TOC concentration, because it indicates accumulation of organic matter on the soil surface where many processes as erosion, water infiltration and gas flux occur and interact with each other. The same author proposed a stratification ratio > 2 as an indicator of improving soil quality. We used similar depths to Franzluebbers (2002a) to calculate the TOC stratification ratio but our ratios were lower than his threshold value of 2. This is somewhat expected because this experiment was only in its second year and the experimental area was previously managed under conventional tillage. Even though it is important to increase SOC on the soil surface, building SOC in deeper soil layers can help to improve soil aggregation, water retention and nutrient cycling deep in the soil where root development is more prominent compared to shallow layers of soil.

In October 2007 there also was a significant RM x Depth interaction for TN (Table 1-3). The TN concentration in the soil to a depth of 2.5-cm followed a similar pattern to TOC, with RET having the higher and significantly different value compared to

NC ($P \leq 0.01$) and REM ($P \leq 0.01$), but differences between the last two treatments were not significant (Fig. 1-2). Rye residue retained had 74 and 54 % greater TN concentration compared to NC and REM, respectively. Similar results were reported by Salinas-Garcia et al. (2001), who reported higher total soil N concentration to a depth of 5-cm when corn stover was retained compared to removed.

Within the 2.5-5-cm depth, the only significant difference occurred between RET and NC (P=0.02), with RET having 39 % higher TN concentration than NC. Within the 5-10-cm depth, there was a significant difference between RET and REM (P=0.02), with RET having TN values 48 % higher than REM. Not significant RM or RM x depth effects were observed for POMN. However, there was a significant RM effect on the maN concentration, averaged across depths (Table 1-3). Rye residue retained had a higher maN concentration when compared to NC ($P \leq 0.01$) and REM ($P \leq 0.01$). As expected, the TN soil concentration at the end of the study had a very similar trend as N inputs with the rye residue (Table 1-2).

The majority of the difference in TN between RET and NC was explained by changes in the maN fraction (74 and 69 % for 0-2.5 and 2.5-5-cm depths, respectively), rather than by changes in POMN. However, 58 % of the TN differences between RET and REM to a depth of 2.5-cm were mainly explained by changes in POMN. This higher contribution of maN to TN differences between RET and NC was unexpected, particularly for the 0-2.5-cm depth, because it is in this shallow soil layer that most of the plant residue accumulate under conservation tillage, increasing the particulate fractions of the soil organic matter. Results for RET and NC are opposite to what happened with TOC, for which most of the differences were explained by the POMC fraction. As the maN fraction includes mineral forms of N, the higher concentration of mineral N (NH_4 + NO_3) we measured at the end of the growing season in 2007 (data not shown) in RET compared to NC could have contributed to this results. As with TOC, there was a pronounced TN stratification in the first layer of the soil. Stratification ratios for NC, REM and RET were 1.2, 1.6 and 1.5, respectively.

Figure 1-3 shows the TOC and TN concentration change between May 2006 and October 2007. A different tendency in the TOC and TN change (expressed as percent change relative to their soil concentration in May 2006) was observed. The highest TOC increment occurred for the 0-2.5 and 2.5-5-cm depths in RET, followed by REM and NC (64, 21 and 5 %, respectively). The ranking of TOC change at these depths showed a close association with the amount of C inputs for each RM (Table 1-2). However, for the 5-10 and 10-20-cm depths results were less clear, with NC and REM decreasing their TOC concentration relative to May 2006 for the 5-10-cm depth. The loss of C deep in the soil was probably associated with soil microbial activity, hinting that C inputs from roots may not be enough to satisfy microbe usage of C as energy source under conservation tillage at these depths.

During the same period of time there was an increase of TN at all depths studied. The highest increment for the 0-2.5-cm depth corresponded to RET, followed by NC and REM with similar values. For other depths, TN increments for REM were noticeably lower compared to NC and RET. Surprisingly the TOC increment occurred in a lower proportion compared to TN.

The sharp increase in TOC and TON after two years of conservation tillage, particularly in RET and REM, is likely explained by the very low C and N levels in the soil at the beginning of the experiment. Possible explanations for the higher increment in TN is that part of the N fertilizer applied to cotton and rye each season could have been incorporated into the organic soil fractions by microbial activity and/or it remained as inorganic forms of N in the soil. Moran et al. (2005) reported that mineral N can be preferentially assimilated into the soil organic matter compared to N in the residue, because microbes prefer N sources of immediate availability.

Table 1-3. Analysis of variance for rye residue management and depth effects on TOC, POMC, maC, TN, POMN and maN, in May 2006, October 2007 and October 2007 vs. May 2006. P-values in bold are significant at $\alpha \leq 0.05$.

Sampling time	Effect	TOC[†]	POMC	maC	TN	POMN	maN
		------------------------	------------------------	--------	P > F ------	------------------------	------------------------
May 2006	RM[‡]	0.21	0.27	**≤0.01**	**≤0.01**	0.73	**≤0.01**
	Depth	0.22	0.24	0.47	**0.02**	0.64	0.10
	RM*Depth	0.43	0.54	0.79	0.21	0.19	0.51
October 2007	RM	**≤0.01**	**≤0.01**	**≤0.01**	**≤0.01**	0.42	**≤0.01**
	Depth	**≤0.01**	**≤0.01**	**≤0.01**	**≤0.01**	**≤0.01**	**≤0.01**
	RM*Depth	**≤0.01**	**≤0.01**	**0.03**	**≤0.01**	0.06	0.52
October 2007 vs. May 2006	RM	**≤0.01**	----	----	0.18	----	----
	Depth	**≤0.01**	----	----	0.16	----	----
	RM*Depth	**≤0.01**	----	----	0.31	----	----

[†] TOC = total organic C, POMC = particulate organic matter C, maC = mineral-associated + water soluble C, TN = total N, POMN = particulate organic matter N, maN = mineral-associated + water soluble N.

[‡] RM = rye residue management.

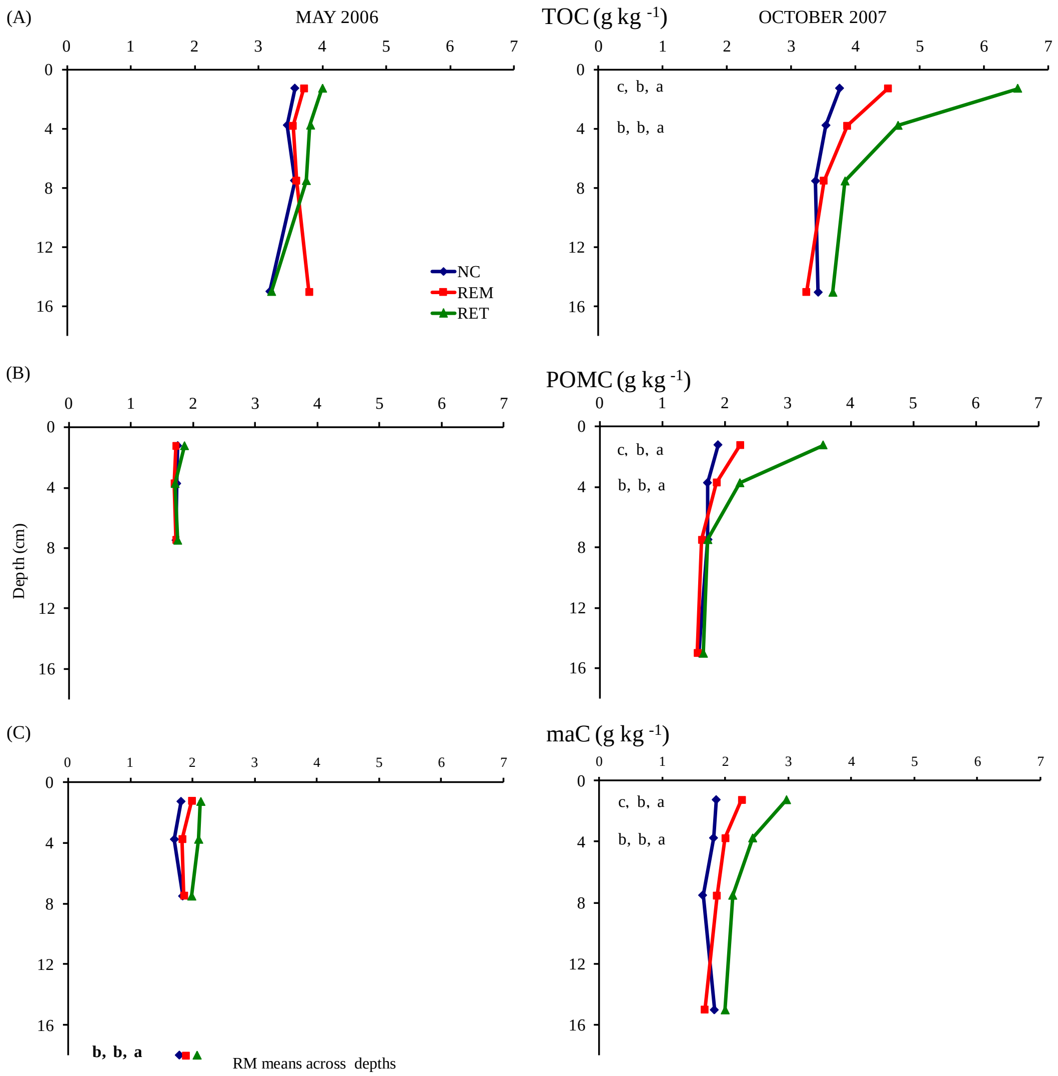

Figure 1-1. Effect of rye residue management and depth on: (A) total soil organic C (TOC), (B) particulate organic matter C (POMC), and (C) mineral associated + water soluble C (maC) in May 2006 and October 2007. For each parameter and sampling time, treatments means followed by different letters within depth are significantly different ($P \leq 0.05$). The sequence of letters showing significance is the same as means appear at each depth. NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

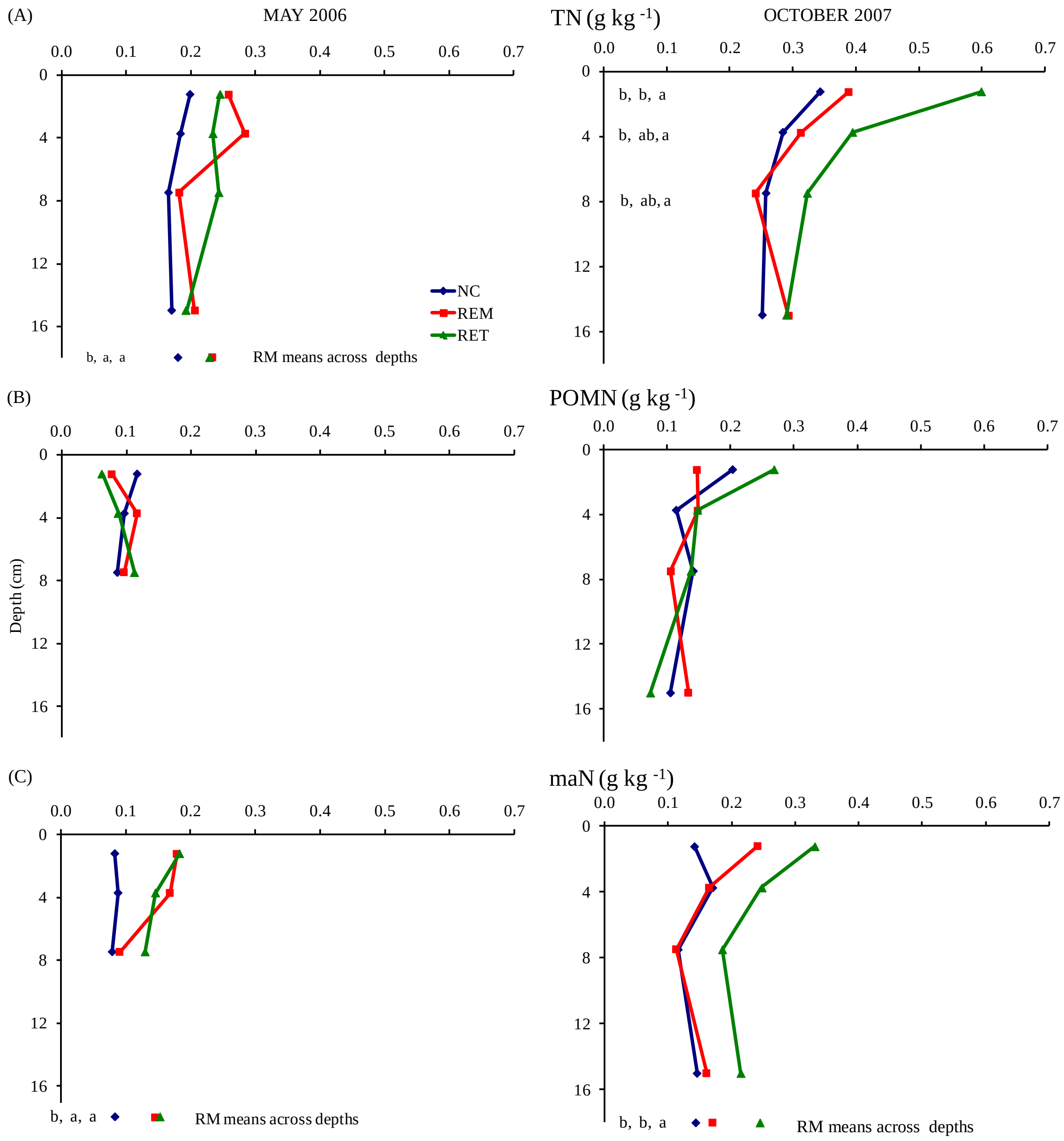

Figure 1-2. Effect of rye residue management and depth on: (A) total soil N (TN), (B) particulate organic matter N (POMN), and (C) mineral associated + water soluble N (maN) in May 2006 and October 2007. For each parameter and sampling time, treatments means followed by different letters within depth are significantly different (P≤0.05). The sequence of letters showing significance is the same as means appear at each depth. NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

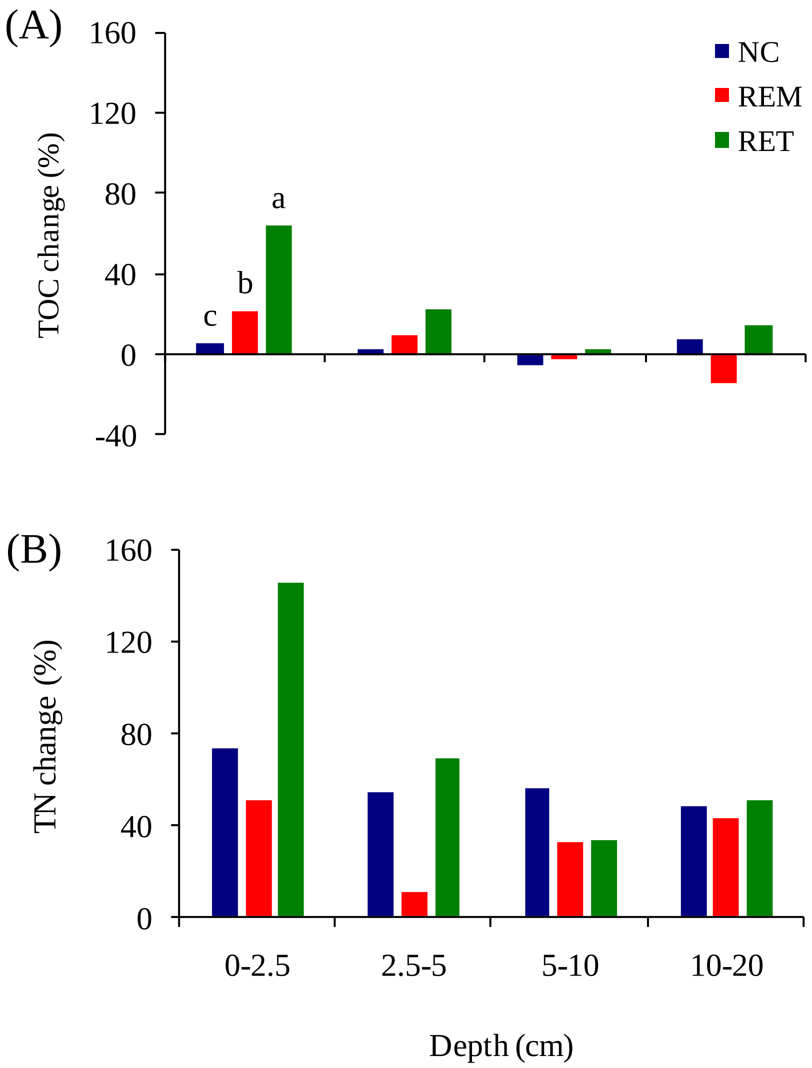

Figure 1-3. Change in total soil organic C (TOC) and total soil N (TN) as affected by rye residue management and depth, between May 2006 and October 2007. Treatments means for each parameter followed by different letters within depth are significantly different ($P \leq 0.05$). NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

Water-stable aggregates

Rye residue management did not significantly affect the percent of water-stable aggregates to a depth of 10-cm, at any of the two sampling times (Table 1-4). Changes in water-stable aggregates can require long-term implementation of different soil management practices. Additionally, short-term impact of RM on water-stable aggregates could have been restricted to the surface layer of the soil while soil samples for its determination were taken to a depth of 10-cm. These results agree with Arshad et al. (2004), who after ten years of working with different wheat rotations did not find significant differences in water-stable aggregates to a depth of 10-cm.

Even though no significant differences among RM treatments were detected, there was an increase in the percent of water-stable aggregates of 34, 33 and 38 % for NC, REM and RET, respectively, between May 2006 and October 2007 (Fig. 1-4). This could have been a response to the change in tillage management when establishing the experiment. Our results agree with Angers et al. (1992), who reported an improvement in water-stable aggregates within 2-3 years after switching from conventional tillage to no-till.

Table 1-4. Analysis of variance for rye residue management and depth effects on water-stable aggregates, soil bulk density, soil water retention and hydraulic conductivity of saturated soil in May 2006 and October 2007. P-values in bold are significant at α≤ 0.05.

Sampling time	Effect	Water-stable aggregates	Soil bulk density	--------------- Soil water retention ---------------				Hydraulic conductivity
				0 kPa	- 30 kPa	- 50 kPa	- 100 kPa	
		--			P > F	--		
May 2006	RM[†]	0.98	0.41	0.15	0.18	0.20	0.51	0.25
	Depth	NA[δ]	**≤0.01**	**≤0.01**	0.07	**≤0.01**	**≤0.01**	**≤0.01**
	RM*Depth	NA	0.27	0.78	0.46	0.26	0.07	0.89
October 2007	RM	0.57	0.09	0.29	**0.03**	**≤0.01**	**≤0.01**	**≤0.01**
	Depth	NA	**≤0.01**	**≤0.01**	0.06	0.55	0.16	**≤0.01**
	RM*Depth	NA	**≤0.01**	**≤0.01**	**0.02**	0.06	0.08	**0.02**

[†] RM = rye residue management

[‡] NA = not an effect

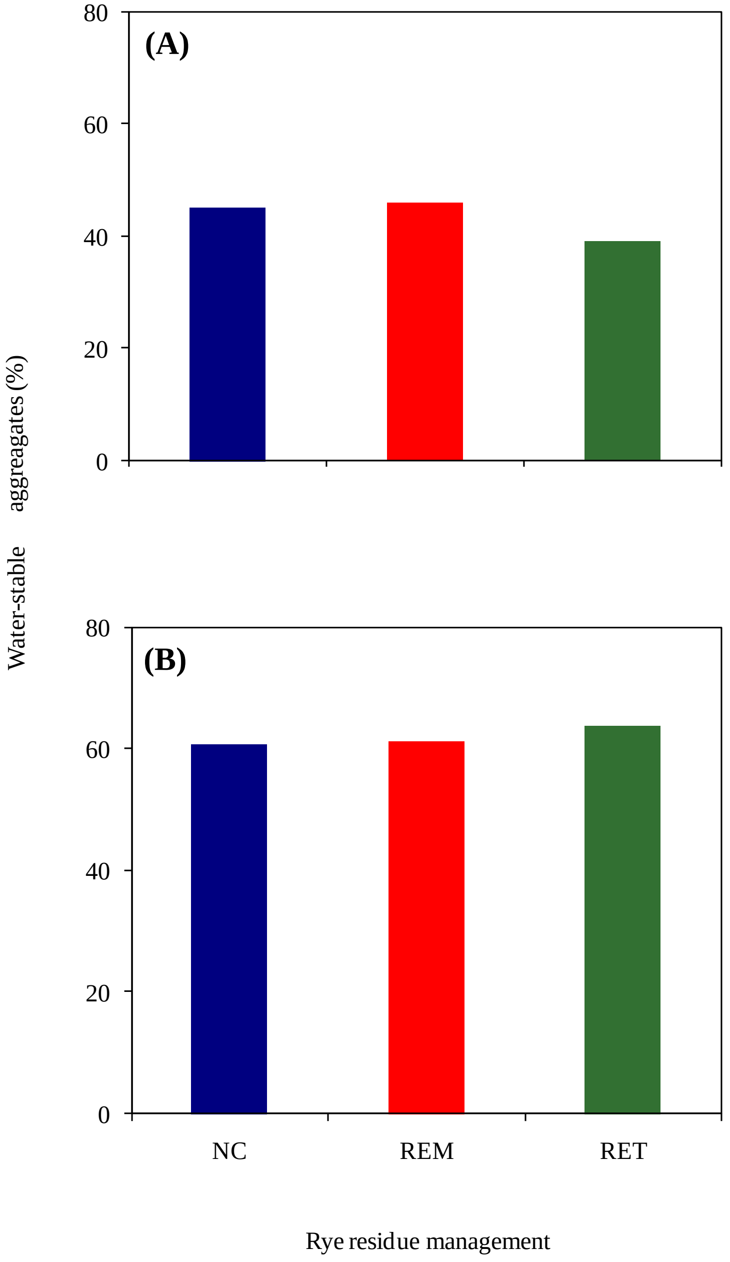

Figure 1-4. Water-stable aggregates to a depth of 10-cm as affected by rye residue management in: (A) June 2006 and (B) October 2007. Within sampling time, columns with different letters are significantly different ($P \leq 0.05$). NC, no cover crop; REM, winter cover crop residue removed; RET, winter cover crop residue retained.

