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AGRONOMY AND SOILS

Thrips and Cotton Response to Relay Intercropping with Wheat in North Carolina

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ABSTRACT

In North Carolina, double cropping cotton (*Gossypium hirsutum* L.) and wheat (*Triticum aestivum* L.) often results in sub-optimal cotton yield and minimal investment return, most often due to lack of sufficient stand as a result of moisture limitations and a short growing season. Relay intercropping of cotton in wheat prior to harvest may be an alternative to traditional double cropping. A relay intercropping system was tested at five locations over three years in North Carolina to determine thrips infestation, cotton yield, and economic return following relay intercropping of cotton and wheat. Relay intercropped wheat yield ranged from 65% to 85% of conventional wheat plantings. Cotton yields were not affected by the presence of relay-intercropped wheat, but plant maturity was delayed in some experiments. Intercropped cotton plants exhibited similar morphology to cotton planted in a traditional strip tillage system with wheat terminated two wks prior to planting with increased nodes above cracked boll, suggesting delayed plant development. In four of five locations, thrips (*Thysanoptera: Thripidae*) populations were lower in the intercropped cotton, most likely due to interference of the ability of thrips to locate cotton seedlings. Thrips levels when seed was treated with abamectin plus thiamethoxam plus azoxystrobin and an additional in-furrow application of aldicarb or acephate applied to foliage were less than that of seed treated with azoxystrobin alone. Estimated economic return of intercropped cotton and wheat equaled that of conventional cotton planting and exceeded double cropping of wheat followed by soybean [*Glycine max* (L.) Merr.] most years when cotton, soybean, and wheat prices were set at \$1.98 kg^{-1} lint, \$0.44 kg^{-1}, and \$0.25 kg^{-1}, respectively.

Traditional agricultural production systems in the southeastern United States typically produce a single crop per year. However, double-cropping grain sorghum [*Sorghum bicolor* (L.) Moench] or soybean with wheat is a relatively common practice in the United States. For example, 246,960 ha of wheat and soybean were double cropped during 2011 in North Carolina, accounting for approximately 45% of the total soybean hectares (USDA-NASS North Carolina Field Office, 2012). However, when the price of cotton or peanut (*Arachis hypogaea* L.) is relatively high, producers often inquire if double cropping these crops is a viable option. Hunt et al. (1997) reported equivalent cotton yields in five of seven years in South Carolina when cotton was doubled cropped with wheat compared with conventionally planted cotton. Smith and Varvil (1982) reported a yield reduction of 35% to 65% in doubled-cropped cotton when compared to mono-cropped cotton in Arkansas. In North Carolina, variations in soil moisture after wheat harvest can require delayed planting and subsequent negative impact on cotton yield (Hamm, 2009). Production systems including double cropping wheat and soybean were found to be more profitable than double cropping wheat and cotton (Hamm, 2009).

A relay intercropping system has been suggested as an alternative to mono-cropped cotton and double-cropped cotton following wheat. Relay intercropping wheat and cotton involves planting wheat in the fall while leaving skip rows for wheel traffic and subsequent cotton planting in the spring, when the wheat is still living. Cotton is planted three to six weeks prior to wheat harvest, often referred to as the relay intercropping period (Zhang et al., 2008a 2008b). Relay intercropping wheat and cotton is a widespread practice in China, accounting for as much as 1,400,000 ha, where it plays an important role in providing food security, fiber production, and farmer income (Zhang et al., 2007).

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The relatively recent and widespread adoption of genetically-modified cotton cultivars exhibiting both herbicide tolerance and caterpillar resistance (*Bacillus thuringiensis* [Bt] endotoxin expression) has impacted cotton production practices. Such genetically-modified attributes may improve relay intercropping system performance, making it more profitable than double cropping soybean and wheat. Previous research associated with wheat and cotton relay intercropping has focused primarily on equipment feasibility, light utilization, temperature associated development delay, nitrogen economy, and crop yield (Hood et al., 1991 1992; Porter and Khalilian, 1995; Zhang et al., 2007; Zhang et al., 2008a 2008b). Relay intercropping wheat and cotton presents many technical challenges, primarily due to the restricted use of pesticides and limited traffic routes caused by the presence of harvestable wheat (Hood et al., 1991). Therefore, early season weed and insect management may be major impediments to implementing a wheat and cotton relay intercropping system.

Effective management of thrips is critical for rapid early cotton growth and establishment of early maturity (Faircloth et al., 2002). Systemic insecticides are applied to the seed or in the seed furrow to control thrips. The limited availability of aldicarb has forced cotton growers to use a combination of seed treatments with follow-up foliar insecticides to manage damaging levels of thrips (Adamczyk and Lorenz, 2012). Cotton seedlings are extremely sensitive to thrips feeding, resulting in deformed leaves, reduced leaf area, delayed plant growth, reduced yield, and delayed crop maturity (Faircloth et al., 2002). When cotton is grown by conventional methods, reduction in yield and delayed maturity due to thrips feeding is variable and can be influenced by environmental conditions (Faircloth et al., 2002). Research in Virginia and North Carolina showed increased lint yield from 340 to 580 kg ha^{-1} when effective insecticide seed treatments were applied compared with non-treated cotton (Herbert, 1998; Herbert et al., 2012). However, during some years, in addition to seed treatments or in-furrow insecticides, foliar insecticide applications are required to protect cotton yield from thrips damage (Adamczyk and Lorenz, 2011; Herbert et al., 2012).

Intercropped winter cereal grains and legumes, or the presence of cover crop residues, have demonstrated the ability to suppress insect pests such as cotton aphids (*Aphis gossypii* Glover), thrips, leafhopper (*Amrasca biguttula* Ishida), and whiteflies (*Bemicia tabaci* Gennadius) in cotton (All and Vencill, 1993; All et al., 1993; Jambhrunkar et al., 1998; Olson et al., 2006). Cotton aphid levels were lower in intercropped cotton than in mono-cropped cotton, most likely due to higher populations of beneficial insects in cover crops that reduce the insect pests of cotton early in the season (Jambhrunkar et al., 1998; Parajulee et al., 1997; Tillman et al., 2004; XiaoMu et al., 2006). For example, compared with conventional tillage, Tillman et al. (2004) observed higher populations of predacious red imported fire ants (*Solenopis invicta* Buren) and big-eyed bugs (*Geocoris punctipes* Say) in cotton planted into cover crops. Similarly, Jambhrunkar et al. (1998) reported a reduction in onion thrips (*Thrips tabaci* Lindeman) and whiteflies in cotton that had been intercropped with strips of green gram (*Vigna radiata* L.), black gram (*Vigna mungo* L.), soybean, pigeon pea (*Cajanus cajan* L.), grain sorghum, sunflower (*Helianthus annuus* L.), and sesame (*Sesamum indicus* L.). In addition, Olson et al. (2006) reported a thrips population reduction in cotton and peanut (*Arachis hypogaea* L.) when mulched with a crimson clover (*Trifolium incarnatum* L.) cover crop or a hand-spread layer of rye (*Secale cereale* L.) residue. Olson et al. (2006) also noted an inverse relationship between the amount of rye residue ground cover and thrips density and the subsequent damage in cotton and peanut crops. They concluded that increasing field coverage by cover crops reduces thrips populations in cotton and any subsequent damage the pests might cause. Toews et al. (2010) found a similar inverse relationship between ground cover and immature thrips densities.

