Winter Crop, Tillage, and Planting Date Effects on Double-Crop Cotton

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ABSTRACT

Canola (*Brassica napus* L.) can be profitably grown as a winter crop in a double-crop system in the southeastern USA. However, stand reductions of double-cropped cotton (*Gossypium hirsutum* L.) following canola have been observed. Field experiments were conducted over 2 yr to examine the effects of previous crop, tillage, planting date, and pesticide use on stand establishment of double-cropped cotton. In all 1999 experiments, cotton stand and seed cotton yields were reduced following canola compared with following winter wheat (*Triticum aestivum* L.). In four of five comparisons, cotton seedling infection by *Rhizoctonia solani* was greater following canola than following wheat or fallow. All *R. solani* isolates were anastomosis group AG-4, indicating that canola production did not selectively increase an unusual biotype of *R. solani*. In both years, *R. solani* AG-4 infection rates were enhanced by use of aldicarb [2-methyl-2-(methylthio)propionaldehyde *O*-(methylcarbamoyl)oxime] granular insecticide regardless of the preceding winter crop. The fungicide treatment did not prevent seedling infection by *R. solani* but did reduce stand and yield losses in 1999. Tillage had no consistent affect on *R. solani* AG-4 infection, stand, or yield following any winter crop treatment. Delayed cotton planting also did not consistently affect *R. solani* AG-4 infection or cotton stand but did reduce seed cotton yield at Tifton. Thus, modified tillage practices and delayed cotton planting are not viable management tools for controlling *R. solani* AG-4 infection and minimizing stand losses of cotton when double-cropped following canola.

Research during the last 15 yr has allowed the development of a viable and profitable system for canola production in the southeastern USA. However, commercial canola production has never exceeded 10 000 ha in this region. Summer crops of cotton, peanut (*Arachis hypogaea* L.), corn (*Zea mays* L.), and soybean [*Glycine max* (L.) Merr.] dominate the southeastern row-crop production systems, and because of their economic importance, producers are often reluctant to incorporate a new winter crop such as canola. A major limitation in the adoption of canola is the lack of information on double-cropping canola with these summer crops. Canola can be planted after peanut and harvested in time to plant soybean, grain sorghum [*Sorghum bicolor* (L.) Moench], or cotton (Duncan and Hoveland, 1985; Thomas et al., 1990; Porter, 1995). In 1999, more than 500 000 ha of cotton were planted in Georgia, but virtually none was double-cropped following canola.

Soybean planted after winter wheat accounts for most of the double-cropped hectarage in the Southeast (Wesley, 1999). Double-cropping canola with summer crops has the potential for increased profits, improved cash flow, and rotational benefits on subsequent wheat crops (Raymer et al., 1990). Canola did not adversely affect productivity of soybean or subsequent winter wheat when grown under a variety of tillage regimes in a double-crop system (Porter, 1995).

Observations in commercial fields have revealed that cotton stand establishment may be reduced following fall-planted canola (Woodruff et al., 1997). This suggests that canola residue itself, or some other factor(s) associated with canola, may adversely affect cotton stand establishment following canola. Regardless of the tillage and cropping system used, cotton stand losses in the southeastern USA are usually associated with seedling disease and most often with *Rhizoctonia solani* (Colyer et al., 1991; Moustafa-Mahmond et al., 1993). *Rhizoctonia solani* is not known to be an economically important pest of canola, but it has been recovered from canola and canola residue in Georgia (Baird et al., 1999).

The objective of this research was to understand and document reductions in stand and early season seedling growth of cotton double-cropped with canola. Research was conducted to evaluate residue management strategies, tillage practices, planting methods, and pesticide applications for their potential to eliminate or minimize problems associated with cotton stand establishment in canola stubble.

MATERIALS AND METHODS

Field experiments were conducted during 1997–1998 and 1998–1999 on a Greenville sandy clay loam (Fine, kaolinitic, thermic, Rhodic Kandiudults) at the Southwest Branch Experiment Station near Plains, GA, and on a Tifton sandy loam (Fine-loamy, siliceous, thermic, Plinthic Kandiudults) at the Coastal Plain Experiment Station near Tifton, GA. Winter wheat and canola were planted with a small-plot grain drill in 18-cm rows at the rate of 77 seeds per meter of row for wheat and 6.7 kg ha^{-1} canola seed. 'LA 128' and 'Flint' canola were used in all experiments conducted during 1997–1998 and 1998–1999, respectively, and 'Coker 9835' wheat was used in all experiments for both years. All canola was planted on 22 Oct. 1997 and 5 Nov. 1998, and wheat was planted on 11 Nov. 1997 and 10 Nov. 1998. Winter crops were harvested on 28 May 1998 and 18 May 1999.