Soil bulk density

In May 2006, bulk density values among RM treatments were not significantly different at any of the two depths evaluated (Table 1-4). This was expected because the lag time since the experiment had been established was only 6 months before this sampling time. However, in October 2007 RM significantly affected bulk density at the 0-5-cm depth (Fig. 1-5). Rye residue retained had a significantly lower bulk density than REM and NC ($P\leq0.01$ and $P\leq0.01$, respectively). Bulk density was lower under RET than REM by 5 % (1.49 vs. 1.57 Mg m^{-3}) and by 6 % under RET than NC (1.49 vs. 1.59 Mg m^{-3}). No significant differences occurred between REM and NC at this depth, as well as between RM treatments at the 5-10-cm depth. The occurrence of differences between RM treatments was unexpected because of the short period of time since the residue management was established. These results are very similar to results of TOC concentration between RM treatments which occurred mainly in the 0-5-cm soil depth, emphasizing the contribution of residue retention to the total soil porosity in this surface layer of the soil.

Our results agree with Blanco-Canqui et al. (2007), who found an increase in bulk density only one year after removing corn stover. Similar results were observed by Clapp et al. (2000), but only after long-term corn residue removal. However, our findings do not agree with Singh and Malhi (2006), who reported no effect of barley residue removal in bulk density after 6 years. Benjamin et al. (2007) indicated that changes in bulk density and other physical properties under crop systems may take many years unless perennial species are rotated with crops.

There was also a difference in how bulk density was affected between May 2006 and October 2007, for the 0-5-cm depth. Rye residue retained was the only treatment having a reduction in bulk density with time, which was 5 %. However, bulk density values for REM and NC tended to remain constant between 2006 and 2007, or they slightly increased. Although changes observed in response to RM were small, they indicate that small amounts of rye residue left on the soil surface in REM plus the residue from rye roots were not enough to affect bulk density. Reductions in bulk density associated with residue retention occur because the residue protects the soil against external forces responsible for soil densification, such as rain-drop impact (Wilhelm et al., 2004). Mulched soils are also reported to have more bio-pores as result of higher earthworm activity (Blanco-Canqui et al., 2006).

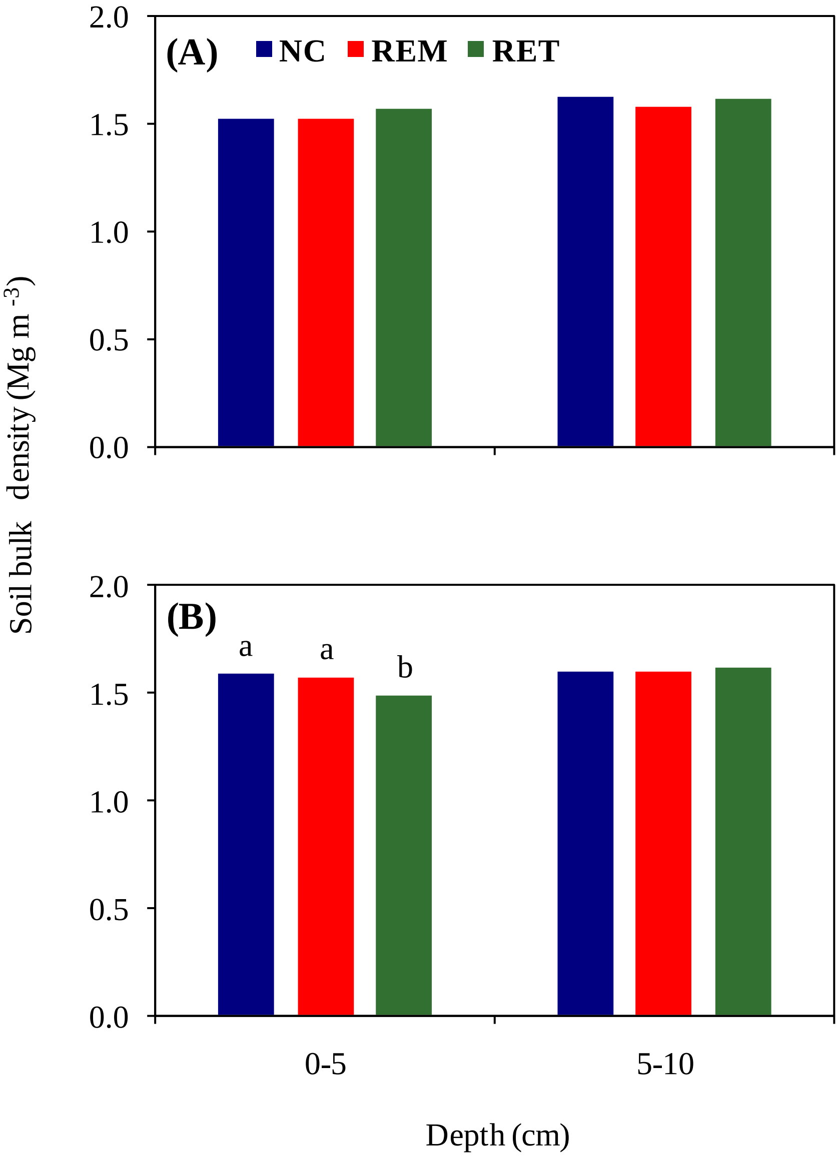

Figure 1-5. Effect of rye residue management on soil bulk density in: (A) May 2006 and (B) October 2007. Within sampling time and depth, columns with different letters are significantly different (P≤0.05). NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

Soil penetration resistance

Soil penetration resistance was significantly affected by RM at different sampling times (Table 1-5). In June 2006, differences among RM treatments were not significant at any of the depths studied (Fig. 1-6 A). In June 2007, NC had a significantly higher soil penetration resistance than REM and RET ($P=0.02$ and $P=0.04$, respectively), to a depth of 20-cm (Fig. 1-6 B). A similar tendency was observed at the 22.5 and 25-cm depths, but differences were not significant. In March 2008, NC had a significantly higher soil penetration resistance with respect to REM at depths of 22.5 and 25-cm ($P=0.03$ and $P\leq0.01$, respectively), and to RET at depths of 17.5, 22.5 and 25-cm ($P\leq0.01$, $P=0.02$ and $P=0.02$, respectively) (Fig. 1-6 C).

Coastal Plain soils in our experimental area are characterized by compacted sub-surface horizons that restrict plant root development and reduce water and gas movement (Pikul and Aase, 1999; Busscher et al., 2002). On June 2006, soil penetration resistance in the experimental area was still under the influence of the Paratill tillage conducted in November 2005. This explains the lack of difference among RM treatments. Pikul and Aase (1999) stated that although sub-surface layers of soil can reconsolidate with time after deep tillage, subsoiling effects on soil penetration resistance can last more than one year. The residual deep tillage effect tended to disappear for NC by June 2007, reaching a maximum soil penetration resistance near 4 MPa at a depth of 20-cm. However, the reconsolidation was less evident for REM and RET in June and October 2007.

The lower soil penetration resistance values for depths between 17.5 and 25-cm in REM and RET compared to NC in June 2007, and March 2008, are likely explained by the presence of rye roots in the soil which can leave channels through which roots of other crops can grow (Rosolem et al., 2002). In March 2008, the pattern was very similar to June 2007, but penetration resistance values were lower. This can be explained by the greater soil water content when the measurements were taken. These results agree with Raper et al., (2000) and Gupta et al. (1987) who reported that aboveground and belowground cover crop residue can improve soil aggregation and water retention, reducing sub-surface soil compaction. Most of the significant differences between RM treatments occurred at soil penetration resistance values higher than 2 MPa, the critical value determined by Blanchar et al. (1978), above which root growth is affected. However, roots growing under residue retained or removed conditions could be in a better environment to grow through compacted sub-surface horizons when the sub-soil water content is high after a rainfall or irrigation. Although cotton was planted in rows that had previously received deep tillage, the lower sub-surface soil compaction in the interrow space for RET and REM would make the water and nutrients stored in this section of the soil more available for plants.

We removed annually about 85 % of the aboveground rye biomass in REM but did not affect soil penetration resistance in the soil surface when compared to RET. These results do not agree with Singh and Malhi (2006), who found that after six years of a barley mono-crop system soil penetration resistance to a depth of 10-cm was significantly lower when residue was retained. Blanco-Canqui et al. (2006) also reported increases in soil penetration resistance for the 5-cm soil surface layer in response to corn stover removal.

Table 1-5. Analysis of variance for soil penetration resistance at three sampling times as affected by rye residue management at different depths. P-values in bold are significant at $\alpha \leq 0.05$.

Depth (cm)	-----------------------	RM[†] -----------------------	
	June 2006	June 2007	October 2007
	-----------------	P > F	------------------
0	0.34	0.07	0.11
2.5	0.15	0.07	0.11
5	0.67	0.14	0.12
7.5	0.30	0.93	0.11
10	0.52	0.54	0.22
12.5	0.55	0.23	0.22
15	0.28	0.63	0.08
17.5	0.10	0.42	**0.04**
20	0.52	**0.04**	0.10
22.5	0.36	0.28	**0.04**
25	0.42	0.32	**≤0.01**
27.5	0.49	0.41	0.16
30	0.32	0.70	0.79
32.5	0.33	0.52	0.76
35	0.41	0.22	0.78
37.5	0.49	----	0.65
40	0.35	----	0.42

[†] RM = rye residue management

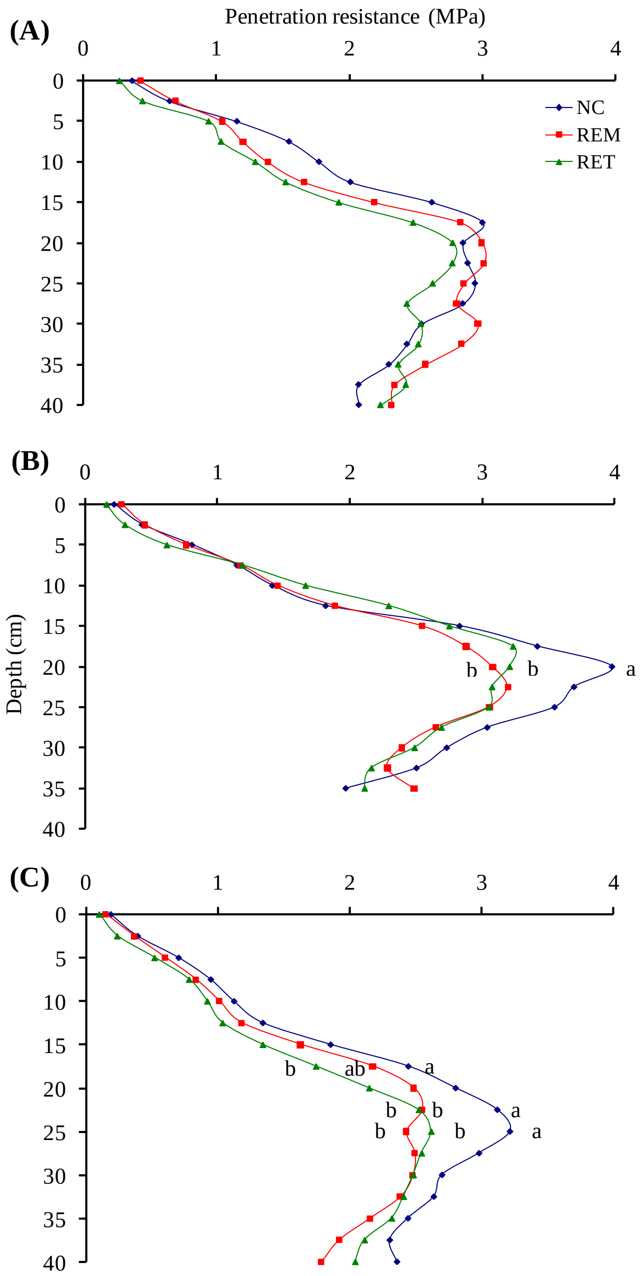

Figure 1-6. Effect of rye residue management on soil penetration resistance in: (A) June 2006, (B) June 2007, and (C) March 2008, at different depths. Within sampling time and depth, treatment means followed by different letters are significantly different ($P \leq 0.05$). The sequence of letters showing significance is the same as means appear at each depth. NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

Infiltration rate

Infiltration rate was not significantly affected by RM in June 2006 (P=0.10) and 2007 (P=0.21), but in October 2007 there were significant differences among RM treatments (P=0.05). Although no significant differences were detected in June 2006, infiltration rate was higher in RET and REM (31 and 30 cm h^{-1}, respectively) and lower in NC (19 cm h^{-1}). A similar trend was observed in June 2007, when RET and REM had a greater but not significantly different infiltration rate than NC (39 and 36 %, respectively) (Fig. 1-7).

In October 2007, RET had a significantly higher infiltration rate compared to NC (P=0.02), while REM was not significantly different from NC and RET. Although differences were not significant, RET had 18 % higher infiltration rate than REM (24 vs. 20.3 cm h^{-1}, respectively). Singh and Malhi (2006), also found higher infiltration rates when barley residue was retained in comparison to residue removed but differences were not significant. However, our results do not agree with Govaerts et al. (2007), who found in continuous no-till corn and in a corn-wheat rotation that plots with residue retained had significantly higher infiltration rates. Truman et al. (2002) reported similar results to Govaerts et al. (2007).

In the three sampling times, the infiltration pattern among RM treatments followed a trend similar to C inputs from rye for each RM (Table 1-2). Residue removal reduces soil coverage, which has been associated with a fast deterioration in soil surface properties and results in crust formation, higher runoff, lower water infiltration and aeration reduction (Franzluebbers, 2002b). Even though not all the rye residue was removed from REM each Spring, the soil cover after removal was low (< 25 %) and a high percent of the soil surface was exposed to the impact of rain drops until cotton's canopy covered the inter-row space. Raindrops may have sealed open macro-pores on the soil surface and reduced infiltration. Blanco-Canqui et al. (2007) reported that soil surface in un-mulched plots had a massive structure, and it was smoother when compared to residue covered soil, affecting water movement in the soil as well as bulk density.

Infiltration was higher for all RM treatments at the beginning of the study rather than at the end (Fig. 1-7). This was probably associated with a residual effect of the Paratill tillage conducted in the entire experimental area during the Fall 2005, before establishing the study. Bennie and Botha (1986) mentioned that deep tillage disrupts compacted sub-surface soil layers, improving water infiltration and movement. Although reconsolidation occurs, the residual effects of deep tillage on water infiltration can extend for a considerable period of time after tillage (Buscher et al., 2002; Pikul and Aase, 1999).

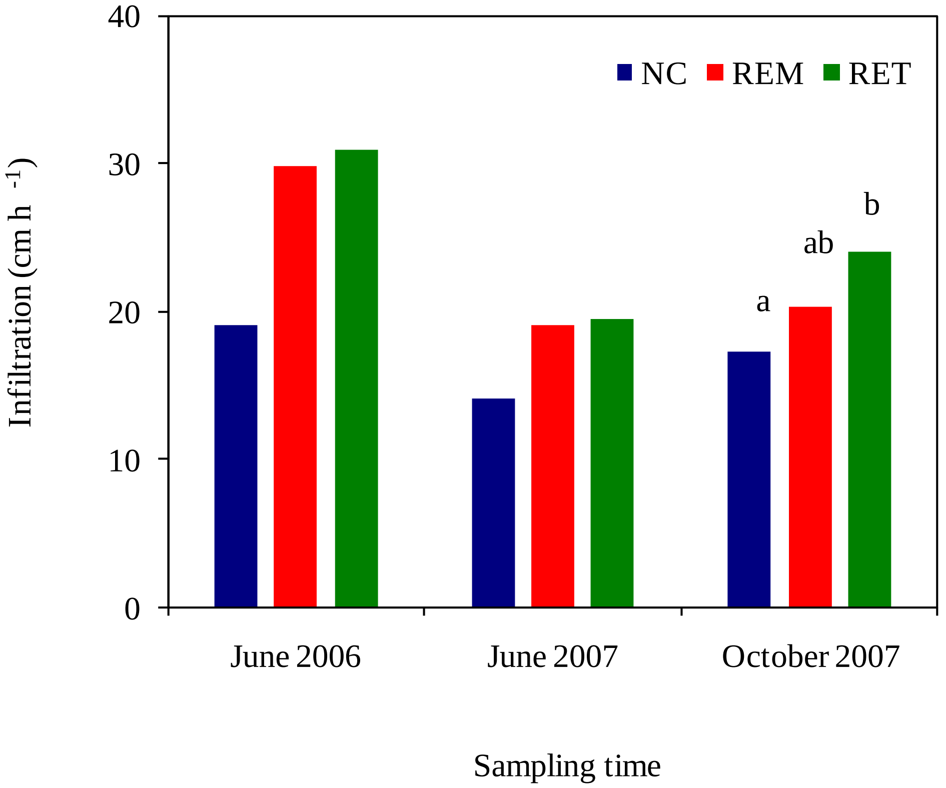

Figure 1-7. Infiltration rate as affected by rye residue management in June 2006, June 2007 and October 2007. Within sampling time, columns with different letters are significantly different ($P \leq 0.05$). NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

Hydraulic conductivity of saturated soil

Rye residue management did not influence the hydraulic conductivity of saturated soil in May 2006 (Table 1-4). However, in October 2007 there was a significant RM x depth interaction. At the 0-5-cm depth, RET and REM had significantly higher hydraulic conductivities than NC ($P \leq 0.01$ and $P \leq 0.01$, respectively), however differences between RET and REM were not significant (Fig. 1-8). The hydraulic conductivity for RET and REM (6×10^{-6} and 6.1×10^{-6} cm s^{-1}, respectively) was 122 and 123 % greater than for NC (2.7×10^{-6} cm s^{-1}), respectively. These results differ from those of Blanco-Canqui et al. (2007) who reported a decrease in soil hydraulic conductivity after only one year of corn stover removal, but agree with Karlen et al. (1994) who found no effect of corn stover removal in hydraulic conductivity after 10 years of continuous no-till corn. Although no significant differences occurred among RM treatments for the 5-10-cm depth, values for RET and REM were 34 and 33 % higher compared to NC.

Although REM had a lower total porosity than RET (greater bulk density), hydraulic conductivity was not significantly affected, indicating that the proportion of pores with large diameter was probably no different between these two treatments. This could be explained by the contribution of rye roots in RET and REM that promoted the formation and preservation of macro-pores, when roots decompose after the end of the season (Cresswell and Kirkegaard, 1995). Hydraulic conductivity is highly influenced by pore volume, arrangement and continuity (Bhattacharyya et al., 2006). Although macro-pores can occupy a small volume of the soil, they have a high contribution to the soil hydraulic conductivity because of their continuous distribution with depth (Osunbitan et al., 2005).

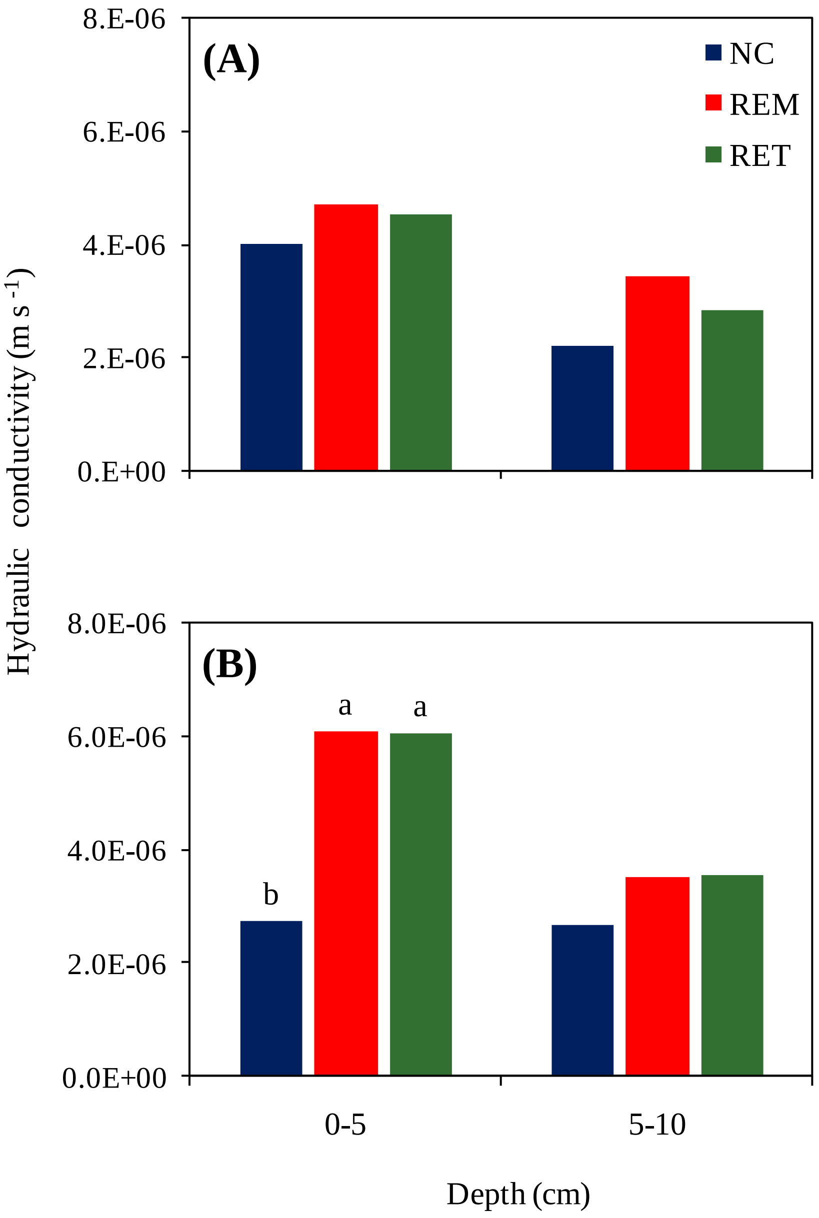

Figure 1-8. Effect of rye residue management and depth in the hydraulic conductivity of saturated soil in: (A) May 2006 and (B) October 2007. Within sampling time and depth, columns with different letters are significantly different ($P \leq 0.05$). NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

Soil water retention

Table 1-4 shows the effects of RM and depth on soil water retention at different matric water potentials. In May 2006 there were no significant RM or RM x Depth effects on soil water retention (Fig. 1-9). However, in October 2007 there was a significant RM x Depth interaction at 0 and -30 kPa, while at -50 and -100 kPa there was a significant RM effect when averaged across depths. At the 0-5-cm depth, RET and REM had a significantly greater amount of water retained at 0 kPa than NC ($P\leq0.01$ and $P\leq0.01$, respectively), but RET and REM were not significantly different. However, at the same depth RET significantly retained more water than REM and NC at -30 kPa ($P\leq0.01$ and $P\leq0.01$, respectively) (Fig. 1-10). At this depth, values of water retained at 0 kPa were 0.370, 0.389 and 0.396 $m^3\ m^{-3}$, and at -30 kPa they were 0.0961, 0.0918 and 0.106 $m^3\ m^{-3}$, for NC, REM and RET, respectively. At 0 kPa, RET and REM had 7 and 5 % more water retained than NC, respectively, and at –30 kPa RET had 10 and 16 % more water than NC and REM, respectively. At these two matric potentials, differences among RM treatments were not significant for the 5-10-cm depth. However, at matric potentials of -50 and -100 kPa, RET had 9 and 12 %, and 10 and 13 % more water retained compared to NC and REM, respectively, averaged across depths. With decreasing matric potentials, the RM effect became more important than the depth effect, as shown by the lack of RM x Depth interaction. Our results are similar to those of Blanco-Canqui et al. (2007), who reported higher soil water retention between 0 and -100 kPa when corn stover was left on the soil surface compared to removed.