Availability of herbicide-tolerant crops, including cultivars resistant to glufosinate and/or glyphosate, have enabled growers to control both emerged summer and winter weeds that were present in wheat after cotton emergence (Riar et al., 2011), a flexibility which minimizes weed control as a pest management challenge in relay intercropping. Overall, growers are interested in increasing their crop selection flexibility to capitalize on marketing opportunities. Thus, determining the feasibility of a relay intercropping cotton and wheat system and its implications for insect management will be important in developing comprehensive management strategies for relay intercropping. In a series of five replicated trials conducted at three North Carolina locations from 2009 to 2011, thrips levels, a number of cotton growth parameters, lint yield and quality, and economic returns of cotton were compared in relay intercropping cotton with wheat to 1) mono-cropping of cotton and 2) double cropping wheat and soybean. The purpose of this experiment was to determine the effects of wheat relay intercropping on thrips levels on cotton, wheat growth, cotton growth, and economic advantage of a proposed relay intercropping system.

MATERIALS AND METHODS

General Field Methodology. Experiments were conducted in North Carolina, during 2009 near Beulaville on a Norfolk fine sandy loam soil (fine-loamy, kaolinitic, thermic, Typic Kandiudult), and near Wendell on a Wedowee sandy loam soil (clayey, kaolinitic, thermic, Typic Kahapludults). During 2010, the experiment was conducted at the Peanut Belt Research Station at Lewiston-Woodville on a Norfolk loamy coarse sand soil (fine-loamy, siliceous, thermic, Typic Paleadults). The experiment was also conducted during 2010 and 2011 near Rocky Mount at the Upper Coastal Plain Research Station on a Lynchburg fine sandy loam soil (fine-loamy, siliceous, thermic Aeric Paleudults) and on a Norfolk loamy sand soil (fine-loamy, siliceous, thermic, Typic Paleadults), respectively.

Treatments consisted of a factorial arrangement of two cropping systems (relay intercropped wheat/cotton and monoculture cotton) and four insecticide treatments to control thrips. The monoculture cotton was planted into residue of the previous summer crop (cotton) and not into a desiccated wheat cover crop. Two additional treatments were included within the relay intercropping system only and included wheat only and a wheat and soybean double-crop system. These treatments did not include cotton or insecticide treatments used in cotton.

Whole plots consisted of 20 rows (96-cm spacing) by 9 m in length; sub-plots were four rows by 9 m in length. Intercropped whole plots were established by planting the wheat cultivar SS8302 (Southern States Cooperative, Richmond, VA) in late November using a grain drill (Great Plains, Salina, KS) with 19-cm row spacing in conventional tillage. The relay intercropping system design is characterized by the three wheat rows alternated with one cotton row. The cotton row occupied the space of two wheat rows (38-cm width) and three wheat rows occupying a 57-cm width. The resulting relay intercropping wheat seed rate was 81 kg ha^{-1}. Wheat was planted for the double-crop wheat/soybean comparison at a seed rate of 134 kg ha^{-1}.

Thrips Collection, Predator and Pest Sweeping, and Identification. Thrips were collected from five randomly selected plants at three, four, and five weeks after cotton planting (WAP) from the center two rows of each plot by severing plants at ground level and immediately immersing plants in a glass jar filled with 500 ml of water and two ml of detergent (Palmolive Original®, Colgate-Palmolive Company, New York, NY). Within six hours of collection, plants were rinsed over a 270 mesh sieve, with 0.053 mm openings, using a Teejet® XR 8002 flat fan nozzle (TeeJet Technologies, Wheaton, IL). Thrips were then rinsed from the sieve into a 20 ml scintillation vial (Fisher Scientific Company, Houston, TX) using a 70% ethyl alcohol solution. Adults and immature thrips were later rinsed into a grid-marked petri dish, separated, and counted using a stereo zoom microscope (Bausch and Lomb®, Rochester, NY). Adults from the non-treated (no insecticide) plots (both mono-culture and intercropped plots) were collected using a Pasteur pipette (Fisher Scientific, Houston, TX) and stored in a 70% ethyl alcohol solution for subsequent species identification. Adult thrips were slide-mounted, preserved using slide-mounting media, sexed, and identified by species (Reed et al., 2006). Following thrips removal, cotton plants were air dried for seven days and weighed. With the exception of the Rocky Mount site during 2010, the middle two rows of cotton plants were swept 25 times with a net within 24 hours after wheat harvest for the presence of beneficial arthropods.

Cotton. The cultivar DP0935 BG2RF® (Monsanto, St. Louis, MO) was planted at all sites between May 13 and 15, at the in-row rate of 16 seeds m^{-1} on 96-cm rows using a self-fabricated, two-row, one-pass strip-till implement with attached planter units. The strip-till/planter consisted of a 56-cm cutting blade, a ripper set to 41-cm depth, two offset roller spider gangs, and a ground driven planter (Model #71 Flexi-Planter, John Deere, Moline, IL) with granular insecticide applicators. The strip-till/planter units were less than 35 cm wide and aligned with the tractor wheels to avoid wheat lodging during planting. The same strip-till/planter was used to plant cotton in the relay intercropping and the monoculture cotton system. The strip-till/planter was also pulled through relay-intercropped wheat plots that were not planted with cotton.