'Paymaster 1220 B/R' cotton was planted with a Monoseem

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Abbreviations: DAP, days after planting.

air planter (A.T.I., Merriam, KS) at the rate of 13 seeds per meter of row. Cotton was fertilized with a 3–19–18 blend at 660 kg ha^{-1} before planting and sidedressed with 55 kg N ha^{-1} 50 d after planting (DAP). Glyphosate [*N*-(phosphonomethyl)glycine] was applied postemergence twice at 1.75 L ha^{-1} to control weeds. Tralomethrin {(1*R*,3*S*)3[(1′ *RS*)(1′,2′,2′,2′,-tetrabromoethyl)]-2,2-dimethylcyclopropanecarboxylic acid (*S*)-α-cyano-3-phenoxybenzyl ester}(Scout X-Tra) at 32 g a.i. ha^{-1} or lambda cyhalothrin (Karate Z) at 44 g a.i. ha^{-1} were applied four to five times during boll development to control cotton bollworm (*Helicoverpa zea* Boddie), cotton budworm (*H. virescens* F.), and stink bugs (*Euschistus servus* Say and *Acrosternum hilare* Say). The two center plot rows were harvested with a two-row cotton picker to measure seed cotton yield. All plots were irrigated to supplement rainfall.

Pesticide Experiment

The effect of winter crop on insect and disease injury to cotton was examined in a separate experiment at Plains in both years. A split-plot experimental design was used with winter crop treatments of canola, wheat, and fallow as whole plots arranged in a randomized complete block design with four replicates. Four pesticide treatments were randomly assigned to subplots within whole plots. Pesticide treatments were applied at planting and were (i) untreated, (ii) insecticide treatment of aldicarb (Temik 15G) at 0.59 kg a.i. ha^{-1} placed in-furrow, (iii) fungicide treatment of Terrachlor 2EC (PCNB, quintozene) at 4.67 L ha^{-1} plus Ridomil Gold EC (metalaxyl) at 73 mL ha^{-1} injected in-furrow, and (iv) both insecticide and fungicide treatments in-furrow. Whole plots measured 12 by 12 m, and subplots measured two rows (1.8 m) by 12 m.

Cotton was planted on 10 June 1998 and 3 June 1999. Seedling stand was measured by counting the number of healthy and dead plants in two adjacent 6-m row sections 13 and 26 DAP in 1998 and 14 and 27 DAP in 1999. On each sample date, two subsamples of plants and ground area measuring 0.1 m^2 from each plot were inspected for false chinch bugs. In addition, five plants were collected and shaken over a screened funnel to collect thrips and aphids. Final stand and plant height (average of three measurements) were recorded before harvest on 30 Oct. 1998 and 9 Nov. 1999.

Plants collected for evaluations of thrips and aphids from the first sample date also were used to determine disease infection levels. The plants were throughly washed in running tap water to remove excess soil and cut just below the cotyledonary node to produce a seedling piece 6 to 7 cm long. The pieces were immersed in a 0.524% (w/v) sodium hypochlorite solution for 2 min, drained, and placed individually on potato-dextrose agar petri plates. Plates were incubated at 25°C, and fungi growing from the seedlings were identified and counted after 5 to 7 d. Microscopic as well as macroscopic characteristics were used to identify the fungi. *Fusarium* spp. and *Alternaria* spp. were identified only to genus. Selected isolates of *R. solani* were classified to anastomosis group after observing hyphal fusions with tester isolates as described by Parmeter et al. (1969).

Results were analyzed using ANOVA for a multiple-factor, split-plot experimental design as described by Gomez and Gomez (1984) (Table 1). Each ANOVA was conducted by year because year × winter crop and year × pesticide treatment interactions were significant at $P = 0.05$ for most variables (ANOVA not shown). The four pesticide treatments were analyzed as a two-by-two factorial experiment, with insecticide and fungicide factors having two levels each (with and without). Percentage values were transformed with a square root–arc sine transformation before analysis (Steel and Torrie, 1980). Means were separated using Fisher's protected least significant difference test at $P = 0.05$. Pearson's correlation analyses were used in each year to show association between disease and insect levels and cotton stand and yield.

Tillage and Planting Date Experiment

The effects of previous winter crop, tillage before cotton planting, and cotton planting date were examined at each location in both years. Winter crop treatments were winter canola, winter wheat, and fallow. Tillage treatments were con-

Table 1. Analysis of variance evaluating winter corp and pesticide treatment effects on cotton stand, *Rhizoctonia solani* infection of seedlings, and seed cotton yield in 1998 and 1999.