Rye residue retained had a greater total porosity relative to REM and NC at the 0-5-cm depth (data not shown), as indicated by its lower bulk density (Fig. 1-5). Considering that the volume of water retained between saturation (0 kPa) and field capacity (-30 kPa) would be equivalent to the volume of soil macropores + mesopores (Benjamin et al., 2007), we estimated that their volume was 0.297 and 0.290 $m^3 m^{-3}$, for RET and REM respectively. These similar values may indicate that most of the difference in total porosity between RET and REM can be explained by changes in micropores, which are holding most the water that can be used by plants (Benjamin et al., 2007). The similar volume of macropores + mesopores in RET and REM can explain similarities in hydraulic conductivity values, but their total porosity was significantly different.

The higher TOC concentration in RET relative to REM and NC may explain the differences observed in soil water retention at all matric potentials evaluated, mainly because RM effects on water retention occurred at the surface layer of the soil where TOC concentration was higher in RET compared to REM and NC. A better soil structure and higher specific surface area of the soil as a result of high residue inputs in RET would account for its higher water holding capacity (Blanco-Canqui et al., 2007). This close association between soil organic carbon and water retention was previously reported by Hudson (1994), who found increments in the water held at field capacity when the soil organic matter content increased.

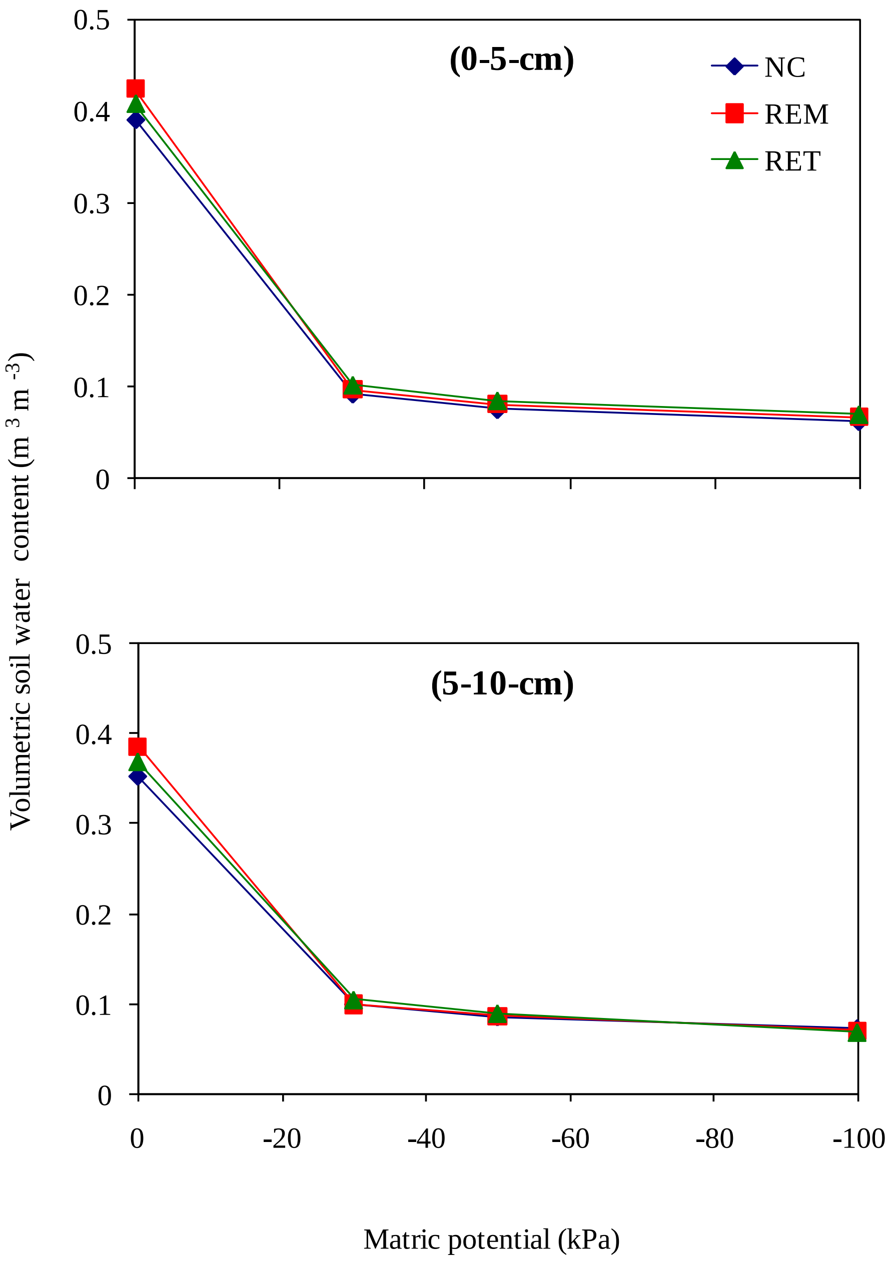

Figure 1-9. Effect of rye residue management and depth on soil water retention at different matric potentials in May 2006. Within depth and matric potential, treatment means followed by different letters are significantly different ($P \leq 0.05$). NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

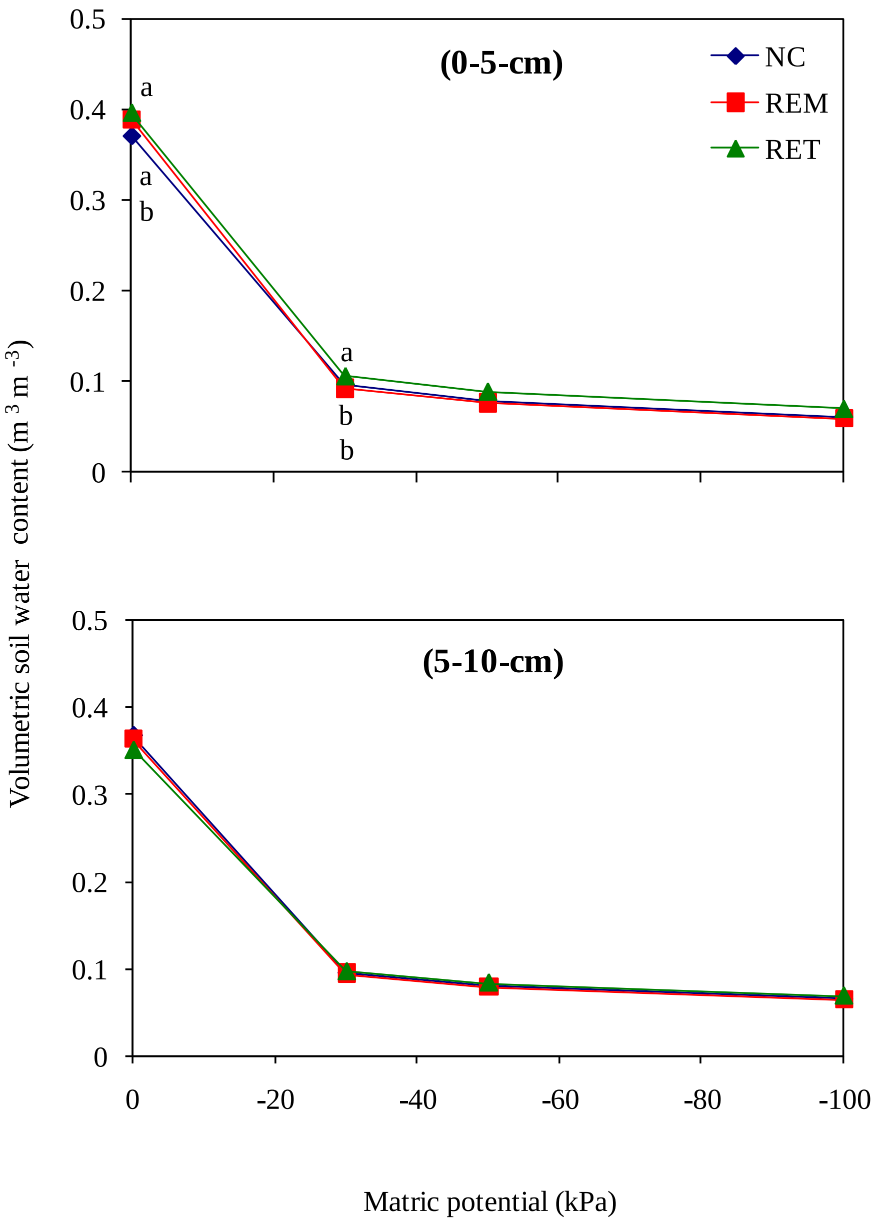

Figure 1-10. Effect of rye residue management and depth on soil water retention at different matric potentials in October 2007. Within depth and matric potential, treatment means followed by different letters are significantly different ($P \leq 0.05$). NC, no winter cover crop; REM, winter cover crop residue removed; RET, winter cover crop residue retained.

Soil water content

Rye residue management significantly affected the soil water content to a depth of 20-cm during the 2006 and 2007 cotton seasons (Table 1-6). Rye residue retained had a significantly higher volumetric water content at 0, 19, 28, 32 and 38 DAP than NC ($P=0.02$, $P\leq0.01$, $P\leq0.01$, $P=0.02$ and $P\leq0.01$, respectively) and REM ($P=0.02$, $P\leq0.01$, $P\leq0.01$, $P<0.01$, and $P\leq0.01$, respectively), in 2006; and at 0, 15, 22 and 55 DAP than NC ($P\leq0.01$, $P\leq0.01$, $P=0.02$, and $P\leq0.01$, respectively) and REM ($P\leq0.01$, $P\leq0.01$, $P=0.03$, and $P=0.02$, respectively), in 2007 (Fig. 1-11).

In each season, rye residue removal decreased the average soil water content between cotton planting and first square by 19 and 7 % in 2006 and 2007, respectively. The difference in favor of RET during the middle of the 2007 cotton season coincided with a period of high rainfall during the first week of July. No significant differences between REM and NC were detected during the 2006 and 2007 cotton seasons. Results for soil water content early during the summer crop season agree with Govaerts et al. (2007) who found higher soil water content in continuous corn and in a corn-wheat rotation with residue retained compared to removed. Our results show that even though the amount of residue left in REM was between 500 and 1,000 kg ha^{-1}, it was not effective in keeping the soil moisture as the RET treatment.

Not only the amount of residue but also its distribution on the soil surface account for soil coverage and reductions in water evaporation. In REM, the residue left was composed of standing basal rye shoots that covered less than 30 % of the soil surface. Residue coverage reduces water losses through evaporation and improves infiltration, increasing the water potentially available for crops (Govaerts et al., 2007). The greater soil water retention capacity for RET compared to REM and NC in October 2007 could also have contributed to these differences in soil water content, particularly during the 2007 cotton season (Fig. 1-10).

In both years, most of the differences for RET vs. NC or RET vs. REM occurred early during the cotton season, when the crop water requirement was low because of the small biomass accumulation. However, after N re-fertilization (37 DAP) the crop water demand increased rapidly. After this point and during two dry growing seasons, in 2006 and 2007, once the summer crop consumed most of the available water, residue by itself did not have an effect on the soil water content until a rain or irrigation event occurred.

In those sampling times when RET had significantly more water than REM and NC, differences in the soil water content were equivalent to a depth of water between 4 and 8 mm in 2006 and between 2.6 and 10 mm in 2007, in the surface 20-cm of soil. However, this extra availability of water in RET at the beginning of the season can improve crop yields only if water stresses do not occur during later stages of crop development.

Table 1-6. Analysis of variance for soil water content as affected by rye residue management during the 2006 and 2007 cotton seasons. P-values in bold are significant at $\alpha \leq 0.05$.

Days after planting	2006	Days after planting	2007
	P > F		P > F
0	**0.03**	0	**≤0.01**
19	**≤0.01**	15	**≤0.01**
28	**≤0.01**	22	**0.04**
32	**≤0.01**	37	0.49
34	0.53	43	0.46
38	**≤0.01**	48	0.18
42	0.48	55	**≤0.01**
49	0.26	69	0.12
54	0.38	76	0.81
73	0.53	82	0.92
87	0.71	----	----

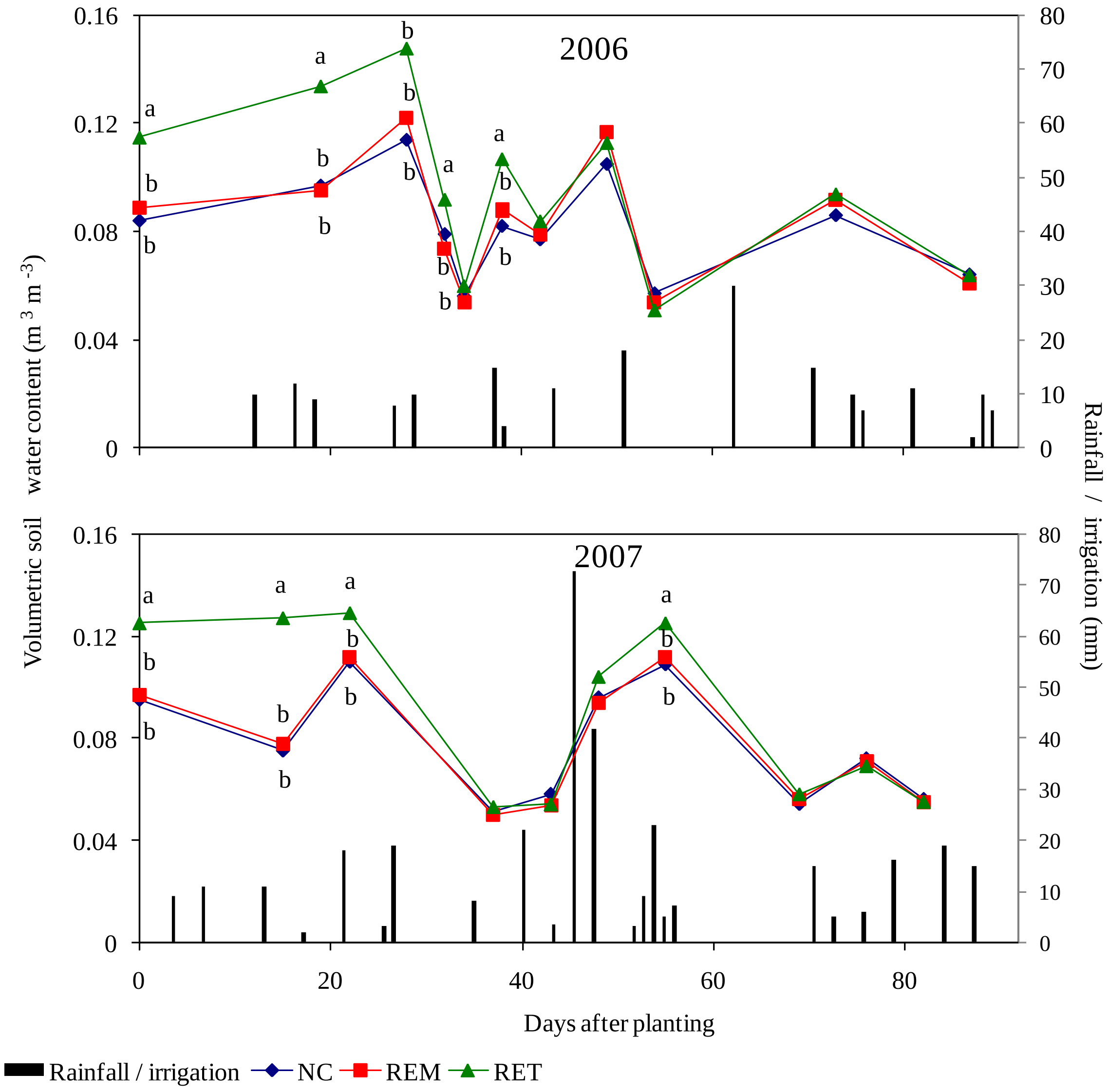

Figure 1-11. Effect of rye residue management on the volumetric soil water content to a depth of 20-cm during the 2006 and 2007 cotton seasons. Treatments means followed by different letters at each sampling time are significantly different (P≤0.05). NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

Soil nitrogen mineralization/immobilization

Rye residue management resulted in differences in the amount of N mineralized/immobilized in both cotton seasons, but differences were not significant (P=0.06 and P=0.62 for 2006 and 2007, respectively). Nitrogen immobilization occurred in RET and REM, while in NC there was N mineralization both years. The amount of N mineralized/immobilized was low (between 4 and 17 kg N ha^{-1}) (Fig. 1-12). Low values of N immobilized in RET and REM could be explained because grass residue immobilizes N during the first weeks of residue decomposition (Kuo and Sainju, 1998; Jensen, 1997). However, our measurements were taken between 8 and 16 weeks after killing the rye. The occurrence of N immobilization in REM was also unexpected because most of the rye residue was removed. Nitrogen immobilization in REM was 320 and 17 % higher compared to RET, in 2006 and 2007, respectively. Our results agree with findings of Kuo and Sainju (1998), who stated that N immobilization occurred until 20 weeks after adding rye residue to the soil. Similar results were reported by Jensen (1997) and Sarrantonio (2003) working with barley and wheat residue, respectively. On the other hand, a study by Schomberg et al. (2006a) revealed that about 66 kg N ha^{-1} were mineralized in a soil with rye residue in a period of 3 months after planting the summer crop.

As reported by Vigil and Kissel (1991), not only the amount of residue left on the soil surface contributes to N immobilization, but also its chemical composition and particularly its C/N ratio. Each year, more than 4,500 kg ha^{-1} of rye residue were left in RET, with C/N ratios between 33 and 47. These C/N ratios are higher than 25-30, the C/N ratio above which N immobilization is expected (Jensen, 1997). However, the amount of rye residue left in REM was between 500 and 1,000 kg ha^{-1}, but the C/N ratios were between 69 and 77. The large amounts of rye residue left in RET and the high C/N ratios of the residue in both treatments could have played an important role in the occurrence of N immobilization. Additionally, as the experiment is in its first phase under conservation tillage, levels of SOC are increasing, with a consequent increase in soil organic N levels at expense of the inorganic N. This close association between C and N cycles in soil was previously reported by Jensen (1997) and Ruffo and Bollero (2003).

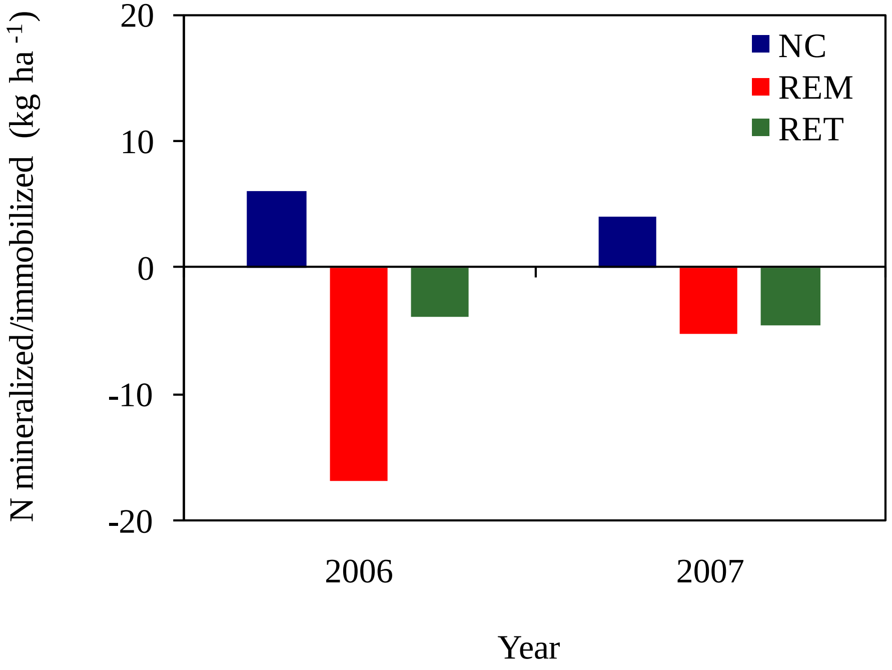

Figure 1-12. Amount of N mineralized/immobilized in the surface 20-cm of soil as affected by rye residue management, between first square and cutout in 2006 and 2007. Treatments means followed by different letters within year are significantly different ($P \leq 0.05$). NC, no winter cover crop; REM, winter cover crop residue removed; RET, winter cover crop residue retained.

CONCLUSIONS

Results of our study indicate that short-term removal of rye residue can induce significant changes in some soil properties of Coastal Plain soils managed with conservation tillage. Reduction in C inputs as a consequence of rye residue removal caused a decrease of TOC, POMC, maC, and TN of 25, 29, 21 and 29 %, respectively, to a depth of 5-cm compared to residue retained. This degradation of the C and N fractions in the surface layer of the soil was associated with a reduction of 7 % in soil water retention as well as an increase of 5 % in bulk density. The lack of residue under removal conditions plus its lower water retention accounted for a decrease in the soil water content early during the summer crop seasons (19 and 7 % for 2006 and 2007, respectively). However, rye residue removal did not produce significant changes in soil penetration resistance, infiltration and hydraulic conductivity. Residue inputs from rye roots and/or channels left behind during root decomposition may explain the absence of significant differences between RET and REM on these soil properties. The proportion of water-stable aggregates was unaffected by RM, possibly indicating that more time under this management is required for differences to occur. Amounts of rye residue and its relative high C/N ratio in RET as well as the large C/N ratio of the residue left in REM could explain the occurrence of N immobilization from these two RM treatments during both seasons. Soil bulk density, infiltration rate, soil water retention and soil water content values were very similar in REM and NC. Our results indicate that rye residue removal can quickly reduce soil C and N concentrations, with a subsequent deterioration of soil quality. A long-term monitoring of this management practice would be required to completely understand its potential impact on soil properties of these Coastal Plain soils.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Mr. Jason Ward (Soils Research Technician, USDA-ARS) and Mr. Bobby Durbin (Associate Director, Field Crops Unit, E.V. Smith Research Center) for their support with this experiment.