Pesticides applied with cotton to both whole plots included:1) azoxystrobin (Dynasty®, Syngenta Crop Protection, Greensboro, NC) at 0.03 mg azoxystrobin seed^{-1}; 2) abamectin plus thiamethoxam plus azoxystrobin (Avicta® Complete Pac®, Syngenta Crop Protection, Greensboro, NC) at 0.15 mg abamectin seed^{-1}, 0.375 mg thiamethoxam, and 0.03 mg azoxystrobin seed^{-1}; 3) abamectin plus thiamethoxam plus azoxystrobin (Avicta® Complete Pac®, Syngenta Crop Protection, Greensboro, NC) applied to seed (same rate as above), followed by a foliar acephate (Orthene 97®, Amvac Chemical Corporation, Los Angeles, CA) at 0.56 kg ai ha^{-1} at 21 days after planting (DAP); and 4) abamectin plus thiamethoxam plus azoxystrobin (same rate as above) applied to seed followed by in-furrow granular aldicarb (Temik® 15G, Bayer Crop Science, Research Triangle Park, NC) (0.59 kg ai ha^{-1}). All insecticide treatments were applied to both mono-culture cotton plots and intercropped plots. Acephate was applied using a CO_2-pressurized backpack sprayer equipped with one regular hollow cone nozzle per row calibrated to deliver 140 L ha^{-1} at 345 kPa and 4.8 kph. All other production and pest management practices were based on North Carolina Cooperative Extension Service recommendations (Bacheler, 2012; Crozier et al., 2012; Edmisten, 2012a; Edmisten, 2012b; York, 2012).

Wheat. Wheat test weights and component yields were obtained by hand-harvesting two randomly selected quadrants (1 m by 0.15 m) from the double-cropped wheat/soybean system, the intercropped wheat pattern without cotton, and the intercropped wheat pattern with abamectin plus thiamethoxam plus azoxystrobin and aldicarb cotton treatments. In the two intercropped treatments, additional component yields were obtained from wheat rows adjacent to the cotton row and from interior wheat rows bordered by wheat on both sides. Wheat grain yield was determined using a Gleaner K2 (Allis Chalmers, West Allis, WI) combine with a bagging attachment and a custom 193-cm head, which lined up over the center two cotton rows that it straddled. The combine's 203-cm wheel spacing with 47-cm wide tires allowed for wheat harvest without running over the cotton.

Plant Mapping. Cotton stands in each plot were determined 14 to 21 DAP from a randomly selected, three m section of each of the two center rows. Except for Rocky Mount during 2010, nodes above cracked boll (NACB) were determined based on 20 randomly selected plants from the middle two rows prior to defoliation. Data for height, total nodes, monopodial nodes, sympodial nodes, number of total and sympodial bolls, and mapping of fruit in all node zones were collected from ten consecutive plants from the middle two rows of each plot prior to harvest.

The center two rows of each plot were machine harvested with a John Deere two-row spindle picker modified for small-plot research. A one-kg sample of seed cotton was collected from each plot during harvest for fiber quality analysis and to determine lint percentage using a saw gin. Cotton was harvested on 18 November 2009, 25 November 2009, 28 October 2010, and 20 October 2010 in Beulaville, Wendell, Rocky Mount, and Lewiston-Woodville, respectively. Cotton was harvested on 10 October 2011 and a second time on 7 November 2011 at Rocky Mount to account for differences in cotton growth and development between some plots.

Economic Analysis. North Carolina Cooperative Extension Service Enterprise Budgets were used to compare treatments for economic analysis (Bullen and Weddington, 2012). Costs associated with seed, insecticide, ginning, hauling, and cotton seed gin payments were removed from the budget to establish a base production cost of \$868 ha^{-1} for the double-cropped wheat/soybean system, \$993 ha^{-1} for the intercropped and monoculture cotton, and \$488 ha^{-1} for intercropped wheat. In the double-crop wheat/soybean system, soybean seed costs were calculated to be \$52 ha^{-1} based on a population of 358,150 seeds ha^{-1}, and a hauling cost of \$0.0055 kg^{-1}was applied to wheat and soybean grain yield (Bullen and Dunphy, 2012). For the intercropped and mono-cropped cotton, total costs were the same and only deviated in response to insecticide treatment. Cost of acephate and aldicarb applications were set at \$8.47 ha^{-1} and \$30 ha^{-1}, respectively. Cost of azoxystrobin-treated seed and abamectin plus thiamethoxam plus azoxystrobin treated seed at 152,890 seeds ha^{-1} was set at \$264 ha^{-1} and

\$301 ha^{-1}, respectively. Ginning cost and payment received for ginned seed were set at \$0.23 kg^{-1} lint and \$0.20 kg^{-1} seed, respectively. The intercropped wheat budget was based on Cooperative Extension Service budgets adjusted to account for reduced seed input of \$45 ha^{-1} based on a seeding rate of 81 kg ha^{-1} and a hauling rate of \$0.0055 kg^{-1} applied to grain yield (Bullen and Weddington, 2012). Crop prices were set at \$1.98 kg^{-1}, \$0.44 kg^{-1}, and \$0.25 kg^{-1} for lint, soybean, and wheat, respectively.

Statistical Analysis. The experimental design was a split plot with cropping system (monoculture cotton or intercropped wheat/cotton) serving as whole plot units and insecticide treatments serving as sub-plot units. Sub-plot units were replicated four times. Two additional treatments which did not conform to the factorial arrangement of treatments, were included. These consisted of intercropped wheat without cotton within the intercropped wheat/cotton cropping system and a double-cropped wheat/soybean system.

Data for wheat yield and cotton seedling weight were subjected to analysis of variance (ANOVA) using the general linear model in SAS (Version 9.2, SAS Institute, Cary, NC) for a five (combination of field and year) by six (combination of insecticide, presence of cotton, and wheat pattern) treatment structure. Wheat yield component data were subjected to ANOVA using the general linear model in SAS for a five (combination of field and year) by five (combination of insecticide, presence of cotton, wheat pattern, and wheat row location) treatment structure. Means of significant main effects and interactions were separated using Fisher's Protected LSD at $p \leq 0.05$.

Cotton plant population, thrips number, and cotton seedling dry weight data were subjected to ANOVA using the general linear model in SAS for a five (combination of field and year) by two (monoculture and relay intercropping treatment) by four (insecticide treatments) treatment structure. Arthropod species data from predator and pest sweeping were subjected to ANOVA using the general linear model in SAS for a four (combination of field and year) by two (monoculture and relay intercropping treatments) by four (insecticide treatments) treatment structure. Thrips species identification data were subjected to ANOVA using the general linear model in SAS for a five (combination field and year) by two (monoculture and relay intercropping treatments) treatment structure. Means of significant main effects and interactions were separated using Fisher's Protected LSD at $p \leq 0.05$.

Data for NACB, height, total nodes, number of monopodial bolls, number of sympodial bolls, percent boll retention by nodal zones, boll distribution by nodal zones, plant stands, boll distribution by position on sympodial branch, height to node ratio (HNR), cotton yield, gin turnout, micronaire, upper half mean, uniformity index, fiber strength, and economic return were subjected to ANOVA using the general linear model in SAS for a four (combination of field and year) by two (monoculture and relay intercropping treatments) by four (insecticide treatments) treatment structure. Means of significant main effects and interactions were separated using Fisher's Protected LSD at $p \leq 0.05$.