Source of variation†	df	Plant stand 13 DAP‡	Plant stand 26 DAP	Plant stand Final	*R. solani* infection	Yield
		F-value				
1998						
Winter crop (WC)	2	1.04	6.36*	1.93	9.62*	6.03
Error a	6					
Insecticide (In)	1	0.44	0.10	0.21	4.68*	8.39**
Fungicide (Fu)	1	3.39	10.51**	1.90	0.04	0.04
In × Fu	1	6.03*	11.54**	2.80	0.94	0.45
WC × In	2	0.80	2.71	0.27	0.46	5.13*
WC × Fu	2	1.50	7.12**	1.11	2.16	1.80
WC × In × Fu	2	3.87*	2.71	0.49	0.54	1.20
Error b	27					
1999						
Winter crop (WC)	2	14.40**	19.98**	20.30**	17.68**	13.11**
Error a	6					
Insecticide (In)	1	0.18	0.53	0.70	5.15*	0.94
Fungicide (Fu)	1	6.21*	14.31**	5.43*	0.01	4.29*
In × Fu	1	0.06	0.63	0.16	0.94	0.15
WC × In	2	0.36	0.56	0.31	0.46	0.22
WC × Fu	2	2.81	1.32	0.25	2.16	2.28
WC × In × Fu	2	0.22	1.35	1.58	0.54	0.14
Error b	27					

* Significant at $P = 0.05$.
** Significant at $P = 0.01$.
† ANOVAs were conducted by year because year × winter crop and year × pesticide treatment interactions were significant at $P = 0.05$ for most variables.
‡ DAP, days after planting.

ventional (chisel plow–disk harrow with complete residue incorporation) vs. strip tillage (a 20-cm strip tilled for each 91-cm row, with the row centers remaining untilled). Planting date treatments were 7 and 17 d after winter crop harvest. The experiment used a strip-block design with the main plots (horizontal factor) being a factorial arrangement of planting date and tillage treatments in a randomized complete block design with four replicates. Winter crops (vertical factor) were striped across main plots (Little and Hills, 1978). Main plots measured 8 rows (7.3 m) by 46 m, and winter-crop plot strips were 15.3 m wide. Cotton was planted at both locations on 29 May and 6 June 1998 and 3 June and 17 June 1999. The same field was used at Tifton, with winter crop treatments rotated between years. Different fields were used at Plains each year. All cotton plots were treated with the insecticide treatment, aldicarb (Temik 15G), in-furrow at planting. At Plains, the fungicide treatment, Terrachlor plus Ridomil Gold, was also applied in-furrow at planting.

Stand counts were made from two adjacent 6-m sections of row at 14 and 26 DAP in 1998 and 14 and 27 DAP in 1999. Number of healthy and dead plants were counted. At the time of the first stand count, usually 14 DAP, 10 or 25 seedlings at Plains and 40 plants at Tifton were randomly collected. Seedlings were washed with tap water to remove excess soil and cut just below the cotyledonary node. The bottom of the root system also was cut away to produce a seedling piece 6 to 7 cm long for use in determining disease infection levels as previously described. Cotton plants also were sampled for thrips and other insects on both sampling dates. Final stand and plant height (mean of five measurements) were measured before harvest in all experiments. Cotton plots were harvested to determine seed cotton yield on 5 Nov. 1998 and 10 Nov. 1999 at Plains and 8 Nov. 1998 and 5 Nov. 1999 at Tifton, respectively.

Results were analyzed with ANOVA for a strip-plot design (Little and Hills, 1978). The ANOVAs were conducted by experiment (Table 2) because year × treatment and location × treatment interactions were significant at $P = 0.05$ for most variables (ANOVA not shown). Percentage values were transformed with a square root–arc sine transformation before analysis. Treatment means were separated using Fisher's protected least significant difference test at $P = 0.05$.

RESULTS

Pesticide Experiment

Stand

In 1998, the cotton stands following canola were not different from the stands following winter fallow and were lower compared with stands following wheat only at 26 DAP (Tables 1 and 3). In 1999, stands following canola were lower than following fallow or wheat at all three sample dates. The stands following wheat were not different than stands following fallow at any sampling date in either year.

The use of an insecticide in-furrow did not affect stand after any crop in either year (data not shown). Fungicides applied in-furrow at planting had no effect on cotton stands following fallow or wheat except at 27 DAP in 1999 following wheat (Tables 1 and 3). The use of fungicides improved stands following canola at all sampling dates in 1999 and at 26 DAP in 1998.

Insects

False chinch bugs, thrips (mostly *Frankliniella fusca* Hinds), and cotton aphids (*Aphis gossypii* Glover) were

Table 2. Analysis of variance evaluating winter crop, planting date, and tillage treatment effects on seedling and final cotton stand, *Rhizoctonia solani* seedling infection, and seed cotton yield at Tifton and Plains, GA in 1998 and 1999.