REFERENCES

Adams, J.F., and C.C. Mitchell. 2000. Soil test nutrient recommendations for Alabama crops [Online]. Available at http://www.ag.auburn.edu/agrn/croprecs/CropRecs/cc10.html (verified 24 April 2007).

Alabama Cooperative Extension System (ACES). 2006. Two thousand five Cotton Research Report. Research Report No. 28. Available at http://www.ag.auburn.edu/aaes/communications/researchreports/05Cottonrr.pdf (verified 25 June 2007).

Angers, D.A., A. Pesant, and J. Vigneux. 1992. Early cropping-induced changes in soil aggregation, organic matter, and microbial biomass. Soil Sci. Soc. Am. J. 56:115-119.

Arshad, M.A., A.J. Franzluebbers, and R.H. Azooz. 2004. Surface-soil structural properties under grass and cereal production on a Mollic Cyroboralf in Canada. Soil and Tillage Research. 77:15-23.

Balasdent, J., and M. Balabane. 1996. Major contribution of roots to soil carbon storage inferred from maize cultivated soils. Soil Biol. Biochem. 28:1261-1263.

Baldock, J.A., and J.O. Skjemstad. 2000. Role of the soil matrix and minerals in protecting natural organic materials against biological attack. Organic Geochemistry. 31:697-710.

Benjamin, J.G., M. Mikha, D.C. Nielsen, M.F. Vigil, F. Calderon, and W.B. Henry. 2007. Cropping intensity effects on physical properties of a no-till silt loam. Soil Sci. Soc. Am. J. 71:1160-1165.

Bennie A.T.P., and F.J.P. Botha. 1986. Effect of deep tillage and controlled traffic on root growth, water – use efficiency and yield of irrigated maize and wheat. Soil Till. Res. 7:85-95.

Bhattacharyya, R., V. Prakash, S. Kundu, and H.S. Gupta. 2006. Effect of tillage and crop rotations on pores size distribution and soil hydraulic conductivity in sandy clay loam soil in the Indian Himalayas. Soil Till. Res. 86:129-140.

Blanchar, R.W., C.R. Edmons, and J.M. Bradford. 1978. Root growth in cores formed from fragipan and B2 horizons of Hobson soil. Soil Sci. Soc. Am. J. 42:437-440.

Blanco-Canqui, H., R. Lal, W.M. Post, R.C. Izaurralde, and M.J. Shipitalo. 2007. Soil hydraulic properties influenced by corn stover removal from no-till corn in Ohio. Soil Till. Res. 92:144-155.

Blanco-Canqui, H., R. Lal, W.M. Post, R.C. Izaurralde, and L.B. Owens. 2006. Corn stover impacts on near-surface soil properties of no-till corn in Ohio. Soil Sci. Soc. Am. J. 70:266-278.

Busscher, W.J., P.J. Bauer, and J.R. Frederick. 2002. Recompaction of a coastal loamy sand after deep tillage as a function of subsequent cumulative rainfall. Soil Till. Res. 68:49-57.

Buyanovsky, G.A., M. Aslam, and G.H. Wagner. 1994. Carbon turnover in soil physical fractions. Soil Sci. Soc. Am. J. 58:1167-1173.

Cambardella, C.A., and E.T. Elliot. 1992. Particulate soil organic-matter changes across a grassland cultivation sequence. Soil Sci. Soc. Am. J. 56:777-783.

Carter, M.R., E.G. Gregorich, D.A. Angers, R.G. Donald, and M.A. Bolinder. 1998. Organic C and N storage, and organic C fractions, in adjacent cultivated and forested soils of eastern Canada. Soil Till. Res. 47:253-261.

Causarano, H.J., A. J. Franzluebbers, J.N. Shaw, D. W. Reeves, R.L. Raper, and C.W. Wood. 2008. Soil organic carbon fractions and aggregation in the Southern Piedmont and Coastal Plain. Soil Sci. Soc. Am. J. 72:221-230.

Clapp, C.E., R.R. Allmaras, M.F. Layese, D.R. Linden, and R.H. Dowdy. 2000. Soil organic carbon and ^{13}C abundance as related to tillage, crop residue, and nitrogen fertilization under continuous corn management in Minnesota. Soil Till. Res. 55:127-142.

Cresswell, H.P., and J.A. Kirkegaard. 1995. Subsoil amelioration by plant roots-the process and evidence. Aust. J. Soil Res. 33:221-239.

Dane, J.H., and J.W. Hopmans. 2002. Pressure plate extractor. *In* J. H. Dane and G. Clarke (ed.) Methods of Soil Analysis. Part 4. Physical Methods. SSSA Book Series No. 5. SSSA, Madison, WI. pp. 688-690.

Dick, W.A. 1983. Organic carbon, nitrogen, and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. Soil Sci. Soc. Am. J. 47:102-107

Economic Research Service (ERS). 1997. General crop management practices [Online]. Available at http://www.ers.usda.gov/publications/sb969/sb969e.pdf (verified 4 October 2007).

Franzluebbers, A.J. 2002a. Soil organic matter stratification ratio as an indicator of soil quality. Soil Till. Res. 66:95-106.

Franzluebbers, A.J. 2002b. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil Till. Res. 66:197-205.

Gale, W.J., and C.A. Gambardella. 2000. Carbon dynamics of surface residue- and root-derived organic matter under simulated no-till. Soil Sci. Soc. Am. J. 64:190-195.

Gonzalez, J.M., and D.A. Laird. 2003. Carbon sequestration in clay mineral fractions from ^{14}C-labeled plant residues. Soil Sci. Soc. Am. J. 67:1715-1720.

Govaerts, B., M. Fuentes, M. Mezzalama, J.M. Nicol, J. Deckers, J.D. Etchevers, B. Figueroa-Sandoval, and K.D. Sayre. 2007. Infiltration, soil moisture, root rot and nematode populations after 12 years of different tillage, residue and crop rotation managements. Soil Till. Res. 94:209-219.

Gupta, S.C., E.C. Schneider, W.E. Larson, and A. Hadas. 1987. Influence of corn residue on compression and compaction behavior of soils. Soil Sci. Soc. Am. J. 51:207-212.

Hart, S.C., J.M. Stark, E.A. Davison, and M.K. Firestone. 1994. Nitrogen mineralization, immobilization, and nitrification . *In* R.W. Weaver et al. (ed. com.) Methods of Soil Analysis. Part 2. Microbiological and biochemical properties. SSSA Book Series No. 5. SSSA, Madison, WI. pp. 985-1018.

Hudson, B.D. 1994. Soil organic matter and available water capacity. J. Soil and Water Cons. 49:189-194.

Hunt, P.G., P.J. Bauer, T.A. Matheny, and W.J. Busscher. 2004. Crop yield and nitrogen accumulation response to tillage of a Coastal Plain soil. Crop Sci. 44:1673-1681.

Jensen, E.S. 1997. Nitrogen immobilization and mineralization during initial decomposition of ^{15}N-labeled pea and barley residue. Biol. Fertil. Soils. 24:39-44.

Kadvir, Y., and A.J.M. Smucker. 2005. Soil aggregate sequestration of cover crop root and shoot-derived nitrogen. Plant and Soil. 272:263-276.

Karlen, D.L., N.C. Wollenhaupt, D.C. Erbach, D.C. Berry, E.C. Swan, J.B. Swan, N.S. Eash, and J.L. Jordahl. 1994. Crop residue effects on soil quality following 10 years of no-till corn. Soil Till. Res. 31:149-167.

Klute, A., and C. Dirksen. 1986. Hydraulic conductivity and diffusivity: laboratory methods. *In* A. Klute (ed.) Methods of Soil Analysis. Part 1. Physical and mineralogical methods. SSSA Book Series No. 5. SSSA, Madison, WI. pp. 687-734.

Kuo, S., and U.M. Sainju. 1998. Nitrogen mineralization and availability of mixed leguminous and non-leguminous cover crop residues in soil. Biol. Fertil. Soils. 26:346-353.

Laird, D.A., D.A Martens, and W.L. Kingery. 2001. Nature of clay-humic complexes in an agricultural soil: I. Chemical, biochemical and spectroscopic analyses. Soil Sci. Soc. Am. J. 65:1413-1418.

Littell, R.C., G.A. Milliken, W.W. Stroup, R.D. Wolfinger, and O. Schabenberger. 2006. SAS for mixed models. Second edition. SAS Institute Inc. Cary, NC. 814 pp.

Malhi, S.S., R. Lemke, Z.H. Wang, and B.S. Chhabra. 2006. Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions. Soil Till. Res. 90:171-183.

McDonald, P.B., J.W. Singer, and M.H. Wiedenhoeft. 2008. Establishment and growth of self-seeded winter cereal cover crops in a soybean-corn rotation. Agron. J. 100:432-439.

Molina, J.A.E., C.E. Clapp, D.R. Linden, R.R. Allmaras, M.F. Layese, R.H. Dowdy and H.H. Cheng. 2001. Modeling the incorporation of corn (Zea mays L.) carbon from roots and rhizodeposition into soil organic matter. Soil Biol. Biochem. 33:83-92.

Moran, K.K., J. Six, W.R. Horwath, and C. Van Kessel. 2005. Role of mineral-nitrogen in residue decomposition and stable soil organic matter formation. Soil Sci. Soc. Am. J. 69:1730-1736.

Morton, T.A., J.S. Bertgold, and A.J. Price. 2006. The economics of cover crop biomass for corn and cotton [Online]. Available at http://www.ag.auburn.edu/auxiliary/nsdl/ scasc/ Proceedings/2006/morton.pdf. (Verified 21 April 2008).

Natural Resources Conservation Service (NRCS). 2007. Web Soil Survey [Online]. Available at http://websoilsurvey.nrcs.usda.gov/app.html (verified 28 July 2007).

Nimmo, J.R., and K.S. Perkins. 2002. Aggregate stability and size distribution. *In* J. H. Dane and G. Clarke (ed.) Methods of Soil Analysis. Part 4. Physical Methods. SSSA Book Series No. 5. SSSA, Madison, WI. pp. 317-328.

Nyakatawa, E.Z., K.C. Ready, and K.R. Sistani. 2001. Tillage, cover cropping, and poultry litter effects on selected soil chemical properties. Soil Till. Res. 58:69-79.

Osunbitan, J.A., D.J. Oyedele, and K.O. Adekalu. 2005. Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria. Soil Till. Research. 82:57-64.

Pikul, J.L., and J.K. Aase. 1999. Wheat response and residual soil properties following subsoiling on a sandy loam in eastern Montana. Soil Till. Res. 51:61-70.

Puget, P., and L.E. Drinkwater. 2001. Short-term dynamics of root- and shoot-derived carbon from a leguminous green manure. Soil Sci. Soc. Am. J. 65:771-779.

Raper, E.L., D.W. Reeves, E.B. Schwab, and C.H. Burmester. 2000. Tillage depth, tillage timing, and cover crop effects on cotton yield, soil strength, and tillage energy requirements. Appl. Eng. Agric. 16(4):379-385.

Reynolds, W.D., D.E. Elrick, and E.G. Youngs. 2002 Single-ring and double- or concentric-ring infiltrometers. *In* J. H. Dane and G. Clarke (ed.) Methods of Soil Analysis. Part 4. Physical Methods. SSSA Book Series No. 5. SSSA, Madison, WI. pp. 821-843.

Roselem, C.A., J.S. Foloni, and C.S. Tiritan. 2002. Root growth and nutrient accumulation in cover crops as affected by soil compaction. Soil Tillage Res. 65:109-115.

Ruffo, M.L., and G.A. Bollero. 2003. Modeling rye and hairy vetch residue decomposition as a function of degree-days and decomposition-days. Agron. J. 95:900-907.

Sainju, U.M., B.P. Singh, and W.F. Whitehead. 2005. Tillage, cover crops, and nitrogen fertilization effects on cotton and sorghum root biomass, carbon, and nitrogen. Agron. J. 97:1279-1290.

Salinas-Garcia, J.R., A.D. Baez-Gonzalez, M. Tiscarenio-Lopez, and E. Rosales-Robles. 2001. Residue removal and tillage interactions effects on soil properties under rain-fed corn production in central Mexico. Soil Till. Res. 59:67-79.

Sarrantonio, M. 2003. Soil response to surface-applied residues of varying carbon-nitrogen ratios. Biol. Fertil. Soils. 37:175-183.

Sims, G.K. 1995. Microscale determination of inorganic nitrogen in water and soil extracts. Commun. Soil Sci. Plant Anal. 26:303-316.

Singh, B., and S.S. Malhi. 2006. Response of soil physical properties to tillage and residue management on two soils in a cool temperate environment. Soil Till. Res. 85:143-153.

Schomberg, H.H., Dinku M. Endale . A. Calegari, R. Peixoto, M. Miyazawa, and M.L. Cabrera. 2006a. Influence of cover crops on potential nitrogen availability to succeeding crops in a Southern Piedmont soil. Biol. Fertil. Soils. 42:299-307.

Schomberg, H.H., R.G. McDaniel, E. Mallard, D.M. Endale, D.S. Fisher and M.L. Cabrera. 2006b. Conservation tillage and cover crop influences in cotton production on a Southeastern U.S. Coastal Plain soil. Agron. J. 98:1247-1256.

Truman, C.C., D.W. Reeves, J.N. Shaw, and C. H. Burmester. 2002. Soil management effects on interrill erodability of two Alabama soils. p. 288-294. . *In.* E. van Santen (ed.) Making conservation tillage conventional: building a future on 25 years of research. Proc. Annu. Southern Conservation Tillage Conf. for Sustainable Agric., 25th, Auburn, AL, 24-26 June 2002. Special Report No. 1, Alabama Agricultural Exp. Station and Auburn University.

Tsuji, H., H. Yamamoto, K. Matsuo, and K. Usuki. 2006. The effects of long-term conservation tillage, crop residue and P fertilizer on soil conditions and responses of summer and winter crops on an Andosol in Japan. Soil Till. Res. 89:167-176.

Vigil, M.F., and D.E. Kissel. 1991. Equations for estimating the amount of nitrogen mineralized from crop residues. Soil Sci. Soc. Am. J. 55:757-761.

Wilhelm, W.W., J.M.F. Johnson, J.L. Hatfield, W.B. Voorhees, and D.R. Linden. 2004. Crop and soil productivity response to corn residue removal: a literature review. Agron. J. 96:1-17.

Williams, S.M., and R.R. Weil. 2004. Cover crop roots channels may alleviate soil compaction effects on soybean crop. Soil Sci. Soc. Am. J. 68:1403-1409.

Wright, A.L., and F.M. Hons. 2004. Soil aggregation and carbon and nitrogen storage under soybean cropping sequences. Soil Sci. Soc. Am. J. 68:507-513.

Zadoks, J.C., Chang, T.T. and C.F. Konzak. 1974. A decimal code for the growth of cereals. Weed Res. 14:415-421.

Zibilske, L.M., J.M. Bradford, and J.R. Smart. 2002. Conservation tillage induced changes in organic carbon, total nitrogen and available phosphorus in a semi-arid alkaline subtropical soil. Soil Till. Res. 66:153–163.

III. RYE RESIDUE AND NITROGEN FERTILIZATION OF COTTON

ABSTRACT

Winter cover crops planted in cotton (*Gossypium hirsutum* L.) fields in the southeastern US could be harvested for biofuels or animal feed use. This practice could impact cotton yields and its response to nitrogen (N) fertilization. An experiment, in central Alabama, examined the effect of rye (*Secale cereale* L.) residue management and nitrogen (N) rates on cotton productivity during 2006 and 2007, in a Marvyn loamy sand (fine-loamy, kaolinitic, thermic Typic Kanhapludult). The treatment arrangement was a split-plot in a randomized complete block design with four replications. No winter cover crop (NC), rye residue removed (REM) and rye residue retained (RET) were the main plots and N rates for cotton (0, 50, 100 and 140 kg ha^{-1}) were subplots. Cotton population, leaf and plant N concentration, cotton biomass and N uptake at first square, and cotton biomass production between first square and cutout were higher for RET, followed by REM and NC. However, leaf N concentration at early bloom and N concentration in the cotton biomass produced between first square and cutout were higher for NC, followed by REM and RET. All cotton growth parameters increased with increasing N rates when averaged across rye residue management (RM) treatments. Seed cotton yield response to N interacted with year and RM. In 2006, the highest estimated

seed cotton yield was about3,950 kg ha^{-1} for RET and REM, with an application of 140 kg N ha^{-1}. In 2007, maximum predicted seed cotton yields for RET and REM were 2,660 and 2,460 kg ha^{-1}, with an estimated N application of 125 and 106 kg N ha^{-1}, respectively. In both years, the lowest observed seed cotton yields corresponded to NC. These results indicate that negative effects of short-term rye residue removal on cotton growth parameters are consistent. Rye residue removal may reduce seed cotton yields only during hotter and dryer years. Long-term studies would be required to completely understand the effect of rye residue removal on cotton production under conservation tillage.

INTRODUCTION

Nitrogen is the most difficult nutrient to manage when growing cotton. About 82 % of the 5,386,905 ha of the cotton planted in 2003 in the US were fertilized with N, receiving an average rate of 103 kg N ha^{-1} (The Fertilizer Institute, 2003; ERS, 2003). Applying optimum N rates is necessary to maximize economic yields and minimize the negative impacts that N over-application can have on the crop and environment (Boquet and Breitenbeck, 2000). Higher N rates than required can result in excessive vegetative growth which increases the proportion of immature bolls, reduces lint quality and cotton yields, and increases disease and insect damage (Gerik et al., 1994; McConnell et al., 1995; Hodgson and MacLeod, 1988; Harris and Smith, 1980). However, N deficiencies

---

Abbreviations: DAP, days after planting; HU, heat units; K, potassium; N, nitrogen; NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained; RM, rye residue management; P, phosphorus; S, sulfur.

can reduce vegetative and reproductive growth, decreasing yields (Gerik et al., 1994). Many parameters combine to determine the optimum N rates for cotton, such as soil type, location, N application method, tillage system, water availability, use of winter cover crops and potential yield (Howard et al., 2001).

Conservation systems for cotton production in the southeastern US have increased in adoption to approximately 50 % of the 2.9 million ha planted in this area (Schomberg et al., 2006). The use of winter cover crops has been well documented as an effective method for improving soil chemical, biological and physical properties (Langdale et al., 1990; Dabney et al., 2001). Among winter crop species, winter cereals like rye can have many benefits because they produce high amounts of biomass, are easy to establish and kill, and provide good ground cover during the winter (Brown et al., 1985; Schomberg et al., 2006). However, the high biomass grass cover crops can produce combined with their high C/N ratios, can lead to N immobilization, which can increase the N fertilizer demand for maximizing cotton yields (Reiter et al., 2002; Dabney et al., 2001; Wagger, 1989). Additionally, the probability of N immobilization increases when the N fertilizer is broadcast over a soil covered with grass residue (Howard, et al., 2001).

Higher N fertilizer requirements for cotton following small grain cover crops were reported by Howard et al. (2001), Varco et al. (1999) and Mitchell (1996). Varco et al. (1999) found that for maximizing cotton lint yield, 120 kg N ha^{-1} as required when cotton followed rye compared to 96 kg N ha^{-1} for cotton following winter fallow, but lint yields were higher after rye compared to winter fallow. Howard et al. (2001) stated that for achieving similar yields, 101 and 67 kg N ha^{-1} were required for maximizing lint yields when cotton followed corn stover and native winter weed vegetation, respectively.

However, it is expected that the long-term use of high biomass cover crops in conservation tillage systems will increase the soil organic carbon levels with a simultaneous increase of organic fractions of N in the soil, and once a new equilibrium is reached, N rates for crops could be reduced due to an increase of N provided through mineralization (Dinnes et al., 2007).

Recently, it has been proposed that winter cover crop biomass could be used as an alternative source of energy or for feeding animals. Alternative uses for cover crop biomass would help farmers to increase revenue while diversifying market opportunities (Siri-Prieto et al., 2007). Cover crop biomass removal could cause significant changes in soil C and N dynamics and also impact crop yields and their response to N fertilization. Crop biomass removal can cause reductions in soil organic C levels with a subsequent deterioration of soil physical, chemical and biological properties (Clapp et al., 2000; Govaerts et al., 2007; Malhi et al., 2006; Wilhelm et al., 2004; Tsuji et al., 2006; Salinas-Garcia et al., 2001). As a result of these changes in soil properties, reductions in crops yields are expected to occur (Cassel and Wagger, 1996; Doran et al., 1984). The impact of residue removal on soil properties and crop productivity has been well documented, but no research has been conducted emphasizing the potential impact of winter cover crop biomass removal on cotton yields and its response to N fertilization under conservation tillage.

We speculate that when rye residue is removed, N rates required for maximizing cotton production could be reduced because of the lower effect of N immobilization under conditions of low levels of residue with a high C/N ratio. Even though differences in soil properties in response to new management practices require some time to occur, we consider that short-term rye residue removal may produce enough changes in the soil environment to cause reductions in cotton yields. The objectives of this research were (i) to determine the effect of rye residue management on cotton growth parameters and yield, (ii) to quantify the impact of rye residue management and cotton response to N fertilization, and (iii) to determine if optimum N rates for cotton can be reduced under rye residue removal conditions.

MATERIALS AND METHODS

A 2-year field experiment under supplemental irrigation was established in November 2005 at the Alabama Agricultural Experiment Station’s E.V. Smith Research Center – Field Crops Unit (32^o 25’ 19’’ N, 85^o 53’ 7’’ W), near Shorter in central Alabama, US. The soil was a Marvyn loamy sand (fine-loamy, kaolinitic, thermic Typic Kanhapludult) (NRCS, 2007). This region is characterized by a humid subtropical climate, with an average annual precipitation of about 1100 mm (Schomberg et al., 2006). The experimental area was previously managed with conventional tillage. Three rye residue management levels schemes and four nitrogen rates were evaluated for cotton production. Rye residue management were: NC, REM and RET. Each RM was evaluated with cotton N fertilization rates of 0, 50, 100 and 140 kg ha^{-1} applied at the first pinhead square stage. Rye residue management were the main plots (18-m long by 8-m wide) and N rates for cotton were the subplots (9-m long by 4-m wide).