In a separate analysis, economic return for double-cropped wheat and soybean was compared with the most effective insecticide treatment in mono-cropped cotton and the intercropped system and subjected to ANOVA using the crop prices of \$1.98 kg^{-1}, \$0.44 kg^{-1}, and \$0.25 kg^{-1} for cotton lint, soybean, and wheat, respectively. Means were separated using Fisher's Protected LSD at $p \leq 0.05$.

RESULTS AND DISCUSSION

Wheat and Cotton Response Prior to Wheat Harvest. Wheat yield was affected by the relay intercropping pattern and insecticide treatments applied to cotton. Wheat yield was approximately 15% lower with the relay intercropping pattern in absence of cotton compared with the standard planting pattern of wheat (Table 1). Wheat yield was further reduced by interference from cotton plants. Cotton plants treated with insecticide treatments resulted in higher plant weights, presumably due to reduced insect feeding (Table 1). An inverse relationship between wheat yield, and cotton seedling dry weight at five WAP was observed. Although wheat occupied only 60% of the available area when intercropped, yield was only 15 to 29% less than the standard broadcast pattern of wheat (Table 2). Compensation through increased tillering by wheat border rows is suggested by the presence of more seed heads in border rows, when compared to interior rows. Zhang et al. (2007) reported similar results when relay intercropping wheat and cotton in China, and attributed this effect to greater light interception and acquisition of nutrients in the border rows compared to wheat within the standard planting pattern.

Table 1. Wheat yield (determined by machine harvest) and cotton seedling dry weight 5 weeks after planting as influenced by wheat pattern, presence of cotton, and insecticide treatment.[z]

Wheat Pattern	Presence of Cotton	Insecticide treatment	Wheat yield kg ha^{-1}	Cotton seedling g m^{-1} row^{-1}
Broadcast	No	None	4140 a	-
Intercrop	No	None	3540 b	0.0 c
Intercrop	Yes	None	3250 bc	3.60 b
Intercrop	Yes	Abamectin plus thiamethoxam	3100 c	6.31 a
Intercrop	Yes	Abamectin plus thiamethoxam then acephate	2930 c	6.60 a
Intercrop	Yes	Abamectin plus thiamethoxam plus aldicarb in furrow	2920 c	6.78 a

[Z] Means within a column followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$. Data are pooled over sites.

Table 2. Wheat seed head number and grain yield as influenced by wheat pattern, cotton presence, insecticide treatment, and row position.[z]

Wheat Pattern	Presence of cotton	Cotton insecticide treatment	Row position	Seed heads No. m^{-2}	Grain yield kg ha^{-1}
Intercrop	No	None	Border	200 a	5,100 a
Intercrop	Yes	Abamectin plus thiamethoxam plus aldicarb in furrow	Border	188 a	4,990 a
Intercrop	No	None	Interior	150 b	3,610 b
Intercrop	Yes	Abamectin plus thiamethoxam plus aldicarb in furrow	Interior	141 b	3,610 b
Broadcast	No	None	Interior	143 b	3,330 b

[a] Means within a column followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$. Data are pooled over sites.

Cotton and Thrips Response Following Wheat Harvest. Cotton population was affected by the interaction of site by cropping system and site by insecticide treatment. Cotton plant population was similar at Beulaville (9.2 vs. 8.5 plants m^{-1} row^{-1}), Lewiston-Woodville (8.7 vs. 8.5 plants m^{-1} row^{-1}), and Rocky Mount during 2010 (5.0 vs. 4.0 plants m^{-1} row^{-1}) when comparing cropping systems (data not shown). The number of cotton plants was lower in monoculture at Wendell compared with relay intercropping (7.6 vs. 6.5 plants m^{-1} row^{-1}) while the opposite response was noted in 2011 at Rocky Mount (6.2 vs. 9.3 plants m^{-1} row^{-1}) (data not shown). Variation in cotton population may have been affected by rainfall and soil moisture immediately following planting (data not shown). The lowest plant population was observed at Rocky Mount in 2010 when a rainfall event of almost ten cm occurred within five days of planting. Soil at this location often forms a crust following excessive rain. A lower cotton stand at Rocky Mount during 2011 for relay intercropping may have been associated with limited rainfall and insufficient soil moisture. Rainfall in Rocky Mount during 2011 within eight days of planting was less than 0.6 cm. Rainfall was greater than 2.2 cm and less than 10.0 cm at sites where cotton population was not affected by cropping system.

A higher and more uniform stand of cotton was established with all insecticide treatments compared with no insecticide in Beulaville (Table 3). At Lewiston-Woodville, lower plant populations were also noted when cotton was not treated with insecticide, while the combination of abamectin plus thiamethoxam followed by acephate had the highest population. Plant population following abamectin plus thiamethoxam seed treatment and the same seed treatment plus aldicarb was intermediate between these treatments. These results indicate there is a potential for reduced plant population when no insecticide is used. The cause of plant death and subsequent reduction in stands was not determined in this experiment.

Tobacco thrips (*Frankliniella fusca* Hinds) was the predominant species when insecticide was not applied in both cropping systems regardless of site, comprising 81% and 88% of total thrips population in intercropped and mono-cropped no-insecticide cotton, respectively (data not shown). Onion thrips (*Thrips tabaci* Lindeman) was the second most abundant species (13%) followed by Western flower thrips (*Frankliniella occidentalis* Pergande), accounting for less than 3%. No other thrips species occurred in sufficient numbers or consistently across sites to evaluate cropping system effects on thrips species distribution.

The interaction of site by cropping system by insecticide treatment was significant for immature thrips at all three evaluation periods (three, four, and five WAP). Data for the four WAP evaluation reflected results for three and five WAP, and therefore will be discussed here. Intercropped cotton had lower thrips populations levels in four of five locations compared with monoculture when pooled over insecticide treatments (expressed as number of thrips five plants^{-1}) at Beulaville, Lewiston-Woodville, and Rocky Mount during 2010 and 2011 expressing values of 32.7 vs. 58, 8.4 vs. 29.5, 23.6 vs. 60.4, and 3.4 vs. 42.9, respectively (data not shown). At Wendell, there was no difference in thrips population when comparing relay intercropping and monoculture (16.5 vs. 19.1) (data not shown).