		Tifton				Plains			
		Stand				Stand			
Source of variation	df	15 DAP†	Final	*R. solani* infection	Yield	15 DAP	Final	*R. solani* infection	Yield
		F-value							
1998									
Planting date (PD)	1	–	27.43**	–	15.01**	14.26**	0.85	0.09	3.24
Tillage (T)	1	–	0.54	–	0.12	3.61	1.58	0.02	0.05
PD × T	1	–	0.08	–	0.84	6.65*	4.70	0.12	0.78
Error a	9								
Winter crop (WC)	2	–	0.11	–	8.97*	6.09*	5.82*	4.93*	0.27
Error b	6								
PD × WC	2	–	0.81	–	0.04	8.11**	5.33*	0.75	0.85
T × WC	2	–	0.18	–	0.88	0.25	0.52	1.82	1.19
PD × T × WC	2	–	0.88	–	0.12	1.22	2.02	1.35	1.86
Error c	18								
1999									
Planting date (PD)	1	0.01	55.24**	0.10	52.71***	112.67***	79.19***	2.05	3.59
Tillage (T)	1	20.32**	7.02*	0.04	0.96	0.24	0.12	13.34*	9.00*
PD × T	1	12.49**	6.84*	0.09	0.15	0.02	0.11	18.12*	0.60
Error a	9								
winter crop (WC)	2	72.59**	26.54**	3.61	8.20*	24.49**	20.33**	5.83*	5.30*
Error b	6								
PD × WC	2	0.57	0.57	0.25	1.70	0.55	1.42	1.29	5.22*
T × WC	2	0.47	2.57	0.37	1.19	2.88	2.93	2.85	7.35**
PD × T × WC	2	1.00	3.60*	2.45	0.84	0.21	0.35	0.40	4.00*
Error c	18								

* Significant at $P = 0.05$.
** Significant at $P = 0.01$.
*** Significant at $P = 0.001$.
† DAP, days after planting.

Table 3. Effect of winter crop and at-planting fungicide treatment on cotton stand in 2 yr at Plains, GA.

Winter crop	Pesticide treatment	1998 13 DAP†	1998 26 DAP	1998 Final	1999 14 DAP	1999 27 DAP	1999 Final
		Plants m^{-2} row					
Main effect							
Canola		6.07	5.63	4.25	4.68	3.47	3.03
Fallow		6.69	6.31	4.70	8.84	8.00	7.24
Wheat		7.01	7.36	5.64	8.92	7.62	7.42
LSD(0.05)		NS‡	1.40*	NS	2.21**	1.95**	1.91**
Effects for fungicide treatment within winter crop (WC)							
Canola	Fungicide−	5.44	4.89	3.79	3.50	2.54	2.46
	Fungicide+	6.70	6.36	4.72	5.86	4.40	3.60
Fallow	Fungicide−	6.78	6.36	4.73	8.76	7.71	7.98
	Fungicide+	6.59	6.26	4.66	8.93	8.30	7.50
Wheat	Fungicide−	6.56	7.19	5.50	8.66	7.02	7.11
	Fungicide+	7.47	7.52	5.78	9.17	8.21	7.74
LSD(0.05)							
Fungicide		NS	0.44	NS	0.83	0.65	NS
Pesticide trt within WC		1.09	0.44	0.82	1.44	1.13	1.35
Pesticide trt among WC		1.19	0.79	1.02	1.73	1.48	1.52
CV, %		19.2	12.1	18.2	18.8	17.4	22.4

* Significant at $P = 0.01$.
** Significant at $P = 0.05$.
† DAP, days after planting.
‡ NS, not significant.
§ Insecticide treatment effects were not significant for any winter crop treatment at $P = 0.05$ (data not shown).

collected from cotton seedlings. In 1998, false chinch bug populations were virtually identical in all winter crop treatments 13 and 22 DAP but were significantly more abundant following canola than following fallow or wheat 22 DAP (Table 4). Cotton aphids and thrips were more abundant following fallow than following canola or wheat. Pesticide treatments did not affect insect numbers, except chinch bugs, which were less numerous in insecticide-treated plots than in untreated plots 22 DAP. Numbers of false chinch bugs, thrips, and aphids were small in 1999 and not significantly affected by pesticide treatments ($F = 0.56$–1.46; df = 1,27; $P = 0.66$–0.32) or winter crop treatments ($F = 0.38$–0.76; df = 1,27; $P = 0.77$–0.55) (data not shown). It is likely that the small subplot size further reduced our ability to detect insecticide effects on insect numbers. Chinch bug numbers were negatively associated with cotton stand counts 22 DAP in 1998 and all stand counts in 1999 (range of values, $r = -0.33$ to -0.53, $N = 36$, $P < 0.05$).

Diseases

Rhizoctonia solani was recovered from seedlings in both years, and all cultures were classified as *R. solani* AG-4. *Rhizoctonia solani* infection levels of seedlings were 2.5-fold greater in 1998 and 6.0-fold greater in 1999 following canola than following fallow (Tables 1 and 5). Insecticide application at planting also increased recovery of *R. solani* AG-4 from seedlings by nearly

Table 4. Main effect of winter crop and pesticide treatments on numbers of insects on seedling cotton at Plains, GA in 1998.