Field methods

Soil management

Before planting rye the first year, the entire area was deep-tilled with a non-inversion, bent-leg subsoiler to a depth of 46-cm to remove any soil compaction from previous tillage. It was leveled with a field cultivator. In early May each year the experimental area was tilled in-row (1-m between rows) with a narrow-shanked subsoiler to a depth of 40-cm. The in-row tillage was conducted using a tractor with a mounted Trimble AgGPS Autopilot automatic steering system (Trimble, Sunnyvale, CA 94088)[1], with centimeter level precision to avoid compaction in cotton rows. The no winter cover crop treatment was kept free of weeds during winter by applying herbicide when required.

Crop management

Rye (cultivar “Elbon”) was drilled at 100 kg ha^{-1}, in early November each year, using a no-till drill. Plots planted with rye received 40 and 30 kg N ha^{-1} as ammonium nitrate applied manually three weeks after planting and in late February, respectively. In the RET treatment, rye was rolled down at the early milk development stage (Zadoks et al., 1974) in late April each year, then sprayed with glyphosate (N-phosphonomethyl glycine) at a rate of 0.9 kg a.i.ha^{-1}. At the same time rye was terminated in the RET treatment, about 85 % of the aboveground rye biomass in the REM treatment was

---

[1] Mention of a company does not imply approval or recommendation by Auburn University or USDA-Agricultural Research Service to the exclusion of others that may be suitable.

mechanically harvested to a height of 10-cm over the soil surface and removed from the plots.

The entire experimental area received an application of 21, 10, 42 and 6 kg ha^{-1} of N, phosphorus (P), potassium (K) and sulfur (S), respectively, each year by early May, based on the Alabama Cooperative Extension System soil test recommendations (Adams and Mitchell, 2000). Cotton, cultivar DP 454 BG/RR (Delta Pine and Land Co., Scott, MS)[1], was planted on May 19 and 18 of 2006 and 2007, respectively, using a four-row planter John Deere Max Emerge Plus (Deere&Company, Moline, IL)[1], at a rate of 17 seeds m^{-1}. Row spacing was one meter. Herbicides, insecticides, defoliant and boll opener applied to cotton were based on the Alabama Cooperative Extension System recommendations (ACES, 2006). The entire research area received supplemental irrigation of 70 and 160 mm during the 2006 and 2007 cotton seasons, respectively, using a linear-movement sprinkler irrigation system. Nitrogen treatments for cotton were applied manually as ammonium nitrate at the first pinhead square stage [37 days after planting (DAP)]. Cotton was chemically defoliated and a boll opener was applied when 60-70 % of the bolls in RET were opened. Before cotton harvest, one meter of each end of the plots was cut off with a rotary mower. After harvesting, cotton stalks were shredded with a rotary mower.

Data Collection

Cotton

Cotton population, leaf blade samples and seed cotton yield were determined from the two middle rows of each subplot, and cotton biomass from the two exterior rows of each subplot. Cotton population was determined by counting the number of plants in 3-m in each of the two middle rows in sub-plots 37 DAP. Ten upper-most fully developed blades leaf were collected from recently matured leaves in the upper canopy of each subplot, at 37 and 65 DAP in 2006 and at 37 and 69 DAP in 2007. Leaf blade samples were oven dried at 55^o C until constant weight, ground with a cyclone grinder (Thomas Scientific, Swedesboro, NJ)[1] until passing a 1 mm screen and analyzed for total N by dry combustion using a LECO TruSpec analyzer (LECO Corp., St. Joseph, MI)[1]. Aboveground cotton biomass was determined at 37 and 92 DAP in 2006 and 2007 by randomly cutting eight plants per subplot and drying them in an air forced oven at 55^o C until constant weight to determine total plant dry weight. Plant samples were ground with a Wiley mill (Thomas Scientific, Swedesboro, NJ)[1] until passing a 2 mm screen and ground again with a cyclone grinder (Thomas Scientific, Swedesboro, NJ)[1] to pass a 1 mm screen. Total N was analyzed in each sample by dry combustion using a LECO TruSpec analyzer (LECO Corp., St. Joseph, MI)[1]. Cotton biomass was calculated taking into account the dry weight per plant and cotton population. The N taken up by the crop at each sampling time was calculated based on the total biomass and plant N concentration. Cotton biomass and N uptake between first square and cutout was calculated by subtracting the amount at first square from the amount at cutout, for each parameter. The cotton biomass N concentration between first square and cutout was calculated based on the cotton biomass and N uptake data during this period of time. Seed cotton was mechanically harvested at 139 and 125 DAP in 2006 and 2007, respectively, using a spindle picker. The harvested area per subplot was 14 m^2 (2-m wide by 7-m long). Seed cotton from each subplot was collected in bags, weighed and the yield calculated.

Soil

Composite soil samples consisting of four cores (1.8-cm diameter) per subplot to a depth of 20-cm were taken immediately before applying N fertilizer to cotton (37 DAP in 2006 and 2007). Soil samples were oven dried at 55^{o} C until constant weight and analyzed for NO_3-N and NH_4-N using the microscale method (Sims, 1995). Amount of mineral N (kg ha^{-1}) was calculated using data of soil bulk density and soil mineral N concentration for each RM.

Weather

Daily average temperature data for both years were taken from an automated weather station located at the Experimental Station, beginning when cotton was planted and ending at the cutout stage of cotton development. Daily heats units (HU) between planting and cutout were calculated as the difference between the average daily temperature and a base temperature of 15.6 ^{o} C (Peng et al., 1989). Rainfall and irrigation during each season were measured directly in the experimental area with a rain gauge connected to a data-logger.

Experimental design and statistical analyses

The experimental design was a split-plot arrangement in a randomized complete block with four replications. Rye residue management was the main factor and N rates for cotton the subfactor. As N treatments were applied at the first pinhead stage of cotton development, data collected before this N application were analyzed using the MIXED procedure of SAS (Littell et al., 2006) only considering the RM effect (randomized complete block design). The LSMEANS PDIFF option was used to establish mean differences between RM treatments. Data collected after applying N treatments to cotton were analyzed through covariance analysis using the MIXED procedure of SAS (Littell et al., 2006) considering N as covariate. Replication and its interactions were considered as random effects. Treatments and year were considered fixed effects. When a significant interaction including year occurred, data were presented separately for each year. When Year x RM x N or RM x N interactions were not significant, the LSMEANS PDIFF option was used to establish means differences between RM treatments. The covariance analysis was used to evaluate linear and quadratic effects of N rates on cotton parameters measured and to fit the best linear or quadratic regression model. Linear or quadratic effects were considered significant when $P \leq 0.15$ (Mitchell and Tu, 2005). Treatments effects and differences of least squares means were considered significant when $P \leq 0.05$.

RESULTS AND DISCUSSION

Climate data

Rainfall plus irrigation during both years were different in amount and distribution (Fig. 2-1). In 2006, rainfall and irrigation between one week before planting cotton and cutout were 247 and 70 mm, respectively. For the same period during 2007, they were 207 and 176 mm, respectively. Rainfall in 2006 and 2007 was 23 and 36 % lower than the 10-year average. In 2006, rainfall was below the 10-year average until mid-season, after which it was similar or greater. However, in 2007 rainfall was below the 10-year average early and late in the cotton season and it was not uniformly distributed, with 75 % of rainfall occurring during the first 10 days of July. As a result of this, a higher amount of irrigation was applied during 2007 (Fig. 2-1).

The main difference in HU between years occurred at the end of the cotton season (Fig. 2-2). For the last 20-day period before cutout, HU in 2007 were 20 % higher than in 2006, indicating that higher temperatures occurred during this period in 2007 respect to 2006.

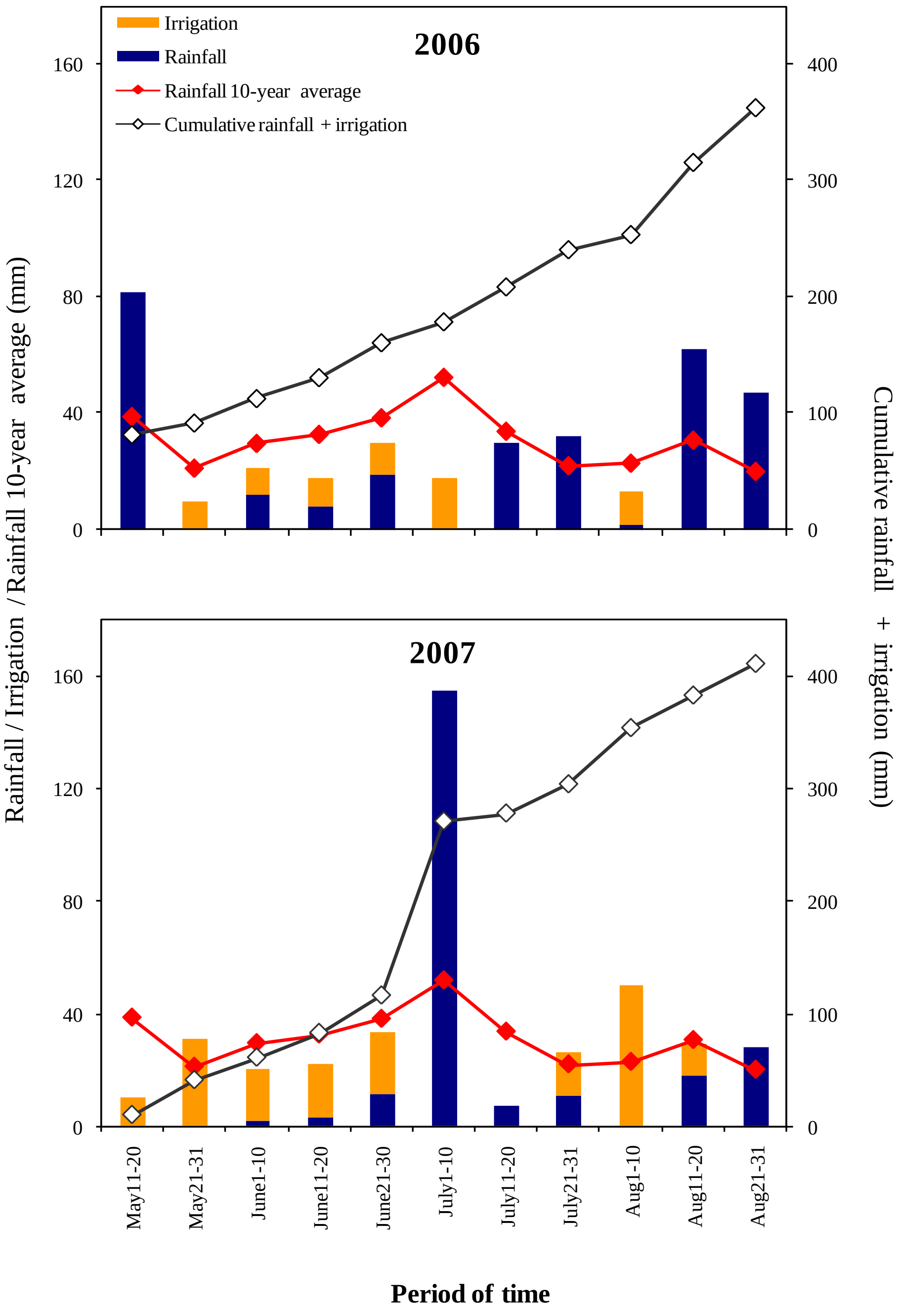

Fig. 2-1. Rainfall 10-year average, and rainfall and irrigation patterns for 10-day periods of time between one week before cotton planting and cutout during the 2006 and 2007 cotton seasons.

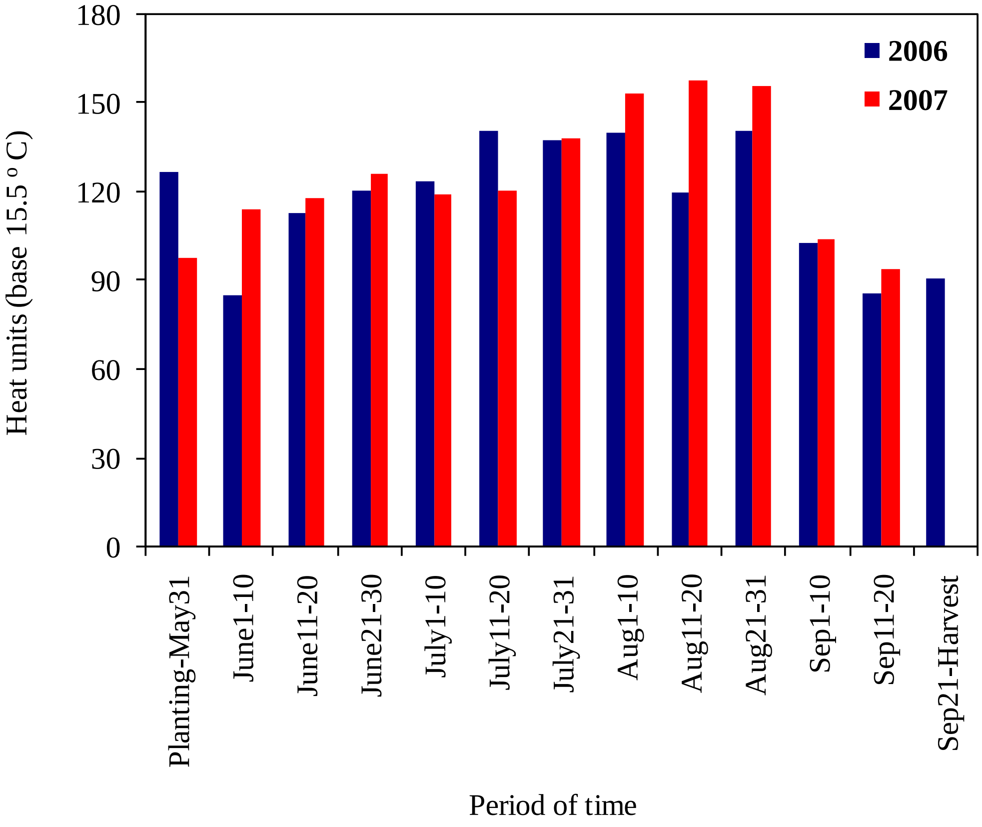

Fig. 2-2. Accumulated heat units for 10-day periods of time between cotton planting and harvest during the 2006 and 2007 cotton seasons.

Cotton population

Rye residue management had a significant effect on cotton population 37 DAP, across years (Table 2-1). Rye residue retained had a significantly higher population than NC ($P \leq 0.01$), but population for REM was not significantly different with respect to the other two treatments (Fig. 2-3 A). Population for RET was 4 and 7 % greater than REM and NC, respectively. Tillage operations were identical among RM so differences in cotton populations can be attributed to differences in soil water content among treatments during the establishment period of the crop. Higher soil water content was measured in RET compared to REM and NC until 20-25 days after cotton planting in both years (Fig. 1-11) which probably contributed to a better plant establishment in both seasons.

Cotton population was also significantly different ($P \leq 0.01$) between years (Fig. 2-3 B) when averaged across RM. Higher cotton populations were observed in 2006 compared to 2007. In both years, the quality of the seed bed at planting as well as the soil water content between planting and the following two weeks were similar, indicating that other factors could be responsible for this difference between years. Accumulated HU during the first 13 days after planting were 24 % lower in 2007 compared to 2006, indicating that this period was colder in 2007. These low temperatures could explain the population reduction in 2007, which probably contributed to slow plant growth, extending the period of time that young plants are susceptible to water deficit, and insect and disease damage. Cotton populations in 2006 and 2007 were about 150,000 and 140,000 plants ha^{-1}, respectively, which were in a range considered high for cotton production, even though seed cotton yields can be stable for a wide range of plant densities (Bednarz et al., 2000). However, this yield stability may be threatened if dry periods occur during the cotton season (MSUES, 2007).

Table 2-1. Analysis of variance for cotton population, leaf N concentration, plant N concentration, cotton biomass and N uptake at first square as affected by year and rye residue management. P-values in bold are significant at α≤ 0.05.

Source of variation	Cotton Population	Leaf N concentration	Plant N concentration	Cotton biomass	N uptake
	----------	----------	P > F	----------	----------
Year	**≤0.01**	**≤0.01**	**≤0.01**	0.64	0.15
RM[†]	**≤0.01**	**≤0.01**	**≤0.01**	**≤0.01**	**≤0.01**
Year*RM	0.58	**0.02**	**≤0.01**	0.33	0.58

[†] Rye residue management

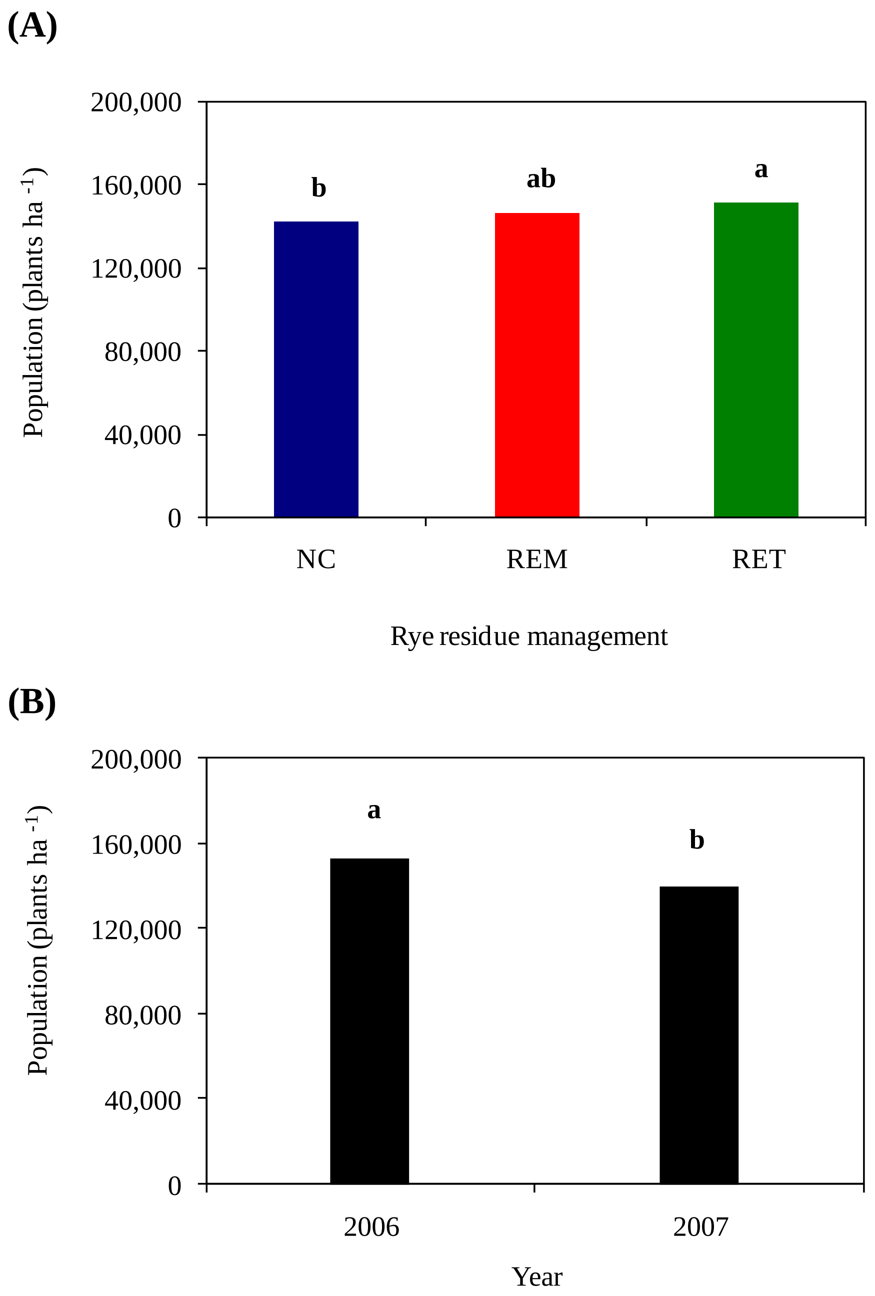

Figure 2-3. Effect of (A) rye residue management (across years) and (B) year (across rye residue management) on cotton population 37 days after planting. Columns sharing the same letter are not significantly different (P≤0.05). NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

Leaf and plant N concentration at first square

There was a significant Year x RM interaction for leaf and plant N concentration at first square (Table 2-1). In 2006, RET had a significantly higher leaf N concentration than NC and REM ($P \leq 0.01$ and $P=0.03$, respectively), and NC was not significantly different from REM (Fig. 2-4 A). In 2007, RET and REM had significantly higher leaf N concentration than NC ($P \leq 0.01$ and $P \leq 0.01$, respectively), but differences between these two treatments were not significant. Leaf N concentration values ranged between 38 and 43 g kg^{-1} in 2006 and between 40 and 46 g kg^{-1} in 2007. These values were lower than the 54 g kg^{-1} critical level reported by Bell et al. (2003) at first pinhead square, for cotton in the southern US. However, leaf N concentration levels in our study were in the sufficiency range reported by Mills and Jones (1996).

Even though cotton biomass accumulation before the first pinhead square is generally low, the N applied before planting plus the N probably provided through mineralization were not enough to increase leaf N concentration to values higher than 46 g kg^{-1} in the conditions of our experiment. Nonetheless, Bell et al. (2003) also mentioned that high cotton yields can still be achieved by cotton crops having low leaf N at first pinhead square, if N deficiencies are corrected at this stage of development and leaf N concentrations at early bloom are in the sufficiency range.

In 2006, RET had a significantly higher plant N concentration than REM and NC ($P \leq 0.01$ and $P \leq 0.01$, respectively), but REM was not significantly different from NC (Fig. 2-4 B). However, in 2007 differences among RM treatments were not significant and plant N concentration values were very similar for each treatment. Plant N concentration for RM in 2006 followed a similar pattern to leaf N concentration, but their values were lower. This is expected because plant samples that include older tissues other than leaves are characterized by low N concentrations, for example shoots and main branches.

The higher accumulation of HU during June 2007 compared to June 2006, plus the water supplied by irrigation offered better conditions for cotton growth in 2007, resulting in higher leaf and plant N concentration at first square. Additionally, the amount of soil mineral N at first square was 19 % higher in 2007 compared to 2006 averaged across RM (Table 2-2), indicating that the N availability during June was probably higher in 2007.