Insecticide treatment had different effects on thrips level across cropping system when pooled over site (Table 4). In the relay intercropping system, the abamectin plus thiamethoxam then acephate and abamectin plus thiamethoxam plus aldicarb treatments resulted in fewer thrips than abamectin plus thiamethoxam seed treatment alone. The seed treatment provided better control than with no insecticide, but less than seed treatment plus acephate or aldicarb. In the mono-cropped system, all insecticide treatments provided different levels of control. The highest level of control was achieved by the abamectin plus thiamethoxam plus aldicarb, followed by abamectin plus thiamethoxam then acephate, followed by abamectin plus thiamethoxam, and then followed by non-treated in descending order.

When pooled over cropping systems, thrips control four WAP by abamectin plus thiamethoxam followed by acephate was similar to control by abamectin plus thiamethoxam plus aldicarb (Table 5).

Table 3. Cotton population as influenced by insecticide treatment.[z]

Insecticide treatment	Beulaville	Wendell	Lewiston-Woodville	Rocky Mount	
				2010	2011
	---------- Plants m^{-1}row^{-1} ----------				
None	7.1 b	6.9 a	7.7 b	5.3 a	8.1 a
Abamectin plus thiamethoxam	9.6 a	6.9 a	8.9 ab	4.7 a	7.7 a
Abamectin plus thiamethoxam then foliar acephate	9.3 a	6.9 a	9.2 a	4.6 a	7.5 a
Abamectin plus thiamethoxam plus aldicarb in furrow	9.4 a	7.8 a	8.7 ab	4.3 a	7.7 a

[z] Means within a site followed by the same letter are not different according to Fisher's Protected LSD at p $\leq$ 0.05. Data are pooled over cropping system.

Table 4. Immature thrips at four weeks after planting (WAP) as influenced by cropping system and insecticide treatment.[z]

Insecticide treatment	Immature thrips at 4 WAP	
	Intercrop	Mono-crop
	---------- No. 5 plants^{-1} ----------	
None	34.7 a	74.6 a
Abamectin plus thiamethoxam	20.1 b	57.9 b
Abamectin plus thiamethoxam then foliar acephate	5.9 c	29.3 c
Abamectin plus thiamethoxam plus in-furrow aldicarb	5.2 c	8.5 d

[z] Means within a column followed by the same letter are not different according to Fisher's Protected LSD at p $\leq$ 0.05. Data are pooled over sites.

Table 5. Immature thrips as influenced by insecticide treatment and site at four weeks after planting (WAP).[z]

Insecticide treatment	Immature thrips at 4 WAP				
	Beulaville	Wendell	Lewiston-Woodville	Rocky Mount	
				2010	2011
	No. 5 plants^{-1}				
None	130.9 a	37.6 a	31.6 a	67.4 a	27.3 ab
Abamectin plus thiamethoxam	51.3 b	25.0 ab	23.0 ab	44.8 ab	50.8 a
Abamectin plus thiamethoxam then foliar acephate	14.1 c	6.3 b	16.8 ab	43.4 ab	12.3 b
Abamectin plus thiamethoxam plus in-furrow aldicarb	12.1 c	2.4 b	4.9 b	13.6 b	2.5 b

[z] **Means within a column followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$. Data are pooled over cropping systems.**

Relay intercropped cotton plant weight at five WAP was lower than mono-cropped plants at all locations except Wendell when pooled over insecticide treatments (data not shown). The difference in plant size between cropping systems suggests that cotton growth suppression during the relay intercropping period is unrelated to thrips feeding. Zhang et al. (2007) found similar cotton responses and reported that dry matter accumulation in intercrops was severely suppressed compared to monoculture. Plant weight at five WAP was affected by insecticide treatment when comparing across sites and cropping systems (Table 1). Insecticide treatments resulted in higher plant weights for both cropping systems regardless of site (data not shown). Abamectin plus thiamethoxam plus aldicarb treatment resulted in the highest plant weights across all cropping systems and sites when compared to non-treated crops. Abamectin plus thiamethoxam followed by the acephate foliar spray resulted in the same plant weights as the abamectin plus thiamethoxam plus aldicarb in the relay intercropping system and in three of five sites (data not shown). Slightly lower plant weights were observed in the abamectin plus thiamethoxam seed treatment than in the same seed treatment plus aldicarb in the mono-cropping system and in three of the five sites (data not shown).

These results suggest that relay intercropping cotton in wheat suppresses thrips populations but also reduces plant growth and development during the relay period compared to mono-cropped cotton. The mechanism of reduced thrips damage in relay intercropping is not established. It is suspected that some thrips remained on wheat and did not damage cotton. Thrips in mono-cropped cotton did not have an alternative plant source other than cotton resulting in greater damage. However, thrips populations in wheat were not determined. Olson et al. (2006) suggested that the presence of wheat (mulch) serves as a disruption of visual cues in the intercropped system compared to mono-crops. Thrips damage was lower in reduced tillage cotton (Parajulee et al., 2006) and peanut (Hurt et al., 2006) compared with conventional tillage cropping system. Also, less tomato spotted wilt (caused by a tosporovirus) is observed in reduced tillage peanut when compared with conventional tillage peanut (Hurt et al., 2006).

Insect Pests and Predators. Arthropods identified and quantified included: aphid (*Aphis* sp.); tarnished plant bug (*Lygus lineolaris* Palisot de Beauvois); fleahopper (*Pseudatomoscelis seriatus* Reuter); green stink bug (*Acrosternum hilare* Say); brown stink bug (*Euschistus servus* Say); and bollworm (*Helicoverpa zea* Boddie). Insect predator species included: big-eyed bug (*Geocoris* sp.); damsel bug (*Nabis* sp.); minute pirate bug (*Orius* sp.); pink ladybird beetle (*Coleomegilla maculata* De Geer); convergent lady beetle (*Hippodamia convergens* Guerin-Meneville); spiders (*Araneae* Clerck); lacewing (*Chrysoperla* sp.); and assassin bug (*Reduviidae* Latreille). Insects other than thrips and beneficial predators were present at relatively low population numbers at five WAP (data not shown). Beneficial predator levels were unaffected by cropping system and insecticide treatment (data not shown).

Plant Mapping. The interaction of site by insecticide was significant for total bolls and bolls on nodal zone 14 to 22. The interaction of site by cropping system was significant for bolls on nodal zone four to seven and zone eight to ten, and cropping system was significant for bolls on nodal zone 14 to 22. Fewer bolls were noted on non-treated cotton compared to all insecticide treatments in

Beulaville. However, the opposite was observed in Wendell where non-treated cotton produced more bolls than all insecticide treatments (Table 6). Boll numbers on nodal zone 14 to 22 followed nearly the same pattern as total bolls; fewer bolls were noted on non-treated cotton in Beulaville compared to all insecticide treatments and the opposite was observed in Wendell. Near optimal rainfall in Wendell from May through August (43 cm) may have allowed the non-treated cotton to compensate for the lack of insecticide protection by producing more bolls later in the season (higher in the canopy) that did not result in harvestable bolls.