Variable	False chinch bugs 13 DAP†	False chinch bugs 22 DAP	False chinch bugs 33 DAP	Thrips 22 DAP	Thrips 33 DAP	Aphids 33 DAP
	no./10 plants					
Winter crop						
Canola	2.6	2.4	4.0	1.5	1.1	0.9
Fallow	1.0	0.7	2.6	3.3	1.3	12.8
Wheat	0.7	1.1	2.4	1.5	0.9	6.3
LSD(0.05)	NS‡	0.8**	NS	1.6*	NS	7.5*
Effects of pesticide treatments						
Insecticide−	2.2	2.3	3.4	3.0	1.0	8.3
Insecticide+	0.7	0.7	2.7	1.8	1.2	5.0
LSD(0.05)	NS	1.0*	NS	NS	NS	NS
Fungicide−	1.5	1.3	2.6	2.5	1.3	8.1
Fungicide+	1.3	1.6	3.4	2.3	1.0	5.2
LSD(0.05)	NS	NS	NS	NS	NS	NS
CV, %	124.6	115.2	135.1	112.5	85.2	123.0

* Significant at $P = 0.01$
** Significant at $P = 0.05$.
† Days after planting.
‡ NS, not significant.
§ Interaction terms listed in Table 1 were not significant at $P = 0.05$ (data not shown).

Table 5. Main effects of winter crop and at-planting pesticide treatments on cotton seedling infection by *Rhizoctonia solani*, *Alternaria* sp. and *Fusarium* sp.

Treatment	1998 *R. solani*	1999 *R. solani*	1999 *Alternaria* sp.	1999 *Fusarium* sp.
	%			
Winter crop				
Canola	27.5a†	33.8a	25.6a	15.0a
Fallow	10.8b	5.6b	27.5a	20.0a
Wheat	6.7b	6.9b	32.5a	18.1a
Main effects of pesticide treatments‡				
Insecticide−	10.0b	10.8b	28.4a	16.7a
Insecticide+	20.0a	20.0a	28.8a	18.8a
Fungicide−	17.8a	15.8a	25.4a	18.8a
Fungicide+	12.2a	15.0a	31.7a	16.7a
CV, %	66.8	68.3	39.9	44.5

† Means within treatment group followed by the same letter are not significantly different at $P = 0.05$.
‡ Interaction terms listed in Table 1 were not significant at $P = 0.05$.

twofold in both 1998 and 1999 (Tables 1 and 5). Fungicides applied in-furrow did not affect recovery of *R. solani* AG-4 from cotton seedlings in either year. *Rhizoctonia solani* infection levels were negatively correlated with cotton stand 26 DAP and with all stand counts in 1999 (range of values, $r = -0.43$ to -0.48, $N = 36$, $P < 0.01$).

Alternaria sp. and *Fusarium* sp. also were recovered from numerous seedlings in 1999, but their incidence was very low in 1998. The recovery of these fungi from cotton seedlings was not influenced by previous crop, insecticide, or fungicide treatment (Table 5), nor were infection levels correlated with cotton stand in either year.

Plant Height and Yield

Final plant height was not affected in either year by pesticide treatment (1998: $F = 0.33$; df = 1,27; $P = 0.81$; 1999: $F = 1.93$; df = 1,27; $P = 0.15$) or by winter crop (1998: $F = 5.82$; df = 2,6; $P = 0.07$; 1999: $F = 2.26$; df = 2,6; $P = 0.19$) (data not shown).

Previous winter crop did not affect cotton yield in 1998 (Tables 1 and 6). Insecticide treatment prevented yield losses following canola and fallow, whereas untreated cotton following wheat yielded more than cotton treated with insecticide. This produced a significant crop × insecticide treatment interaction for yield in 1998 (Table 1). Cotton yield in 1999 was reduced following canola and fallow compared with following wheat. Conversely, insecticide treatment did not affect yield following any winter crop in 1999.

Fungicide treatment did not affect yield following any crop in 1998 but did prevent yield loss following canola in 1999. Yield was highly correlated with stand counts in both years (range of values, $r = 0.45$ to 0.61, $P < 0.05$), but was not correlated with *R. solani* infection levels or false chinch bug populations in either year.

Tillage and Planting Date Experiment

Stand

Winter crop treatments in 1998 did not affect final stand at Tifton, but cotton stand was lower following

Table 6. Effect of winter crop and pesticide treatments at planting on seed cotton yield at Plains, GA.