The amount of soil mineral N measured at first square each year was unexpected, particularly for RET. High levels of rye residue with C/N ratios of 33 and 47 for 2006 and 2007, respectively, were left on the soil surface in the RET treatment (Table 1-2). These C/N ratios were higher than the critical range of 25-30 reported by Jensen (1997), above which N immobilization is expected to occur. Even though conditions were favorable for N immobilization, amounts of soil mineral N at first square in RET were 33 and 42 kg ha^{-1}, in 2006 and 2007, respectively. These levels of N in soil would indicate that N availability was not a limiting factor for cotton growth at first square. The combination of available soil mineral N and a high soil water content in RET until first square in both seasons (Fig. 1-11) provided good growing conditions for cotton, which can explain why leaf and plant N concentrations in RET were higher or similar to REM and NC.

Table 2-2. Amount of mineral N (NH_4+NO_3) in soil to a depth of 20-cm at first square as affected by rye residue management.

RM[†]	Soil mineral N		
	2006	2007	Average
	---------------	kg N ha^{-1}	----------------
NC[‡]	30.0	43.0	36.5
REM	46.0	45.0	45.5
RET	33.0	42.0	37.5
Effect	Analysis of variance (P > F)		
RM	0.07	0.91	0.21

[†] RM = Rye residue management

[‡] NC = no winter cover crop

REM = rye residue removed

RET = rye residue retained

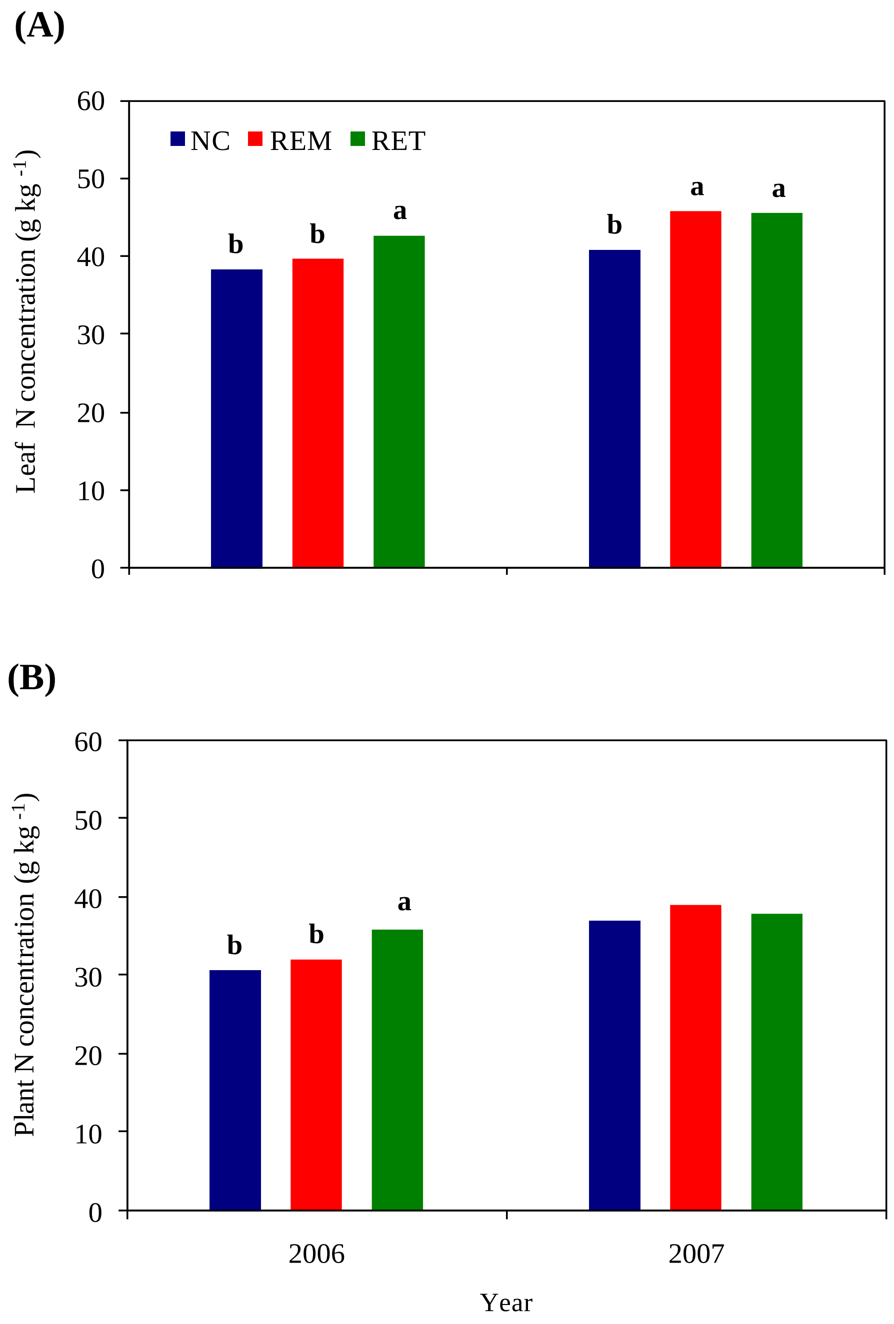

Figure 2-4. Effect of rye residue management and year on: (A) leaf N concentration and (B) plant N concentration, at first square. Columns sharing the same letter for each parameter inside of year are not significantly different ($P \leq 0.05$). NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

Cotton biomass and N uptake at first square

Rye residue management had a significant influence on cotton biomass and N uptake at first pinhead square, averaged across years (Table 2-1). Rye residue retained had significantly higher cotton biomass than NC and REM ($P \leq 0.01$ and $P \leq 0.01$, respectively) (Fig. 2-5). Rye residue removed had a cotton biomass 35 % higher than NC, but this difference was not significant. Similar results were obtained for N uptake, with RET having values 96 and 166 % higher than REM and NC ($P \leq 0.01$ and $P \leq 0.01$, respectively). No significant differences occurred between REM and NC, but N uptake was 39 % higher for REM (Fig. 2-5).

Differences in N uptake among RM treatments can be explained by differences in cotton biomass and plant N concentration. When averaged across years, plant N concentration was 34, 35.7 and 37.1 g N kg^{-1} for NC, REM and RET, respectively. Although these two growth parameters influenced N uptake in the same manner, cotton biomass could have had the highest impact on N uptake, because its variability between RM treatments was higher in proportion to plant N concentration.

Results show that in both years RET provided better conditions for cotton growth and uptake of N. This could have been a consequence of greater N availability between planting and first square, as indicated by the residual levels of N at this time, and also because of the high soil water content this treatment had during this period of time (Fig. 1-11). The higher cotton biomass RET had compared to REM and NC was not only explained by a higher cotton population, but also by greater plant weight. Averaging over the two seasons, the weight per plant was 1.57, 2.04 and 3.62 g for NC, REM and RET, respectively. Growing conditions for cotton in RET prior to first square were favorable both years, because even though its population was higher with respect to REM and NC, plants managed to grow more reaching an individual weight that was 130 and 77 % higher than in NC and REM, respectively. The absence of a Year x RM interaction and a year effect in cotton biomass and N uptake suggests that at least until this stage of development the crop was very similar in both seasons. Although rainfall plus irrigation prior to first square was lower in 2007 compared to 2006, the amount of water cotton received in 2007 was still adequate to satisfy the cotton water requirements during this initial period of growth.

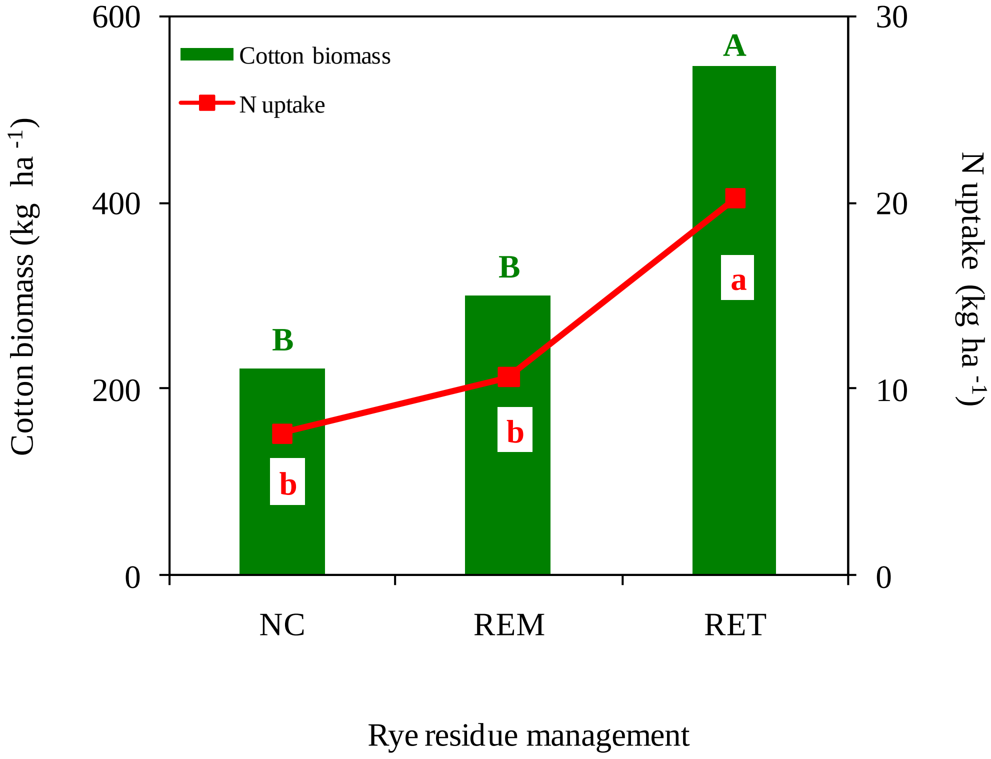

Figure 2-5. Effect of rye residue management on cotton biomass and N uptake at first square, averaged across years. Means followed by the same letter for each parameter are not significantly different ($P \leq 0.05$). NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

Leaf N concentration at early bloom

Leaf N concentration at early bloom was significantly affected by RM, N and year, but interactions were not significant (Table 2-3). No winter cover crop and REM had significantly higher leaf N concentration compared to RET ($P \leq 0.01$ and $P \leq 0.01$, respectively) (Fig. 2-6). This could be evidence that the rye residue immobilized some of the soil mineral N between first square and this sampling time, decreasing the availability of N for cotton and reducing the N concentration in cotton tissues. Data presented in Fig. 1-12 support that N immobilization effectively occurred between first square and cutout for RET and REM, but amounts of N immobilized were low. This could indicate that N immobilization did not have a great impact on the leaf N concentration differences between RM treatments. We speculate that the higher cotton biomass production in RET could have caused a N dilution within cotton tissues. Cotton biomass was not measured when sampling leaves, but plant heights at this sampling time averaged across years and N rates showed that plants in RET were taller than in REM and NC (data not shown), indicating a possible higher cotton biomass and potential dilution of N in this treatment. Similar results were reported by Fridgen and Varco (2004), and Balkcom et al. (2007), who found a dilution of leaf N when cotton biomass production was high.

In spite of differences among RM, leaf N concentration in all treatments was below the 43 g kg $^{-1}$ critical value for the southeastern US (Bell et al., 2003). This could be explained because data presented for the RM effect were averaged across cotton N rates. The average N rate for cotton in our experiment was 72.5 kg ha^{-1} which was lower than the recommendation for cotton growing under conservation tillage with a small grain cover crop (Mitchell, 1996). It appears this average N rate plus the N already in the soil when applying the fertilizer was not enough to increase leaf N concentration up to published sufficiency levels.

Averaged across years and RM, leaf N concentration response to N was quadratic, achieving fitted a quadratic model and it occurred up to the highest N rate applied, achieving values around 40 g kg^{-1} at the highest N rate applied (Fig. 2-7 A). This value was very close to the sufficiency range reported Bell et al. (2003). However, ours results do not agree with Fridgen and Varco (2004), who found a higher leaf N concentration using similar N rates as we did. Even though leaf N concentration increments decreased with increasing N rates, a maximum leaf N concentration was not achieved, even with the highest N rate applied. This indicates that to reach the maximum leaf N concentration in the conditions of this experiment would require higher N rates than those we used.

Year also significantly affected leaf N concentration at early bloom. The leaf N concentration was significantly lower ($P \leq 0.01$) in 2007, with a decrease of 22 % with respect to 2006 (Fig. 2-7 B). Rainfall distribution during 2007 could explain this trend between years. A more detailed analysis of the rainfall effect on cotton growth parameters will be provided when data of cotton biomass N concentration are presented.

Table 2-3. Analysis of variance for the effect of year, rye residue management and N fertilization on leaf N concentration at early bloom, cotton biomass, cotton biomass N concentration and N uptake between first square and cutout, and seed cotton yield. P-values in bold are significant at α≤ 0.05.

Effect	Leaf N concentration[†]	Cotton biomass[‡]	Cotton biomass N concentration[‡]	N uptake[‡]	Seed cotton yield
	------------	------------	P > F	------------	------------
Year	**≤0.01**	**0.04**	**≤0.01**	**≤0.01**	**≤0.01**
RM[δ]	**0.03**	**≤0.01**	**≤0.01**	0.63	**≤0.01**
N	**≤0.01**	**≤0.01**	**≤0.01**	**≤0.01**	**≤0.01**
Year*RM	0.23	0.95	0.30	0.79	**≤0.01**
Year*N	0.57	**0.02**	0.15	**≤0.01**	**≤0.01**
RM*N	0.76	0.07	0.82	**0.05**	**0.02**
Year*RM*N	0.16	0.99	0.45	0.83	**≤0.01**

[†] At early bloom

[‡] Between first square and cutout

[δ] RM=rye residue management
N=nitrogen

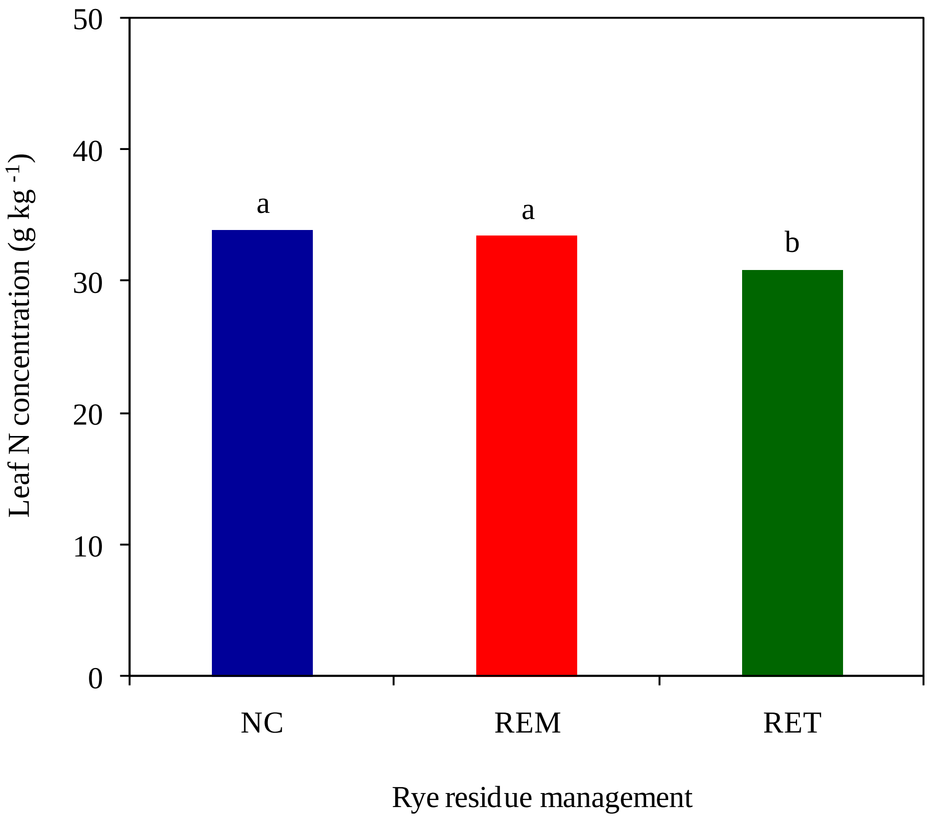

Figure 2-6. Effect of rye residue management on leaf N concentration at early bloom, averaged across years and N rates. Columns sharing the same letter are not significantly different ($P \leq 0.05$). NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

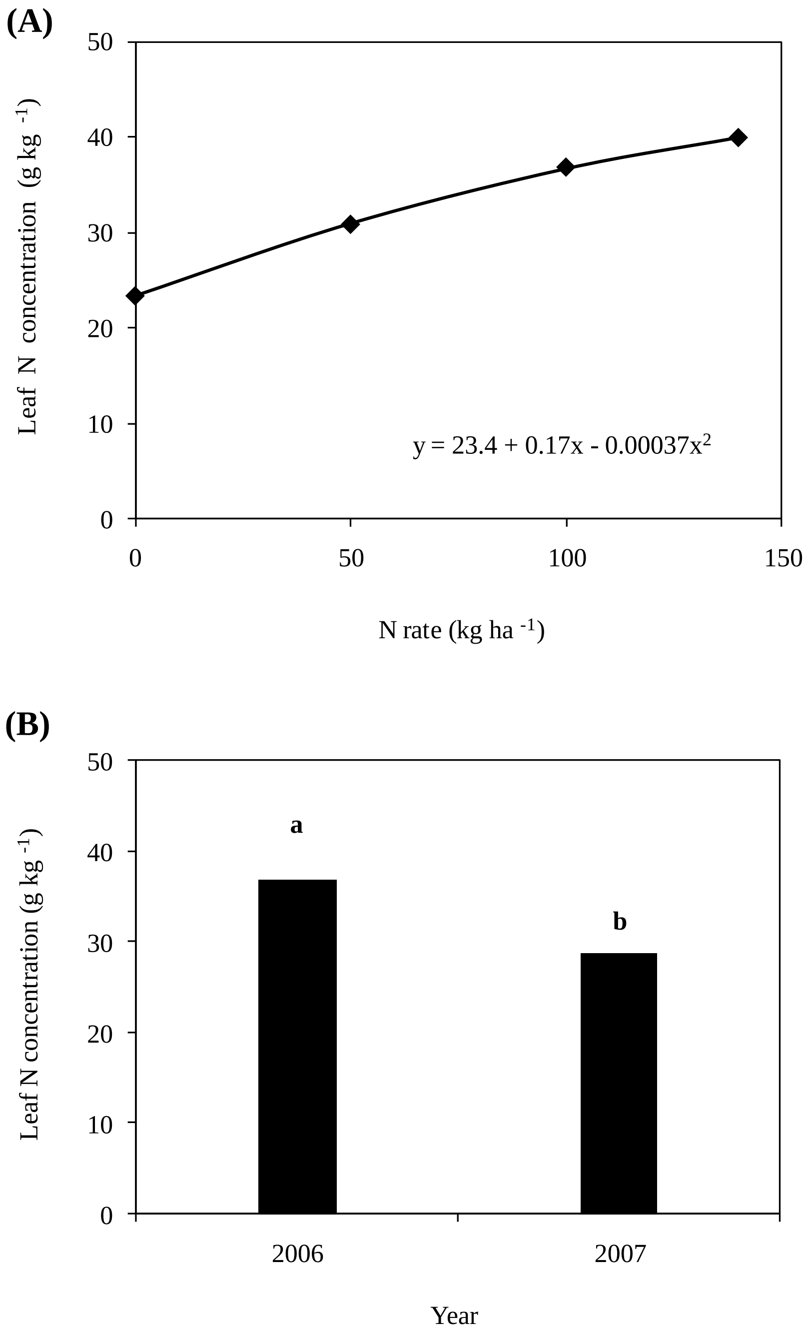

Figure 2-7. Leaf N concentration at early bloom as affected by: (A) N rate (averaged across years and rye residue management) and (B) year (averaged across rye residue management and N rates). Columns followed by different letters are significantly different ($P \leq 0.05$).

Cotton biomass production between first square and cutout

Rye residue management had a significant effect on cotton biomass production between first square and cutout, averaged across years and N rates (Table 2-3). Rye residue retained had significantly higher cotton biomass production than REM and NC ($P \leq 0.01$ and $P \leq 0.01$, respectively), and REM was significantly higher than NC ($P \leq 0.01$) (Fig 2-8). Cotton biomass production for RET was 24 and 43 % higher than REM and NC, respectively, while REM was 16 % higher compared to NC. These results demonstrate that residue retention provided better conditions for cotton growth which was probably associated WITH an increase in soil water content. Govaerts et al. (2007) reported that keeping residue on the soil surface improves infiltration, increasing water available for plants. Nonetheless, for almost most soil water content measurements collected in both seasons to a depth of 20-cm (Fig. 1-11) there were not significant differences among RM after first square. Higher infiltration rates measured in RET and REM relative to NC during both seasons (Fig. 1-7) could have improved the soil water content in the soil profile which was used as cotton roots explored deeper soil layers during the season.

The cotton biomass response to N produced a significantly interaction with year, when averaged across RM treatments (Table 2-3). In both seasons, cotton biomass response to N was quadratic (Fig. 2-9). The small increase between the 100 and 140 kg ha^{-1} N rates indicates that the N rate required to maximize cotton biomass would be similar to the highest rate used in this experiment. Cotton biomass in 2006 was similar to the one reported by Bassett et al. (1970) for a N rate of 134 kg ha^{-1}, but it was extremely low compared to the findings of Boquet and Breitenbeck (2000). In spite of the similar trend between both seasons, cotton biomass was lower for all N rates in 2007 with respect to 2006. The difference for the no N control was very low between years, with a decrease of 9 % in 2007 compared to 2006. However, when N was applied to cotton, the decrease in cotton biomass was about 20 % for 2007 compared to 2006, independent of the N rate used. This cotton biomass reduction could be explained by the low rainfall and non-uniform distribution during 2007. Additionally, the last 20 days before cutout in 2007 were characterized by elevated temperatures as indicated by the higher accumulation of HU units relative to 2006. High temperatures and low rainfall in 2007 could have imposed a stress to the crop causing lower biomass production. This may have occurred even though irrigation was applied mainly because the low amount of applied water in each irrigation event (10 to 12-mm) and high temperatures can have increased the proportion of the applied water that was lost by evaporation and not available to the crop. These results agree with Balkcom et al. (2007), who reported lower cotton biomass in a hot and dry year regardless of irrigation.