Boll distribution by nodal zone was inconsistent across sites and followed no trend except for bolls on zones 14 to 22. Mono-cropped cotton produced more bolls on nodes 14 to 22 than intercropped cotton (Table 7). More bolls were noted on intercropped cotton on zones four to seven and zones eight to ten in Wendell, although fewer bolls were observed on intercropped cotton on zones four to seven in Lewiston-Woodville and on zones eight to ten in Rocky Mount in 2011. In response to wide variability in cotton population, total bolls and boll numbers by zones were inconsistent across all the sites and no general conclusions can be made in regard to the number and distribution of bolls.

Table 6. Total bolls and bolls on nodal zone 14 to 22 as influenced by insecticide.[z]

Insecticide treatment	Beulaville	Wendell	Lewiston-Woodville	Rocky Mount 2011
	Total bolls, No. m^{-2}			
None	114 b	144 a	85 a	89 a
Abamectin plus thiamethoxam	135 ab	116 b	89 a	89 a
Abamectin plus thiamethoxam then foliar acephate	145 a	104 b	95 a	82 a
Abamectin plus thiamethoxam plus in-furrow aldicarb	139 a	118 b	97 a	98 a
	Bolls on nodal zone 14 to 22, No. m^{-2}			
None	32 b	20 a	7 a	6 a
Abamectin plus thiamethoxam	40 a	15 ab	6 a	7 a
Abamectin plus thiamethoxam then foliar acephate	39 a	9 b	10 a	7 a
Abamectin plus thiamethoxam plus in-furrow aldicarb	41 a	16 ab	4 a	9 a

[z] Means within a site followed by the same letter are not different according to Fisher's Protected LSD at $p < 0.05$. Data are pooled over cropping system.

Table 7. Boll distribution by nodal zones as influenced by cropping system.

Cropping system	Bolls on nodal zones			
	Beulaville	Wendell	Lewiston-Woodville	Rocky Mount 2011
	Bolls on nodal zones 4 to 7, No. m^{-2}			
Relay intercropping	21	25	20	17
Monoculture	20	20*	25*	20
	Bolls on nodal zones 8 to 10, No. m^{-2}			
Relay intercropping	33	40	32	30
Monoculture	31	32*	31	37*
	Bolls on nodal zones 11 to 13, No. m^{-2}			
Relay intercropping	31	29	18	19
Monoculture	31	27	20	21
	Bolls on nodal zones 14 to 22, No. m^{-2}			
Relay intercropping	34	15	7	6
Monoculture	42*	16	7	8

* Significant at $p \leq 0.05$. Data are pooled over insecticide treatments.

The interaction of site by cropping system was significant for plant height, HNR, and NACB. Insecticide treatment was significant for HNR. Intercropped cotton was shorter in Beulaville and taller in Rocky Mount 2011 compared to mono-cropped cotton. Intercropped cotton in Rocky Mount 2011 exhibited higher HNR than mono-cropped cotton (Table 8). Plant height to node ratio was also higher in abamectin plus thiamethoxam plus aldicarb treatment regardless of site. Higher NACB were noted in Rocky Mount 2011 intercropped cotton compared to mono-cropped cotton (data not shown). Higher NACB values are indicative of delayed plant development at Rocky Mount during 2011. Delayed maturity may have been caused by a number of factors such as lower plant population, moisture and light stress due to wheat competition, and reduced soil temperature. Zhang et al. (2008a) reported a 15-day maturity delay in intercropped cotton due to reduced soil and air temperature in relay intercropping environment, mainly due to shading by wheat (Zhang et al., 2008b).

Lint Yield and Fiber Quality. Lint yield was not affected by cropping system but was affected by insecticide treatment. Yield in monoculture and relay intercropping was 1,230 kg ha^{-1} and 1,210 kg ha^{-1}, respectively (data not shown). Lint yield was lower when insecticide was not applied compared to abamectin plus thiamethoxam and acephate or abamectin plus thiamethoxam plus aldicarb treatments (Table 9). Yield of cotton following the abamectin plus thiamethoxam seed treatment alone was intermediate between the no-insecticide control and other treatments. Differences in yield across insecticide treatments were most likely reflections of differences in thrips control.

The interaction of site and insecticide was significant for micronaire and fiber strength, and the interaction of site and cropping system was significant for fiber strength. Intercropped cotton lint was stronger in Lewiston-Woodville and weaker in Rocky Mount during 2011 when compared to mono-cropped cotton (Table 10). Lower micronaire and higher fiber strength were noted when no insecticide was applied to cotton in Rocky Mount during 2010 (Table 11).

Table 8. Plant height, height to node ratio (HNR), and nodes above cracked boll (NACB) as influenced by cropping system.

Cropping system	Beulaville	Wendell	Lewiston-Woodville	Rocky Mount 2011
	---------- Plant height, cm ----------			
Relay intercropping	130	111	74	101
Monoculture	139*	111	71	89*
	---------- HNR, cm node ----------			
Relay intercropping	6.2	6.0	4	5.6
Monoculture	6.2	6.1	4	5.2*
	---------- NACB, No. ----------			
Relay intercropping	8.1	5.3	3.3	7.7
Monoculture	7.8	4.8	2.8	4.0*

*** Significant $p \leq 0.05$. Data are pooled over insecticide treatments.**

Table 9. Lint yield as influenced by insecticide treatment.[z]

Insecticide treatment	Cotton lint yield kg ha^{-1}
None	1100 b
Abamectin plus thiamethoxam	1210 ab
Abamectin plus thiamethoxam then acephate	1260 a
Abamectin plus thiamethoxam plus aldicarb	1300 a

[z] Means within column followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$. Data are pooled over sites.

Table 10. Fiber quality, micronaire, and fiber strength, as influenced by cropping system site.

Cropping system	Beulaville	Wendell	Lewiston-Woodville	Rocky Mount 201
	Micronaire, no units			
Relay intercropping	3.869	4.088	4.513	4.519
Monoculture	3.988	4.075	4.575	4.487
	Fiber strength, g tex^{-1}			
Relay intercropping	28.49	29.56	28.70	29.15
Monoculture	28.27	29.41	28.11*	29.93*

* Significant at $p \leq 0.05$. Data are pooled over insecticide treatments.