Winter crop	Pesticide treatment	1998	1999
		kg ha^{-1}	
Main effects			
Canola		2774	1922
Fallow		2399	2261
Wheat		3064	2719
LSD(0.05)		NS	383**
Effects of pesticide treatments by winter crop (WC) treatment			
Canola	Insecticide−	2531	1919
	Insecticide+	3020	1925
	Insecticide−	2765	1665
	Insecticide+	2785	2179
Fallow	Insecticide−	2115	2198
	Insecticide+	2684	2325
	Insecticide−	2471	2255
	Insecticide+	2328	2268
Wheat	Insecticide−	3273	2637
	Insecticide+	2857	2802
	Insecticide−	2918	2668
	Insecticide+	3212	2770
LSD(0.05)			
Insecticide		167	NS
Fungicide		NS	131
Pesticide trts within WC		298	364
Pesticide trts among WC		321	336
CV, %		14.4	15.4

** Significant at $P = 0.01$.

fallow than following canola and wheat at Plains in 1998 (Tables 2 and 7). Seedling and final cotton stands were reduced following canola but not following wheat or fallow at both locations in 1999. For the first planting date at Plains in 1999, stand following fallow also was lower than following wheat. Tillage had little effect on cotton stand in any experiment, except at Tifton in 1999 where stands generally were lower in strip than conventional tillage (Tables 2 and 7). Delayed planting had a variable effect on cotton stand. In both years at Tifton, delayed planting reduced final cotton stand. At Plains, delayed planting did not affect final stand in 1998 and improved both seedling and final stands in all winter crop treatments in 1999 (Table 7). Lack of timely irrigation following the first planting at Plains in 1999 may partly account for this stand reduction.

Diseases

Seedling diseases were not sampled at Tifton in 1998. Seedling infection by *R. solani* was greater in 1999 than 1998 at Plains (Table 8). Infections by *R. solani* were always greater following canola than following wheat or fallow at Plains. Winter crop did not affect *R. solani* infection rate at Tifton in 1999 where the infection level was high following all crops. Recovery of *R. solani* from seedlings was not different between wheat and fallow treatments in any experiment. Planting date did not affect *R. solani* infection levels in any experiment (Table 8). Tillage did not affect recovery of *R. solani* from cotton seedlings, with the exception of Plains in 1999 where the recovery rate averaged 11.3% in the conven-

Table 7. Effect of winter crop, planting date, and tillage treatment on seedling and final cotton stand in four experiments.

		1998			1999			
		Tifton	Plains		Tifton		Plains	
Winter crop	Planting–tillage treatment	Final	15 DAP†	Final	14 DAP	Final	14 DAP	Final
		Plants m^{-1} row						
Main effect of winter crop								
Canola	–	9.02	8.27	7.66	6.49	5.17	4.98	3.18
Fallow	–	8.72	7.94	6.85	8.91	7.36	6.58	5.60
Wheat	–	8.91	8.56	7.75	8.54	7.18	7.27	6.26
LSD(0.05)		NS‡	0.44*	0.71*	0.53**	0.81**	0.82**	1.24**
Planting date (PD) by tillage (T) treatments within winter crop (WC)								
Canola	PD1-conv.	10.33	8.52	6.89	6.10	5.55	3.63	1.85
	PD1-strip	9.75	8.16	7.19	6.56	6.32	3.20	1.54
	PD2-conv.	7.62	8.09	8.38	7.52	5.15	6.44	4.84
	PD2-strip	8.03	8.30	8.20	5.76	3.64	6.64	4.51
Fallow	PD1-conv.	9.10	8.28	6.33	9.19	8.47	3.48	3.03
	PD1-strip	9.67	7.30	7.13	8.70	8.05	4.49	4.08
	PD2-conv.	8.36	7.83	7.85	9.65	7.53	8.93	7.25
	PD2-strip	7.70	8.36	6.15	8.07	5.36	9.41	8.01
Wheat	PD1-conv.	9.92	9.59	8.42	8.90	8.21	5.61	5.55
	PD2-strip	9.02	9.18	7.93	8.35	7.83	5.43	4.84
	PD2-conv.	8.44	7.97	7.64	9.19	6.32	9.00	7.19
	PD2-strip	8.28	7.50	6.99	7.69	6.32	9.02	7.46
LSD(0.05)								
PD		0.67	0.30	NS	NS	0.53	0.84	0.61
T		NS	NS	NS	0.45	0.53	NS	NS
PD or T across WC		2.38	1.95	2.71	2.10	2.39	3.90	3.50
WC within PD or T		2.04	2.03	2.70	2.04	2.41	3.69	3.69
CV, %		14.6	8.7	12.3	8.8	8.3	20.1	22.8

* Significant at $P = 0.05$.
** Significant at $P = 0.01$.
† DAP, days after planting.
‡ NS, not significant.

tional tillage treatments and 17.5% in the strip-tillage treatments.

Alternaria sp. and *Fusarium* sp. were isolated from cotton seedlings in 1999, and winter crop and tillage treatments did not affect either pathogen (Table 9). Delaying planting reduced the recovery of *Alternaria* spp. from seedlings in both experiments but did not affect *Fusarium* spp. infection levels in either experiment.

Plant Height and Yield

Final plant height was not affected by tillage, planting date, or winter crop treatment, except at Tifton in 1998 when plants were 10.4% shorter in the first planting compared with the second planting ($F = 10.06$; df = 1,9; $P = 0.05$) (data not shown).