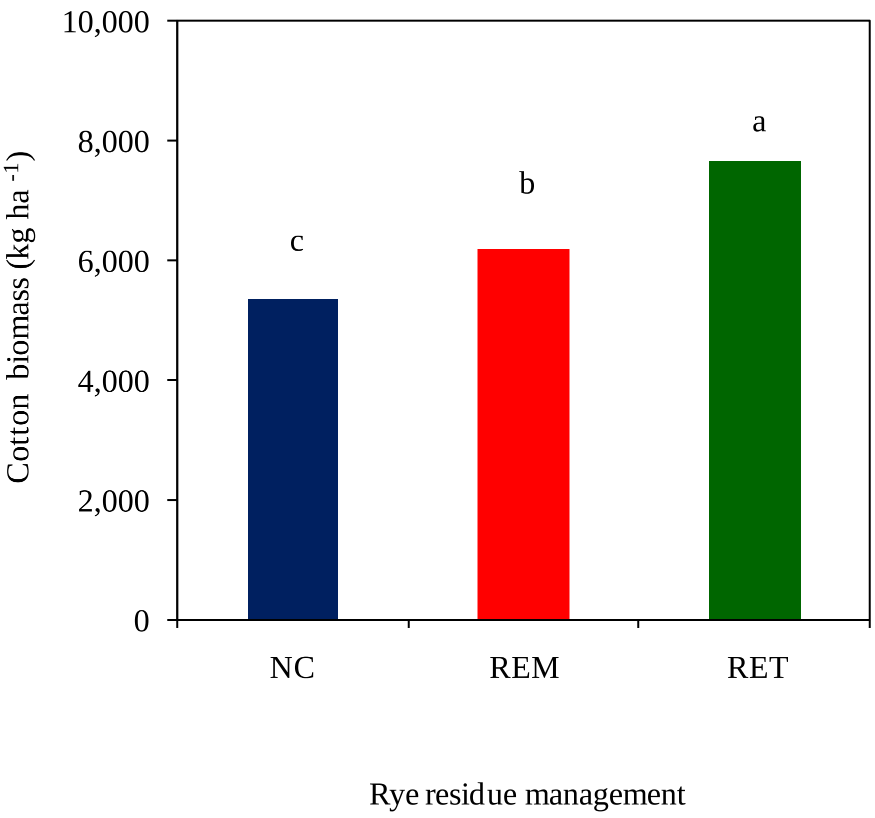

Figure 2-8. Effect of rye residue management on cotton biomass production between first square and cutout, averaged across years and N rates. Columns sharing the same letter are not significantly different ($P \leq 0.05$). NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

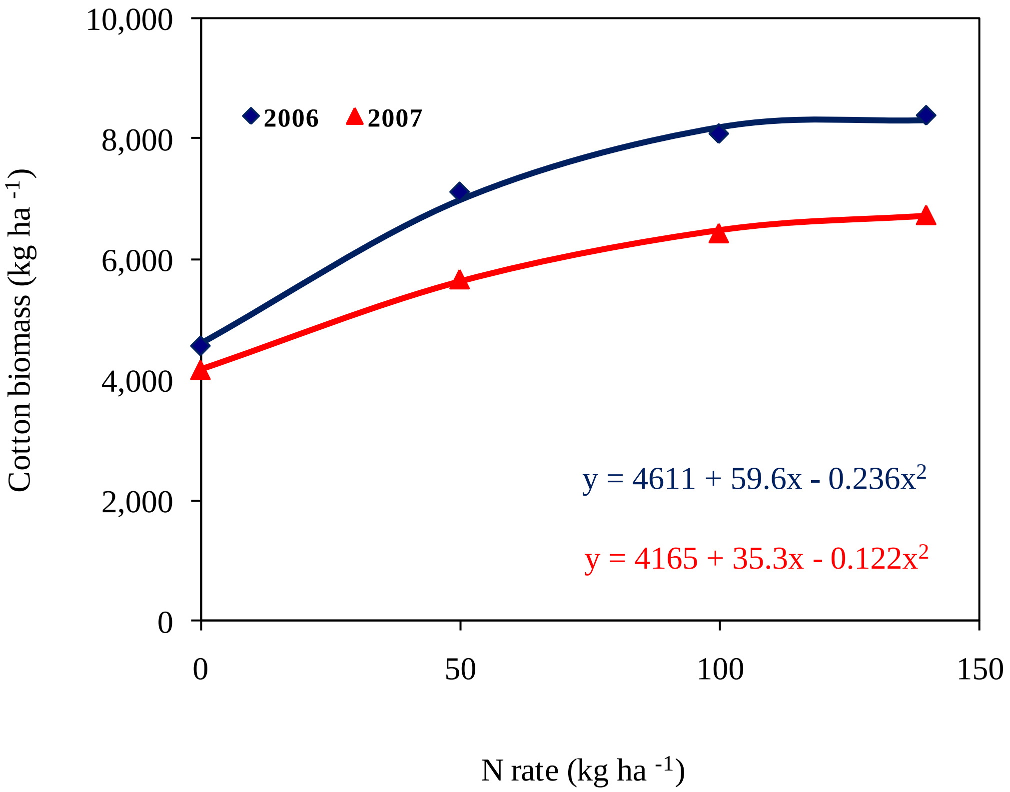

Figure 2-9. Cotton biomass production between first square and cutout as affected by year and N rate, averaged across rye residue management.

Cotton biomass N concentration

The N concentration in cotton biomass accumulated between first square and cutout was significantly affected by RM, N and year, but interactions were not significant (Table 2-3). No winter cover crop had significantly higher cotton biomass N concentration compared to REM and RET ($P=0.03$ and $P\leq 0.01$, respectively) with increments of 12 and 22 %, respectively (Fig. 2-10). Rye residue removed had a higher cotton biomass N concentration compared to RET (9 %), but this difference was not significant. As previously mentioned, N immobilization occurred in both cotton seasons but at low levels. This would indicate that the reduction in cotton biomass N concentration in REM and RET relative to NC could be explained by the higher cotton biomass compared to NC (Fig. 2-8) which may have contributed to a dilution of N in cotton tissues. Rye residue retained and REM accumulated 43 and 16 % more biomass between first square and cutout than NC, respectively, but their increment in N uptake relative to NC was only 18 and 5 %, respectively. This data also suggests an occurrence of N dilution in the accumulated biomass. Gerik et al. (1994) and Bell et al. (2003) reported that under conditions of high availability of N cotton plants increase vegetative growth very quickly which leads to a N dilution in the biomass produced, with subsequent drop in tissue N concentration.

Cotton biomass N concentration response to N rates was linear (averaged across years and RM), indicating that the highest N rate applied did not maximize N concentration in the biomass (Fig. 2-11 A). This trend was similar to that observed for leaf N concentration, even though that response to N was quadratic.

Cotton biomass N concentration was significantly influenced by year (Table 2-3). In 2007, there was a significant decrease ($P \leq 0.01$) of about 28 % in cotton biomass N concentration compared to 2006 (Fig. 2-11 B). This pattern was also observed at early bloom for leaf N concentration and cotton biomass production. There was a simultaneous decrease in cotton biomass and N concentration, but the reduction in cotton biomass N concentration was greater with respect to cotton biomass (28 vs. 18 %, respectively), providing strong evidence that N dilution in tissues occurred. These results indicate that the 2007 crop was affected by N dynamics in the soil-plant system. The rainfall regime during 2007 may have played an important role in these results. The high rainfall that occurred during the first 10 days of July (about 150-mm) was twice than the 70-mm of available water that the soil in the experimental area can retain to a depth of 50-cm (NRCS, 2008). The excess rainfall above the soil water holding capacity could have leached part of the N fertilizer out of the root zone, leading to N deficiencies for the crop. These high rainfall events at the beginning of July in 2007 occurred only one week after the N fertilizer was applied to cotton.

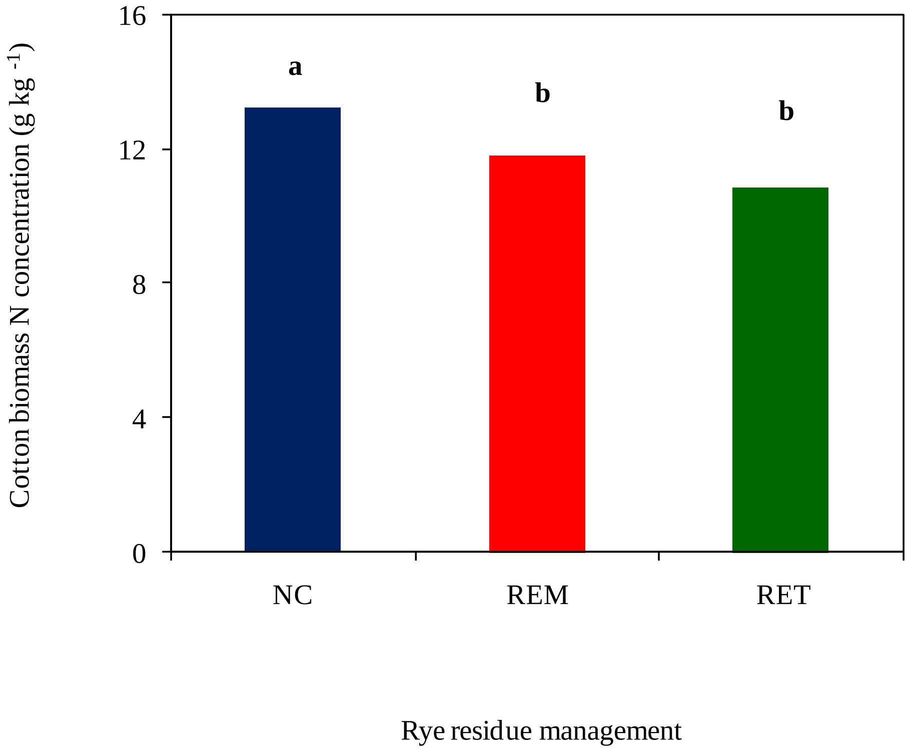

Figure 2-10. Effect of rye residue management on cotton biomass N concentration between first square and cutout, averaged across years and N rates. Columns sharing the same letter are not significantly different ($P \leq 0.05$). NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

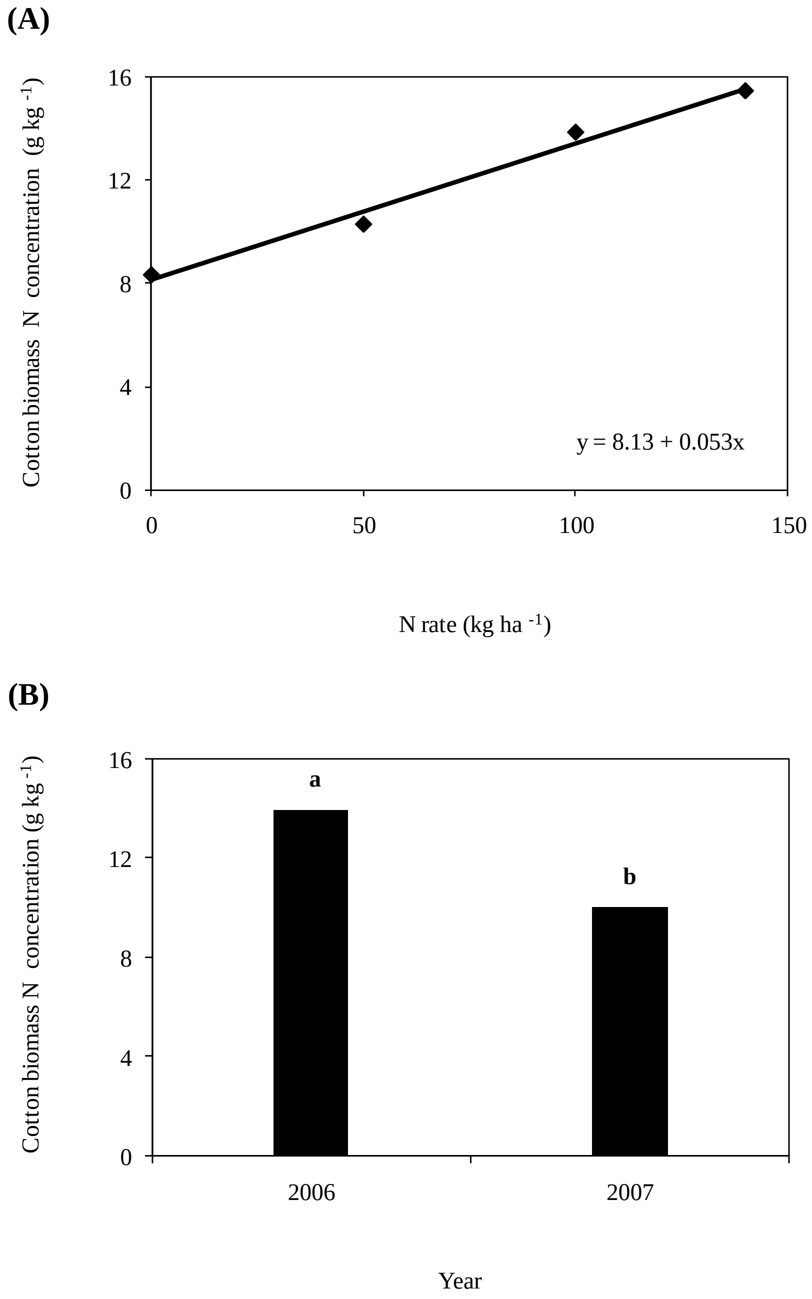

Figure 2-11. Cotton biomass N concentration between first square and cutout as affected by: (A) N rate (averaged across years and rye residue management) and (B) year (averaged across rye residue management and N rates). Columns followed by the same letter are not significantly different ($P \leq 0.05$).

Nitrogen uptake between first square and cutout

Table 2-3 shows there was a significant RM x N interaction for N uptake between first square and cutout. Nitrogen uptake response to N rates was linear for RET and REM, whereas for NC this relationship was best described by a quadratic model. The response of N uptake per kg of N added up to the highest N rate was 0.49, 0.61 and 0.68 for NC, REM and RET, respectively. Cotton plants in RET absorbed more N independent of the N rates applied. Even though RET had higher values of N uptake than REM and NC at all N rates, these differences were magnified with increasing rates of N fertilizer (Fig. 2-12 A). The highest N uptake for each RM treatment occurred at the highest N rate applied. At this N rate, N uptake for RET was 32 and 15 % higher than NC and REM, respectively, and it was 15 % higher for REM compared to NC. The linear relationship between N uptake and N rate for RET and REM indicates that the highest N rate applied was not enough to maximize N uptake under the conditions of this experiment. Conversely, NC had a quadratic relationship with a very low N uptake increment between the 100 and 140 kg ha^{-1} N rates, indicating that the N rate required for maximizing N uptake was very similar to the highest N rate we applied. Our results for RET were similar to the findings of Basset et al. (1970), who found a total N uptake of 142 kg ha^{-1} for irrigated cotton receiving 134 kg N ha^{-1}. However, a study by Mullins and Burmester (1990) revealed greater N taken up with a N rate of 112 kg ha^{-1}. The N uptake by cotton plants at the highest N rate (140 kg N ha^{-1}) represented 72, 83 and 95 % of the N added, for NC, REM and RET, respectively. This would indicate that better growing conditions for cotton provided by RET could have improved the N use efficiency of the N fertilizer applied.

The amount of N absorbed by a crop depends on its biomass production and its N tissue concentration. Table 2-3 shows that the interaction RM x N was not significant for cotton biomass N concentration and cotton biomass production between first square and cutout, when averaged across years. Even though no interaction existed, cotton biomass N concentration values were slightly higher for NC, followed by REM and RET, but cotton biomass was higher for RET, followed by RM and NC, at each N rate (Table 2-4). This pattern would corroborate the higher biomass production that RET exhibited compared to REM and NC (particularly for the 100 and 140 kg ha^{-1} N rates) and also explain its higher N uptake. These results agree with Gastal and Lemaire (2002), who stated that the N taken up by crops is mainly affected by the crop growth rate.

There was a significant Year x N interaction for N taken up by cotton between first square and cutout (Table 2-3). Nitrogen uptake response was quadratic in 2006 and linear in 2007. In both years, the uptake response to N occurred up to the highest N rate applied, with 0.7 and 0.4 kg of N taken up per kg of N added in 2006 and 2007, respectively. Nitrogen uptake was lower for 2007 compared to 2006 for all N rates, but differences were greater when N was applied. Nitrogen uptake in 2007 was 33 % and 39 % lower for the no N control and for the 140 kg ha^{-1} N rate, respectively, relative to 2006 (Fig. 2-12 B). This observed reduction in N uptake can be attributed to the lower cotton biomass production in 2007 for all N rates and the reduction in cotton biomass N concentration measured for both years (Figs. 2-9 and 2-11 B).

Table 2-4. Effects of rye residue management and N fertilization on cotton biomass production and cotton biomass N concentration between first square and cutout, averaged across years.

N rates	Cotton biomass			Cotton biomass N concentration		
	NC[†]	REM	RET	NC	REM	RET
kg ha^{-1}	-----------	kg ha^{-1}	-----------	-----------	g kg^{-1}	------------
0	3,620	4,190	5,281	9.8	7.9	7.3
50	5,430	6,060	7,684	11.4	10.1	9.4
100	6,371	7,034	8,365	15.0	13.9	12.7
140	5,954	7,468	9,258	16.7	15.4	14.3

[†] NC=no winter cover crop

REM=rye residue removed

RET=rye residue retained

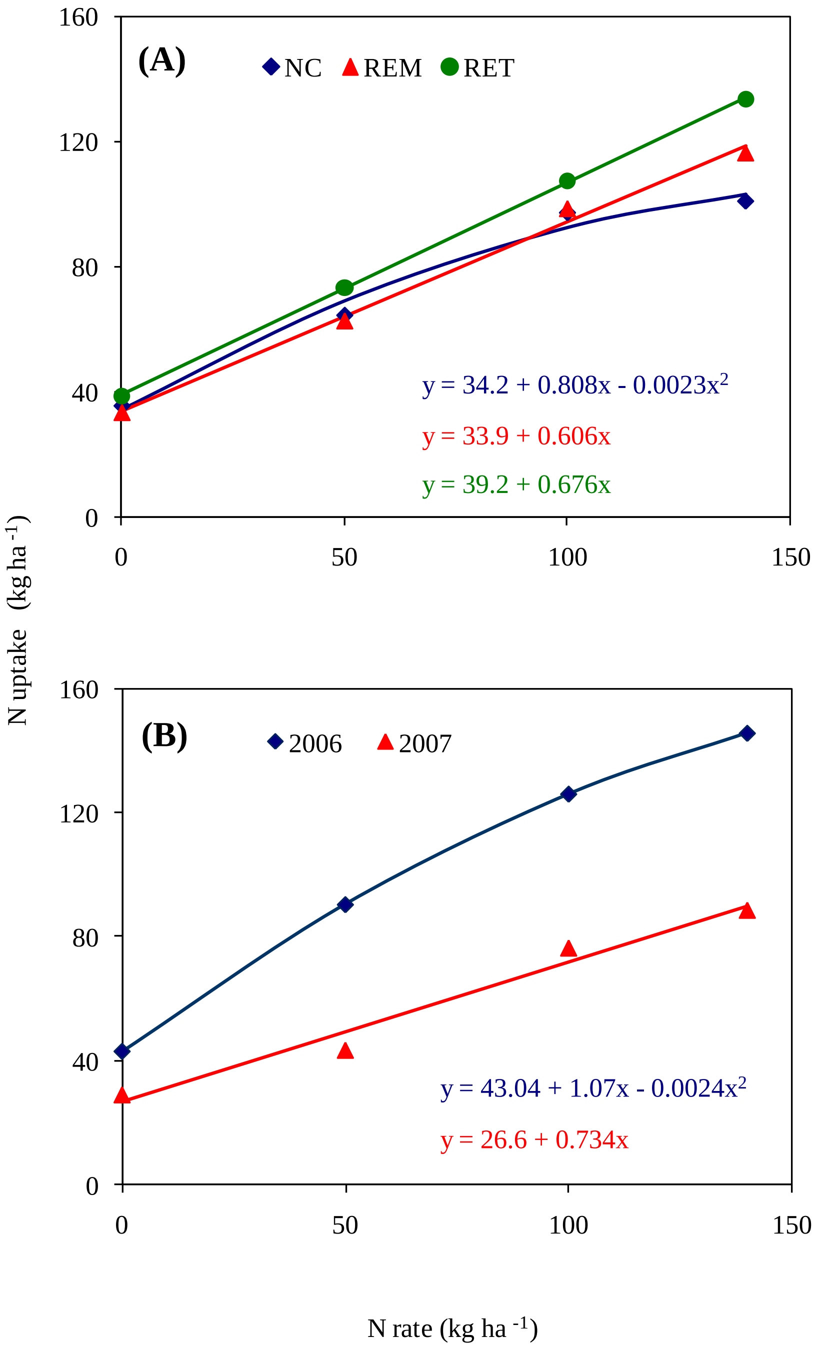

Figure 2-12. Cotton N uptake between first square and cutout as affected by: (A) rye residue management and N rate (averaged across years), and (B) year and N rate (averaged across rye residue management).

Seed cotton yield

A significant Year x RM x N interaction occurred for seed cotton yield (Table 2-3). In 2006, observed seed cotton yields ranged from 1,740 (REM, no N control) to 3,970 kg ha^{-1} (REM, 140 kg of N ha^{-1}). The seed cotton yield response to N for RET was linear, while REM and NC were quadratic. Highest observed and predicted yields corresponded to RET and REM with the application of 140 kg N ha^{-1}, with both treatments producing similar yields (Fig. 2-13). Seed cotton yield response to N for RET and REM occurred up to the highest N rate applied without reaching a maximum. The fact that a plateau yield was not achieved in RET and REM indicates that the conditions of 2006 required a higher N rate than applied to produce maximum yield in these treatments that included rye as a cover crop. However, seed cotton yield in NC reached an estimated maximum at a N rate of 102 kg ha^{-1} and higher N rates caused a decrease in yields. The highest predicted seed cotton yield for RET and REM was about 17 % higher than for NC, showing that growing a cover was the best scenario for obtaining higher yields during 2006, whether or not the cover crop residue was removed or left on the soil surface. Our results for RET and REM are similar to the findings of Reiter et al. (2002) who found that conservation-tilled cotton on a Decatur silt loam responded up to 134 kg N ha^{-1}. Seed cotton yields observed in RET and REM were also similar to results of Clawson et al. (2006), who found cotton response to N up to 151 kg ha^{-1}. However, Wiatrak et al. (2005) reported a linear increase in lint yields up to 200 kg N ha^{-1}, a rate considerably greater than the highest we applied.