Table 11. Fiber quality, micronaire, and fiber strength, as influenced by insecticide treatment.[z]

Insecticide treatment	Beulaville	Wendell	Lewiston-Woodville	Rocky Mount 2010
	Micronaire, no units			
None	3.888 a	3.925 a	4.400 a	3.988 b
Abamectin plus thiamethoxam	3.925 a	4.188 a	4.600 a	4.638 a
Abamectin plus thiamethoxam then foliar acephate	3.900 a	4.100 a	4.575 a	4.613 a
Abamectin plus thiamethoxam plus in-furrow aldicarb	4.000 a	4.113 a	4.600 a	4.814 a
	Fiber strength, g tex^{-1}			
None	28.36 a	29.74 a	27.89 a	30.89 a
Abamectin plus thiamethoxam	28.51 a	29.73 a	28.56 a	29.24 b
Abamectin plus thiamethoxam then foliar acephate	28.18 a	29.71 a	28.49 a	28.80 b
Abamectin plus thiamethoxam plus in-furrow aldicarb	28.46 a	28.76 a	28.68 a	29.24 b

[z] Means within a site followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$. Data are pooled over cropping system.

Economic Analysis. Economic return was higher (p = 0.1171) when cotton was treated with abamectin plus thiamethoxam plus aldicarb compared to cotton grown without insecticide (Table 12). Abamectin plus thiamethoxam seed treatment and abamectin plus thiamethoxam and acephate treatment was intermediate between no-insecticide control and abamectin plus thiamethoxam and aldicarb.

Comparison of economic return of production systems (intercrop cotton and wheat, mono-crop cotton, and double-crop wheat and soybean) revealed a great deal of variability across sites (Table 13). In Beulaville and Wendell, there were no differences in production systems. However, the intercropped cotton and wheat system produced higher net returns compared to double crop wheat/soybean system in Lewiston-Woodville and Rocky Mount in 2010. The opposite response was noted in Rocky Mount in 2011. No difference was noted when cotton and wheat were intercropped compared with the monocropped cotton system, regardless of site.

Table 12. Estimated net return as influenced by insecticide treatment when cotton is set at \$1.98 kg^{-1} lint and wheat at \$0.25 kg^{-1}.[z]

Insecticide treatment	Estimated net return \$ ha^{-1}
None	1,280 b
Abamectin plus thiamethoxam	1,460 ab
Abamectin plus thiamethoxam then foliar acephate	1,530 ab
Abamectin plus thiamethoxam plus in-furrow aldicarb	1,600 a
P > F	0.1171
Coefficient of Variation (%)	42.5

[z] Means followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$. Data are pooled over cropping system and site.

Table 13. Production system net return when cotton is set at \$1.98 kg^{-1}, soybean at \$0.44 kg^{-1}, and wheat at \$0.25 kg^{-1}.[z]

Production system	Production system net return				
	Beulaville	Wendell	Lewiston-Woodville	Rocky Mount	
				2010	2011
	---------- $ ha^{-1} ----------				
Wheat intercropped with cotton, abamectin plus thiamethoxam then foliar acephate insecticide treatment	2,550 a	762 a	1,280 a	2,340 a	1,210 b
Double-cropped soybean and wheat	1,460 a	1,150 a	760 b	500 b	1,670 a
Cotton alone, abamectin plus thiamethoxam then foliar acephate insecticide treatment	1,760 a	570 a	1,030 ab	2,250 a	1,520 ab
P > F	0.1922	0.3447	0.0909	0.0042	0.0735
Coefficient of Variation (%)	39.7	62.9	26.6	30.9	15.5

[z] Means within site followed by the same letter are not different at the P value indicated. Data are pooled over cropping system.

SUMMARY

Relay intercropping cotton and wheat has been proposed as an alternative to conventionally-planted cotton and double-crop soybean/wheat. The intercropped system proved to be resilient enough to only suffer a 15 to 30% wheat yield loss with reduced seeding rates and competition during the relay period, while producing cotton yields equal to conventionally-planted cotton. The intercropped system consistently demonstrated the ability to suppress thrips establishment, suggesting that relay intercropping may be an effective thrips management strategy in regions with high thrips population. An important impediment to the relay intercropping system is delayed cotton growth and development which may be intensified when low soil moisture prevails following planting. Delayed plant maturity may be partially alleviated by increased cotton plant density via increased seeding rates, in agreement with Zhang et al. (2008a). However, the increased seed cost most likely would reduce the net return. Even though cotton maturity was delayed 14 days in Rocky Mount in 2011, the relay intercropping system produced lint yield equal to the mono-cropping system. Semi-dwarf wheat cultivars may improve light interception by cotton seedlings (Zhang et al., 2008b), and producers with irrigation capability would be expected to overcome the liability of lower possible moisture levels in intercropped systems. However, any practice that improves the competitiveness of cotton during the relay intercropping period may run the risk of reducing wheat yield. Our studies demonstrate that relay intercropping cotton and wheat may also subject producers to higher risk. This increased risk was not offset by higher expected returns, but periodically recalculating the production system net returns in changing commodity price fluctuations may be warranted. If wheat price increase without an accompanied increase in cotton or soybean prices, the net return of relay intercropping may become more favorable.

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REFERENCES

Adamczyk, J.J., and G.M. Lorenz. 2012. 65th annual conference report on cotton insect research and control. p. 981-1000. *In* Proceedings Beltwide Cotton Conferences. Orlando, FL. Jan 3-6, 2012. National Cotton Council, Memphis, TN.

Adamczyk, J.J., and G.M. Lorenz. 2011. 64th annual conference report on cotton insect research and control. p. 955-980. *In* Proceedings Beltwide Cotton Conferences. Atlanta, GA. Jan 4-11, 2011. National Cotton Council, Memphis, TN.

All, J.N., and W.K. Vencill. 2008. Surface residue influence on insecticide rate requirements for thrips management. p. 1413-1418. *In* Proceedings Beltwide Cotton Conferences, Nashville, TN. January 8-11 2008. National Cotton Council, Memphis, TN.

All, J.N., W.K. Vencill, G. Langdale, and P.M. Roberts. 1993. Interaction of cover crop, tillage, and insecticide on thrips populations in seedling cotton. p. 1066-1067.*In* Proceedings Beltwide Cotton Conferences. New Orleans, LA. Jan. 10-14, 1993. National Cotton Council, Memphis, TN.

Bacheler, J.S. 2012. Managing insects on cotton. p. 124-146. *In* K.L. Edmisten (ed.) North Carolina Cotton Information. Publ. AG-417 ed. North Carolina Cooperative Ext. Service, Raleigh, NC.

Bullen, G., and J. Dunphy. 2012. Soybeans-wheat, double crop, no-till 2012 [Online]. Available at http://ag-econ.ncsu.edu/sites/ag-econ.ncsu.edu/files/extension/budgets/soybeans/2012SoybeanWheatDoubleCrop.pdf (verified 19 August 2014).