Seed cotton yield in 1998 was lower following wheat than following canola and fallow at Tifton but was not significantly affected by winter crop treatments at Plains. Yields in 1999 were reduced following canola compared with following wheat at both locations (Table 10). Tillage did not consistently affect cotton yield. A significant tillage effect occurred at Plains in 1999 be-

Table 8. Effect of winter crop, planting date, and tillage treatments on cotton seedling infection by *Rhizoctonia solani*.

	R. solani–infected plants		
Main effect	1998 Plains	1999 Tifton	1999 Plains
	%		
Winter crop			
Canola	10.6a*	43.1a	25.6a
Fallow	5.0ab	31.1a	8.8b
Wheat	1.9b	22.2a	8.8b
Planting date			
1	6.3a	32.6a	17.1a
2	5.4a	31.2a	11.7a
Tillage			
Conventional	5.8a	31.7a	11.3b
Strip	5.8a	32.1a	17.5a

* Means followed by the same letter within a column and main effect group are not significantly different at $P = 0.05$.

Table 9. Main effect of winter crop, planting date, and tillage on cotton seedling infection by *Alternaria* sp. and *Fusarium* sp. in 1999.

	Alternaria sp.		*Fusarium* sp.	
Factor	Plains	Tifton	Plains	Tifton
	%			
Winter crop				
Canola	15.0a*	10.9a	5.6a	5.2a
Fallow	15.0a	12.8a	3.1a	6.6a
Wheat	17.5a	14.4a	5.6a	6.3a
Planting date				
1	31.7a	15.5a	4.6a	5.6a
2	0b	9.9a	5.0a	6.4a
Tillage				
Conventional	14.2a	10.3a	2.9a	5.9a
Strip	17.5a	15.1a	6.7a	6.0a
CV, %	72.4	38.4	132.8	43.7

* Means within a treatment group followed by the same letter are not significantly different at $P = 0.05$. No interaction terms listed in Table 5 were significant at $P = 0.05$.

Table 10. Effect of winter crop, planting date, and tillage treatment on seed cotton yield at Tifton and Plains, GA in 1998 and 1999.

Winter crop	Planting–tillage treatment	1998 Tifton	1998 Plains	1999 Tifton	1999 Plains
		kg ha^{-1}			
Main effect of winter crop					
Canola	–	3415	3083	1609	1685
Fallow	–	3443	3187	2073	1728
Wheat	–	3190	3087	1987	1945
LSD(0.05)		160	NS*	298	209
Planting date (PD) by tillage treatment (T) within winter crop (WC)					
Canola	PD1-conv.	3692	3321	2009	1484
	PD1-strip	3615	3059	2038	1451
	PD2-conv.	3151	3013	1211	1865
	PD2-strip	3203	2938	1179	1941
Fallow	PD1-conv.	3855	2980	2610	1309
	PD1-strip	3533	3485	2642	2066
	PD2-conv.	3218	3231	1667	1659
	PD2-strip	3165	3052	1373	1878
Wheat	PD1-conv.	3501	3189	2573	1918
	PD1-strip	3410	3371	2282	2091
	PD2-conv.	2813	2894	1649	1733
	PD2-strip	3036	2895	1443	2033
LSD(0.05)					
PD		294	NS	293	NS
T		NS	NS	NS	183
PD or T across WC		597	634	389	413
WC within PD or T		446	621	369	357
CV, %		8.3	10.3	12.0	12.0

* NS, not significant at $P = 0.05$.

cause of low cotton yields in conventional tillage treatments at the first planting date following winter fallow. Delaying planting reduced cotton yield at Tifton in both years but did not affect yield at Plains in either year (Table 10).

DISCUSSION AND CONCLUSIONS

Cotton was successfully grown as a double crop with fall-planted canola in 1998 with no adverse effect on cotton stand or yield. However, in 1999, final cotton stand was reduced by an average of 37.5% following canola compared with following winter wheat or fallow and resulted in reduced seed cotton yield. Stand losses occurred in the first few weeks after planting, after which stands remained stable throughout the season. Cotton seedling infection rates by *R. solani* were greater when canola was used as the previous winter crop, and stand losses in all experiments were associated with the level of seedling infection by this pathogen. Seedlings also were infected by *Alternaria* spp. and *Fusarium* spp., but levels of these fungal pathogens were not affected by winter crop treatments and were not associated with cotton seedling losses.

In 1998, the pesticide experiment also indicated that false chinch bugs were more abundant on cotton seedlings following canola than following wheat or fallow. False chinch bug has a wide host range but is often associated with cruciferous plants (Sweet, 2000). In Georgia, this insect completes a generation in canola in the spring and can reach large numbers as the crop reaches maturity. Fribourg et al. (1989) in Tennessee also reported that large numbers of false chinch bug from rapeseed attacked seedling soybean and cotton in adjacent fields during the spring. Conversely, thrips and cotton aphids were more abundant following fallow than following canola or winter wheat. Presumably, the presence of crop residue reduced the host-finding ability and colonization of cotton seedlings by these insects.