The seed cotton yield response to N during 2006 was 11.3, 15.9 and 9.7 kg of seed cotton per kg of N added for NC, REM and RET at N rates of 102, 140 and 140 kg ha^{-1}, respectively. The highest yield increase with respect to the no N control corresponded to REM, followed by RET and NC (128, 53 and 45 %, respectively), at the previously mentioned N rates. The lower response to N for RET is explained by its higher seed cotton yield for the no N control, compared to REM and NC. Rye residue removed had the lowest seed cotton yield when no N was applied, with a yield reduction of 22 and 33 % relative to NC and RET, respectively. Lower yields in REM compared to NC for the no N control were unexpected, since all cotton growth parameters for REM were at least similar or better than for NC when N was not applied. This yield decrease could be related to a factor or combination of factors directly affecting some of the yield components. However, the application of 50 and 100 kg of N ha^{-1} were enough to increase yields up to levels similar to NC and RET. With 140 kg of N ha^{-1} the yield for REM was one of the highest. The observed trend for REM indicates that a severe N deficiency occurred in this treatment when no N was added. The higher N immobilization for this treatment in 2006 may have contributed to a low seed cotton yield (Fig. 1-12). This contrasting pattern observed for REM of very low seed cotton yield in the absence of N fertilization and very high with high N rates, can explain its high seed cotton yield response per kg of N added.

In 2007, seed cotton yields ranged from 1,295 kg ha^{-1} (NC, no N control) to 2,677 kg ha^{-1} (RET, 140 kg of N ha^{-1}). Rye residue retained and REM had a quadratic seed cotton yield response to N fertilization, while the yield increase for NC followed a linear trend (Table 2-9). Rye residue retained had the highest predicted yield with 125 kg N ha^{-1}, followed by REM and NC at N rates of 106 and 140 kg N ha^{-1}, respectively (Fig. 2-13). Boquet et al. (2004) and Varco et al. (1999) reported an optimum N rate of about 118 kg

ha^{-1} for conservation tillage cotton, a value similar to the one we found for RET in 2007. Rye residue retained required 21 kg N ha^{-1} more than REM for maximizing yields but it had a higher yield. The highest estimated seed cotton yield for RET was 12 and 8 % higher than NC and REM, respectively. Nitrogen rates above the optimum for REM tended to slightly decrease yields. A similar reduction in seed cotton yields occurred for NC in 2006 for N rates higher than 102 kg ha^{-1}. Cotton yield reductions with application of high N rates were reported by McConnell et al. (1993) and Boquet et al. (1994). High N levels in soil can cause excessive vegetative growth, with a subsequent competition between vegetative and reproductive structures, which generally is detrimental to bolls and lint development, lint quality and yield (McConnel et al., 1995). Regardless of its linear response to N, the decreasing yield with increasing N rate for NC indicates that the 140 kg N ha^{-1} we applied was near the optimum rate. In 2007, not only did NC have the lowest yield but also it required the highest N rate for achieving its highest seed cotton yield. Yields during 2007 were highly dependent on residue management. The best situation for achieving high seed cotton yields was to have a cover crop and keeping the residue on the soil surface.

The seed cotton yield response to N in 2007 was very similar among RM treatments, 7, 8 and 7 kg of seed cotton per kg of N for NC, REM and RET (at N rates of 140, 106 and 140 kg ha^{-1}, respectively). No winter cover crop had the highest yield increase relative to the no N control, followd by REM and RET (75, 53 and 43 %, respectively), for the previously mentioned N rates. As in 2006, in 2007 RET had the lowest yield increment compared to the no N control, even though it had the highest estimated seed cotton yield. This pattern is explained by its greater seed cotton yield when no N was added.

In both years, RET had higher seed cotton yield than REM and NC in the no N control. This result was not expected because the presence of rye residue with a high C/N ratio on the soil surface has been commonly associated with the occurrence of N immobilization, which reduces levels of soil mineral N and decreases yields (Dabney et al., 2001). In situations with no N added this effect would have a greater negative impact on crop yields. However, results of cotton N uptake between first square and cutout in the no N control averaged across years (Fig. 2-12 A) followed a similar trend as seed cotton yield. The cotton N uptake in RET was 9 and 15 % higher than in NC and REM, respectively, for the no N control. These results indicate that under the conditions of our experiment N immobilization was of not high enough to reduce seed cotton yields in RET.

Seed cotton yields during 2007 were considerably lower than in 2006 as well as the response to N for each RM. This yield variability across years has been reported for the southeastern US (Mitchell and Tu, 2005). We speculate that the combination of three factors could have contributed to lower seed cotton yields during the 2007 cotton season:

a) A rainfall shortage early and late in the cotton season. Rainfall during these two periods was significantly lower than the historic average (Fig. 2-1), and as a consequence, more irrigation was applied. However, when low rainfall occurs combined with high temperatures, yield reduction may occur independent of irrigation (Balkcom et al., 2006). The main effect of moisture stress on cotton yields is by decreasing the number of bolls produced and the amount of lint per seed (Pettigrew, 2004).

b) Most of the rainfall occurring in 2007 was concentrated during the first ten days of July, exceeding the soil water capacity and probably contributing to N leaching since N fertilizer was applied one week before this period of time.

c) Temperatures during August 2007 were higher than in 2006, as indicated by the higher accumulation of heat units (Fig. 2-2). Reddy et al. (1999) reported that boll retention is the most temperature-sensitive cotton parameter and that temperatures above 32^o C reduce boll survival. During the 2006 season the daily average temperature was never higher than this critical value, but late in the 2007 season there were 5 days with average temperatures higher than 32^o C (data not shown) which could have reduced boll survival, decreasing cotton yields.

This particular combination of low rainfall, probable low N availability and high temperatures during part of the reproductive period of cotton in 2007 could have accounted for the decrease in seed cotton yields, compared to 2006.

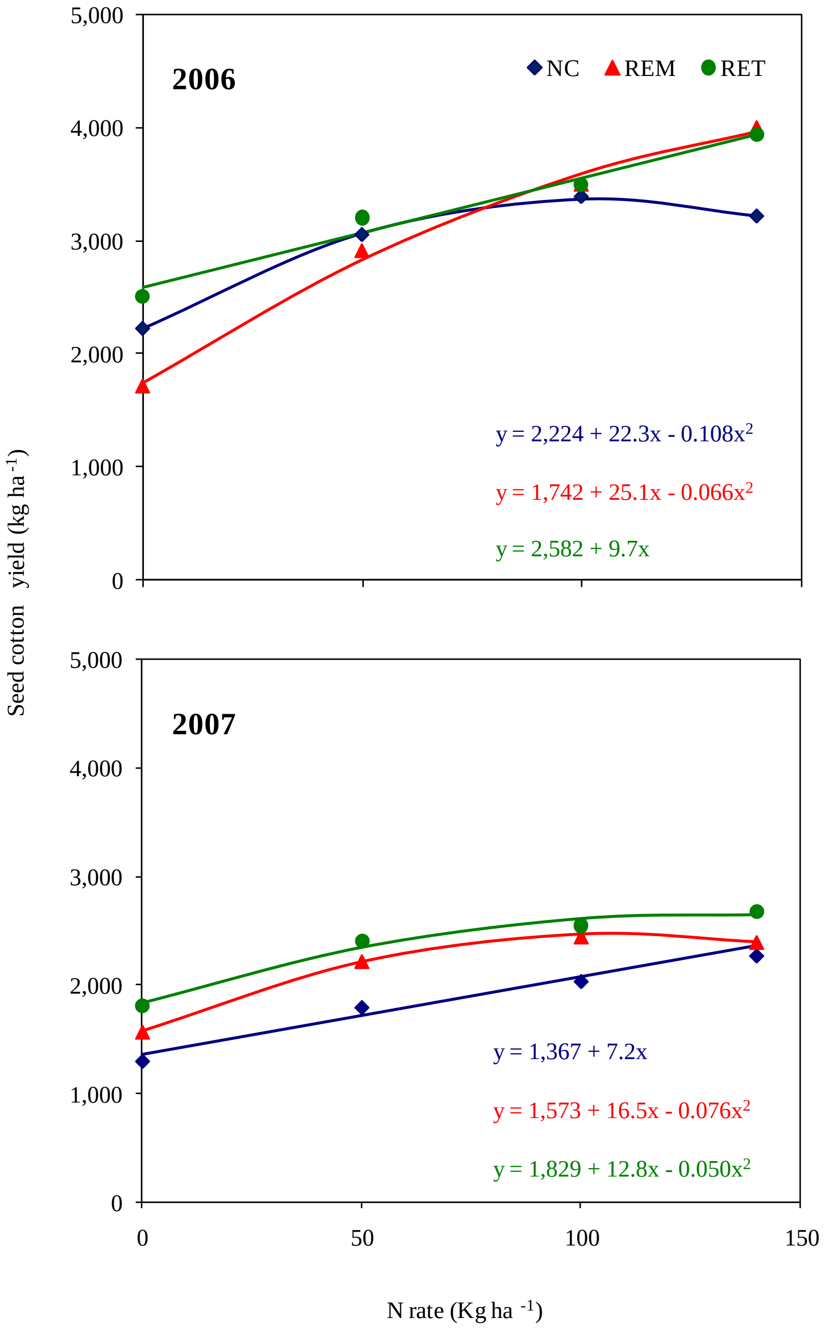

Fig. 2-13. Seed cotton yield as affected by rye residue management and N rate, for the 2006 and 2007 seasons. NC, no winter cover crop; REM, rye residue removed; RET, rye residue retained.

CONCLUSIONS

Rye residue management treatments significantly influenced cotton growth parameters and seed cotton yield. In general, cotton population, leaf and plant N concentration, cotton biomass and N uptake at first square, and cotton biomass production between first square and cutout were higher for RET. However, leaf N concentration at early bloom and cotton biomass N concentration between first square and cutout were higher for NC. Leaf N concentration at early bloom, cotton biomass and its N concentration between first square and cutout increased with increasing N rates, when averaged across RM treatments. The highest N uptake was measured in RET, at the highest N rate. In 2006, the highest predicted seed cotton yield corresponded to RET and REM with the application of 140 kg N ha^{-1} (about 3,950 kg ha^{-1}). In 2007, RET had the highest predicted seed cotton yield with 125 kg N ha^{-1} (2,657 kg ha^{-1}) followed by REM with 106 kg N ha^{-1} (2,466 kg ha^{-1}). In both years, the lowest predicted yield was for NC. In 2006, the increase in cotton biomass for RET compared to REM did not necessarily result in an increase in seed cotton yields. However, a stronger association between cotton biomass production and seed cotton yields was observed in the hot and dry 2007 season. Even though RET had low leaf N concentration values at early bloom, it had high yields in both years, indicating that in our study leaf N concentration was not a good predictor of seed cotton yields. Results of this study show that short-term effects of rye residue removal can occur mainly in vegetative cotton parameters, but its effect on seed cotton yield and cotton response to N fertilization would depend more on the characteristics of the season. No rye residue removal effect would be expected in years with average temperatures and rainfall. However, during hot and dry years, rye residue removal may lead to a decrease in cotton yields. We anticipate that cotton N requirements under rye residue removed conditions would not be lower compared to residue retained. The year dependence of rye residue removal impact on seed cotton yields and cotton response to N fertilization suggests that long-term studies are required to strengthen conclusions concerning this management practice.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Mr. Jason Ward (Soils Research Technician, USDA-ARS) and Mr. Bobby Durbin (Associate Director, Field Crops Unit, E.V. Smith Research Center) for their support with this experiment.

REFERENCES

Adams, J.F. and C.C. Mitchell. 2000. Soil test nutrient recommendations for Alabama crops [Online]. Available at http://www.ag.auburn.edu/agrn/croprecs/CropRecs/cc10.html (verified 24 April 2007).

Alabama Cooperative Extension System (ACES). 2006. 2005 Cotton Research Report. Research Report No. 28 [Online]. Available at http://www.ag.auburn.edu/aaes/communications/researchreports/05Cottonrr.pdf (verified 25 June 2007).

Balkcom, K.S., J.N. Shaw, D.W. Reeves, C.H. Burmester, and L.M. Curtis. 2007. Irrigated cotton response to tillage systems in the Tennessee Valley. J. Cotton. Sci. 11:2-11 [Online]. Available at http://www.cotton.org/journal/2007-11/1/upload/jcs11-2. pdf.

Balkcom, K.S., D.W. Reeves, J.N. Shaw, C.H. Burmester, and L.M. Curtis. 2006. Cotton yield and fiber quality from irrigated tillage systems in the Tennessee Valley. Agron. J. 98:596-602.

Basset, D.M., W.D. Anderson, and C.H.E. Werkhoven. 1970. Dry matter production and nutrient uptake in irrigated cotton (*Gossypium hirsutum*). Agron. J. 62:299-303.

Bednarz, C.W., D.C.Bridges, and S.M. Brown. 2000. Analysis of cotton yield stability across population densities. Agron. J. 92:128-135.

Bell, P.F, D.J. Boquet, E. Millholln, S. Moore, W. Ebelhar, C.C. Mitchell, J. Varco, E.R. Funderburg, C. Kennedy, G.A. Breitenbeck, C. Craig, M. Homlman, W. Baker, and J.S. McConnell. 2003. Relationship between leaf-blade nitrogen and relative seedcotton yields. Crop Sci. 43:1367-1374.

Boquet, D.J., R.L. Hutchinson, and G.A. Breitenbeck. 2004. Long-term tillage, cover crop and nitrogen rate effects on cotton: Yield and fiber properties. Agron. J. 96:1436-1442.

Boquet, D.J. and G.A. Breitenbeck. 2000. Nitrogen rate effect on partitioning of nitrogen and dry matter by cotton. Crop Sci. 40:1685-1693.

Boquet, D.J., E.B. Moser, and G.A. Breithenbeck. 1994. Boll weight and within-plant yield distribution in field-grown cotton given different levels of nitrogen. Agron. J. 86:20-26.

Brown, S.M., T. Whitwell, J.T. Touchton, and C.H. Burmester. 1985. Conservation tillage for cotton production. Soil Sci. Soc. Am. J. 49:1256-1260.

Cassel, D.K., and M.G. Wagger. 1996. Residue management for irrigated maize grain and silage production. Soil Tillage Res. 39:101-114.

Clapp, C.E., R.R. Allmaras, M.F. Layese, D.R. Linden, and R.H. Dowdy. 2000. Soil organic carbon and 13C abundance as related to tillage, crop residue, and nitrogen fertilization under continuous corn management in Minnesota. Soil Till. Res. 55:127-142.

Clawson, E.L., J.T Cothren, and D.C. Blouin. 2006. Nitrogen fertilization and yield of cotton in ultra-narrow and conventional row spacings. Agron. J. 98:72-79.

Dabney, S.M., J.A. Delgado, and D.W. Reeves. 2001. Using winter cover crops to improve soil and water quality. Commun. Soil Sci. Plant Anal. 32:1221-1250.

Dinnes, D., D. Jaynes, T. Kaspar, T. Colvin, C.A. Cambardella and D.L. Karlen. 2007. Plant-soil-microbe N relationships in high residue management systems [Online]. Available at http://www.sdnotill.com/Newsletters/Relationships.pdf (verified 30 April 2008).

Doran, J.W., W.W. Wilhelm, and J.F. Power. 1984. Crop residue removal and soil productivity with no-till corn, sorghum and soybean. Soil Sci. Soc. Am. J. 48:640-645.

Economic Research Service (ERS). 2003. Cotton and wool Yearbook 2003 [Online]. Available at http://usda.mannlib.cornell.edu/usda/ers/89004/2003/table04upland plantedacreage .xls (verified 22 January 2008).

Fridgen, J.L., and J.J. Varco. 2004. Dependency of cotton leaf nitrogen, chlorophyll, and reflectance on nitrogen and potassium availability. Agron. J. 96:63-69.

Gastal, F., and G. Lemaire. 2002. Nitrogen uptake and distribution in crops: an agronomical and ecophysiological perspective. Journal Experim. Botany. 53:789-799.

Gerik, T.J., B.S. Jackson, C.O. Stockle, and W.D. Rosenthal. 1994. Plant nitrogen status and boll load of cotton. Agron. J. 86:514-518.

Govaerts, B., M. Fuentes, M. Mezzalama, J.M. Nicol, J. Deckers, J.D. Etchevers, B.Figueroa-Sandoval, and K.D. Sayre. 2007. Infiltration, soil moisture, root rot and nematode populations after 12 years of different tillage, residue and crop rotation managements. Soil Tillage Res. 94:209-219.

Harris, C.H., and C.W. Smith. 1980. Cotton production affected by row profile and nitrogen rates. Agron. J. 72:919-922.

Hodgson, A.S., and D.A. MacLeod. 1988. Seasonal and soil fertility effects on the response of waterlogged cotton to foliar-applied nitrogen fertilizer. Agron. J. 80:259-265.

Howard, D.D., C.O. Gwathmey, M.E. Essington, R.K. Roberts, and M.D. Mullen. 2001. Nitrogen fertilization of no-till cotton loess-derived soils. Agron. J. 93:157-163.

Jensen, E.S. 1997. Nitrogen immobilization and mineralization during initial decomposition of ^{15}N-labeled pea and barley residue. Biol Fert. Soils. 24:39-44.

Langdale, G.W., R.L. Wilson, Jr., and R.R. Bruce. 1990. Cropping frequencies to sustain long-term conservation tillage systems. Soil Sci. Soc. Am. J. 54:193-198.

Littell, R.C., Milliken, G.A., Stroup, W.W., Wolfinger, R.D. and O. Schabenberger. 2006. SAS for mixed models. Second edition. SAS Institute Inc. Cary, NC. 814 pp.

Malhi, S.S., R. Lemke, Z.H. Wang, and B.S. Chhabra. 2006. Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions. Soil Till. Res. 90:171-183.

McConnell, J.S., R.E. Glover, E.D. Vories, W.H. Baker, B.S. Frizzell, and F.M. Bourland. 1995. Nitrogen fertilization and plant development of cotton as determined by nodes above white flower. J. Plant Nutr. 18:1027-1036.

McConnell, J.S., W.H. Baker, D.M. Miller, B.S. Frizzell, and J.J. Varvil. 1993. Nitrogen fertilization of cotton cultivars of differing maturity. Agr. J. 85:1151-1156.

Mills, H.A., and JB. Jones. 1996. Plant analysis handbook II : a practical sampling, preparation, analysis, and interpretation guide. Micro-Macro Pub. Athens, GA, 422 pp.

Mississipi State University Extension Service (MSUES). 2007. Cotton, what final live plant population should I target? [Online]. Available at http://msucares.com/crops /cotton/ population.html (verified 25 March 2008).

Mitchell, C.C. 1996. Fertility. P. 7-9. *In* C.D. Monks and M.G. Paterson (ed.) Conservation tillage cotton production guide. ANR-952. Auburn Univ. Agron. And Soils Dep., Auburn, AL, U.S.

Mitchell, C.C. and S. Tu. 2005. Lont-term evaluation of poultry litter as a source of nitrogen for cotton and corn. Agron. J. 97:399-407.

Mullins, G.L., and C.H.Burmester. 1990. Dry matter, nitrogen, phosphorus, and potassium accumulation by four cotton varieties. Agr. J. 82:729-736.

National Resources Conservation Services (NRCS). 2008. Web Soil Survey [Online]. Available at http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx (verified 5 January 2008).

National Resources Conservation Service (NRCS). 2007. Official Soil Series Descriptions [Online]. Available at http://soils.usda.gov/technical/classification/osd/index.html (verified 25 February 2007).

Peng, S., Krieg, D.R. and S.K. Hicks. 1989. Cotton lint yield to accumulated heat units and soil water supply. Field Crops Res. 19:253-262.

Pettigrew, W.T. 2004. Moisture deficit effects on cotton lint yield, yield components, and boll distribution. Agron. J. 96:377-383.

Reddy, K.R., G.H. Davidonis, A.S. Johnson, and B.T. Vinyard. 1999. Temperature regime and carbon dioxide enrichment alter cotton boll development and fiber properties. Agron. J. 91:851-858.

Reiter, M.S., D.W. Reeves, and C.H. Burmester. 2002. Nitrogen management for cotton in a high-residue cover crop conservation tillage system. p. 136-141. *In.* E. van Santen (ed.) Making conservation tillage conventional: building a future on 25 years of research. Proc. Annu. Southern Conservation Tillage Conf. for Sustainable Agric., 25th, Auburn, AL, 24-26 June 2002. Special Report No. 1, Alabama Agricultural Exp. Station and Auburn University.

Salinas-Garcia, J.R., A.D. Baez-Gonzalez, M. Tiscarenio-Lopez, and E. Rosales-Robles. 2001. Residue removal and tillage interactions effects on soil properties under rain-fed corn production in central Mexico. Soil Till. Res. 59:67-79.

Schomberg, H.H., R.G. McDaniel, E. Mallard, D.M. Endale, D.S. Fisher and M.L. Cabrera. 2006. Conservation tillage and cover crop influence on cotton production on a Southeastern U.S. Coastal Plain soil. Agron. J. 98:1247-1256.

Sims, G.K. 1995. Microscale determination of inorganic nitrogen in water and soil extracts. Commun. Soil Sci. Plant Anal. 26:303-316.

Siri-Prieto, G., D.W. Reeves, and R.L. Raper. 2007. Tillage requirements for integrating winter-annual grazing in cotton production: plant water status and productivity. Soil Sci. Soc. Am. J. 71:197:205.

The Fertilizer Institute. 2003. U.S. fertilizer data [Online]. Available at http://www.tfi.org/mediacenter/stats.cfm (verified 3 April 2008).

Tsuji, H., H. Yamamoto, K. Matsuo, and K. Usuki. 2006. The effects of long-term conservation tillage, crop residue and P fertilizer on soil conditions and responses of summer and winter crops on an Andosol in Japan. Soil Till. Res. 89:167-176.

Varco, J.J., S.R. Spurlock, and O.R. Sanabria-Garro. 1999. Profitability of nitrogen rate optimization associated with winter cover management in no-tillage cotton. J. Prod. Agric. 12:91-95.

Wagger, M.G. 1989. Time of dessication effects on plant composition and subsequent nitrogen release form several winter annual cover crops. Agron. J. 81:236-241.

Wiatrak, P.J., D.L. Wroght, J.J. Marois, W. Koziara, and J.A. Pudelko. 2005. Tillage and nitrogen application impact on cotton following wheat. Agron. J. 97:288-293.

Wilhelm, W.W., J.M.F. Johnson, J.L. Hatfield, W.B. Voorhees, and D.R. Linden. 2004. Crop and soil productivity response to corn residue removal: a literature review. Agron. J. 96:1-17.

Zadoks, J.C., Chang, T.T. and C.F. Konzak. 1974. A decimal code for the growth of cereals. Weed Res. 14:415-421.