Bullen, G., and E. Weddington. 2012. Wheat for grain conventional 2012 [Online]. Available at http://ag-econ.ncsu.edu/sites/ag-econ.ncsu.edu/files/extension/budgets/wheat/2012WheatConventionalTill.pdf (verified 19 August 2014).

Crozier, C.R., D.H. Hardy, and B.R. Cleveland. 2012. Fertilization. p. 33-47. *In* K.L. Edmisten (ed.) North Carolina Cotton Information. Publ. AG-417 ed. North Carolina Cooperative Extension Service, Raleigh, NC.

Edmisten, K.L. 2012a. Cotton defoliation. p. 147-165. *In* K.L. Edmisten (ed.) North Carolina Cotton Information. Publ. AG-417 ed. North Carolina Cooperative Extension Service, Raleigh, NC.

Edmisten, K.L. 2012b. Suggestions for growth regulator use. p. 48-54. *In* K.L. Edmisten (ed.) North Carolina Cotton Information. Publ. Ag-417 ed. North Carolina Cooperative Extension Service, Raleigh, NC.

Faircloth, J.C., J.R. Bradley, J., and J.W. Duyn. 2002. Effect of insecticide treatments and environmental factors on thrips populations, plant growth and yield of cotton. J. Entomol. Sci. 37:308-316.

Hamm, G.S. 2009. Agronomics of cotton grown on a 38-cm row spacing in North Carolina. MS Crop Science. North Carolina State University, Raleigh, NC.

Herbert, D.A., J. 1998. Evaluation of thrips damage on maturity and yield of Virginia cotton. p. 1177-1180. *In* Proceedings Beltwide Cotton Conferences, San Diego, California, USA, 5-9 January 1998. National Cotton Council, Memphis, TN.

Herbert, D.A., J., S. Malone, J. Samler, J.S. Bacheler, D. Reisig, and D. Mott. 2012. Thrips wars: Challenges from northeast region. p. 942-952. *In* Proceedings Beltwide Cotton Conferences, Orlando, FL. Jan 3-6, 2012. National Cotton Council, Memphis, TN.

Hood, C.E., A. Khalilian, T.H. Garner, and J.H. Palmer. 1992. Improved interseeding methods and equipment. Paper - American Society of Agricultural Engineers 12-12.

Hood, C.E., A. Khalilian, J.H. Palmer, T.H. Garner, T.R. Garrett, and J.C. Hayes. 1991. Double-cropping interseeding system for wheat, soybeans and cotton. Appl. Eng. Agric. 7:530-536.

Hunt, P.G., T.A. Matheny, and P.J. Bauer. 1997. Crop production in a wheat-cotton doublecrop rotation with conservation tillage. J. Prod. Agric. 10:462-465.

Hurt, C.A., R.L. Brandenburg, D.L. Jordan, B.M. Royals, and P.D. Johnson. 2006. Interactions of tillage with management practices designed to minimize tomato spotted wilt of peanut (*Arachis hypogaea* L.). Peanut Science 33:83-89.

Jambhrunkar, S.R., M.N. Nachane, V.U. Sonalkar, and A.K. Sadawarte. 1998. Management of sucking pests in cotton through cropping systems. Journal of Soils and Crops 8:50-52.

Olson, D.M., P. Roberts, S.C. Phatak, R.F. Davis, and S.L. Brown. 2006. Cover crop, rye residue and in-furrow treatment effects on thrips. Journal of Applied Entomology 130:302-308.

Parajulee, M.N., R.B. Shrestha, and J.F. Leser. 2006. Influence of tillage, planting date, and Bt cultivar on seasonal abundance and within-plant distribution patterns of thrips and cotton fleahoppers in cotton. Int. J. Pest Manage. 52:249-260.

Parajulee, M.N., J.E. Slosser, and R. Montandon. 1997. Relay intercropping to enhance abundance of insect predators of cotton aphid (*Aphis gossypii*Glover) in Texas cotton. Int. J. Pest Manage. 43:227-232.

Porter, P.M., and A. Khalilian. 1995. Wheat response to row spacing in relay intercropping systems. Agron. J. 87:999-1003.

Reed, J.T., C. Allen, R. Bagwell, D. Cook, E. Burris, and B. Freeman. 2006. A key to the thrips on seedling cotton in the midsouthern United States. Office of Agricultural Communications, Division of Agriculture, Forestry, and Veterinary Medicine, Mississippi State University, Mississippi State, MS.

Riar, D.S., J.K. Norsworthy, and G.M. Griffith. 2011. Herbicide programs for enhanced glyphosate-resistant and glufosinate-resistant cotton (*Gossypium hirsutum*). Weed Technol. 25:526-534.

Smith, C.W., and J.J. Varvil. 1982. Double-cropping cotton and wheat. Agron. J. 74:862-865.

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

Toews, M.D., R.S. Tubbs, D.Q. Wann, and D. Sullivan. 2010. Thrips (*Thysanoptera: Thripidae*) mitigation in seedling cotton using strip tillage and winter cover crops. Pest Manag. Sci. 66:1089-1095.

USDA-NASS North Carolina Field Office. 2012. 2011 crop summary [online]. Available at http://www.ncagr.gov/stats/release/CropRelease01.pdf (verified 23 April 2012).

XiaoMu, M., L. XiaoXia, Z. QingWen, J.Z. Zhao, C. QinGNian, M. YongAn, and C. DongMei. 2006. Assessment of cotton aphids, *Aphis gossypii*, and their natural enemies on aphid-resistant and aphid-susceptible wheat varieties in a wheat-cotton relay intercropping system. Entomol. Exp. Appl. 121:235-241.

York, A.C. 2012. Weed management in cotton. p. 66-123. *In* K.L. Edmisten (ed.) North Carolina Cotton Information. Publ. Ag-417 ed. North Carolina Cooperative Extension Service, Raleigh, NC.

Zhang, L., B. Li, J.H.J. Spiertz, d.W. van, and S. Zhang. 2008a. Temperature-mediated developmental delay may limit yield of cotton in relay intercrops with wheat.Field Crops Res. 106:258-268.

Zhang, L., B. Li, J.H.J. Spiertz, W. Werf, and S. Zhang. 2007. Growth, yield and quality of wheat and cotton in relay strip intercropping systems. Field Crops Res. 103:178-188.

Zhang, L., B. Li, J.H.J. Spiertz, S. Zhang, d.W. van, and L. Bastiaans. 2008b. Light interception and utilization in relay intercrops of wheat and cotton. Field Crops Res. 107:29-42.