Populations of all insects were greatest in 1998 when seedling stand losses in all experiments were minimal. Furthermore, lack of an insecticide effect on stand in both years supports the conclusion that damage by insects was not an important factor in reducing cotton stands. These points suggest that the negative association between false chinch bug numbers and cotton stand was coincidental because stand losses caused by *R. solani* were greatest in plots where chinch bugs also were most abundant. However, the insecticide treatment did prevent yield losses following canola and fallow in 1998 when insect populations were greatest. Cotton in Georgia typically is treated with an insecticide at planting to prevent seedling injury by insects (Roberts et al., 1997). Interestingly, the insecticide treatment also enhanced *R. solani* infection levels by about twofold in both years. To our knowledge, this phenomenon has not been previously documented. Possibly, the aldicarb treatment caused some root injury, thereby allowing increased levels of *R. solani* infection.

Canola as a winter crop definitely increased the percentage of cotton seedlings infected by *R. solani* AG-4. *Rhizoctonia solani* AG-4 infection levels in cotton seedlings were higher following canola than following wheat or fallow in four of five comparisons. The final cotton stand and yield were also lower following canola than following wheat or fallow in all experiments in 1999. *Rhizoctonia solani* is ubiquitous in Georgia soils and is often considered to be the primary pathogen involved in stand losses in cotton (Moustafa-Mahmond et al., 1993). All of the isolates from these research plots tested were anastomosis group AG-4, which is commonly associated with cotton and other crops grown in Georgia. It is also the group most frequently associated with canola. Thus, there is no indication that canola production is selectively increasing an unusual biotype of *R. solani*.

The increase in infection levels of cotton seedlings could be associated with sublethal seedling injury by isothiocyanates released during the decomposition of the canola residue. Isothiocyanates are known to be phytotoxic, and seedling cotton is known to be sensitive to chemical injury from some herbicides and insecticides (Moustafa-Mahmond et al., 1993). The increase in *R. solani* AG-4 infection levels observed in this study in plots treated with aldicarb is an example.

An alternative explanation might be that canola is increasing the population of *R. solani* AG-4 in the soil. This could be a result of pathogenic activity of the fungus on canola or a saprophytic increase on canola residue after harvest. In a study of the survival of fungi on canola stubble after harvest, *R. solani* AG-4 was not found on canola stubble from Georgia immediately after harvest. The fungus invaded the stubble after it was buried in soil and persisted on buried stubble for 4 mo (Baird et al., 1999). The level of infestation of the stubble detected in that study would probably be too low to cause the magnitude of increased seedling infection found in these experiments.

The fungicide treatment used in this study did not reduce seedling infection by *R. solani* in either pesticide experiment, but it did reduce stand and yield losses in 1999 when *R. solani* infection levels were high. Although the fungicide did not reduce infestation rates, it possibly reduced the intensity of infection, and thereby reduced the severity of injury and level of plant mortality. *Rhizoctonia solani* infection levels and stand losses were minimal following wheat and fallow, and fungicide treatment did not affect subsequent cotton stands following these winter crops.

The delayed planting variable in these experiments was included to allow some additional time for residue decomposition. However, dry weather during this period in 1998 and 1999 may have impeded additional decomposition. The delay in planting did not cause a change in *R. solani* AG-4 infection levels in any experiment. There was an increase in stand between the first and second planting date only at Plains in 1999. In that experiment, the difference was due to extremely low stands in the first planting, probably caused, at least in part, by the very dry soil conditions at planting. Delayed planting did not increase yield in any experiment and consistently decreased yield at the Tifton location.

In a double-cropping system, the summer crop is often planted using minimum tillage. Both conventional and strip tillage were included as variables in both years of this study. There was no consistent affect of tillage on *R. solani* AG-4 infection, final stand, or yield of cotton following any winter crop treatment or planting date. Tillage regime also did not affect double-cropped soybean yield after winter wheat and canola in South Carolina (Porter, 1995).

Therefore, tillage practices and delayed planting do not seem to be viable management tools for minimizing cotton stand losses when double-cropping cotton following canola. Although the fungicide treatment did not reduce seedling infection levels, it may be a useful tool in preventing stand losses caused by *R. solani*. Cotton is very tolerant of differences in stand above a plant population of about seven plants per square meter (Bednarz et al., 2000) so completely preventing all stand loss may not be necessary. It may be possible to simply increase cotton seeding rate to compensate for expected loss of cotton stand when following canola. The economic feasibility of increasing seeding rate to compensate for stand losses will depend on cotton seed prices and the economic benefit of growing canola relative to other winter crop alternatives.

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