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A Comparison of Winter Cereal Species and Planting Dates as Residue Cover for Cotton Grown with Conservation Tillage

Philip J. Bauer* and D. Wayne Reeves

ABSTRACT

Winter cereals are often used as cover crops before planting cotton (*Gossypium hirsutum* L.). Black oat (*Avena strigosa* Schreb.) is the predominate cereal cover crop for cash crops in southern Brazil and Paraguay, but limited information is available on the suitability of black oat as a cover crop in the southeastern USA. The objectives of this study were to compare black oat with adapted winter cereals for this region and to determine the effect of cereal residue species and amount on cotton growth, N status, and lint yield. In a greenhouse study in which black oat and rye (*Secale cereale* L.) residues were mixed with soil, tap root elongation of both cotton and radish (*Raphanus sativa* L.) was inhibited more by black oat residue than by rye residue. In a field experiment on a Goldsboro loamy sand (fine-loamy, siliceous, thermic Aquic Kandiudult), cotton was grown in 1995 and 1996 following black oat, oat (*Avena sativa* L.), rye, and wheat (*Triticum aestivum* L.) that were planted at three different times (October, November, and December). All four winter cereals had similar biomass production at each planting date in 1995. In 1996, rye was the only species not visibly damaged by a low temperature of −12.2°C that occurred during the winter. Black oat biomass was comparable to wheat in all planting dates but averaged 60% less than rye over all three planting dates and was 37% less than oat in the October planting date in that year. Black oat tended to have a higher N concentration than the other cereal species. Cotton plant density was lowest following black oat and rye. Cotton growth, leaf blade N, and petiole NO_3-N were more dependent on residue amount than on residue species. Cotton lint yield following black oat was 120 kg ha^{-1} higher than lint yield of cotton following rye. Cotton following black oat, wheat, and oat had similar lint yield. Black oat may be a promising cover crop for the southeastern USA, but evaluations of other cultivars and/or improvement programs to improve cold hardiness are needed to improve the utility of this species.

WINTER CEREALS are often used as cover crops for cotton because they grow rapidly in the fall and provide ground cover throughout the winter. Several winter cereal species, including rye, wheat, and oat, are recommended as cover crops (Sustainable Agriculture Network, 1998) in the southeastern USA. A species that may also have potential is black oat. Black oat is the most widely grown cover crop species in southern Brazil and Paraguay, where climatological and environmental features are similar to the southeastern USA. Limited information exists on the suitability of black oat as a winter cover crop for cotton production in this region of the U.S. Cotton Belt.

Management of cotton following a cereal cover crop can be different from that following winter fallow. Most notably, stand establishment and N management require special attention following winter cereals. Reductions in plant population have been attributed to poor seed to soil contact (Grisso et al., 1984) because of the plant residues interfering with the planting operation. Allelopathic compounds in winter cereal residues can also affect cotton stands. For example, Hicks et al. (1989) reported that compounds arising from decaying wheat cover crop residues can stunt and kill young cotton seedlings. When residues are left on the soil surface, allelopathy is less a factor in causing stand reductions (White and Worsham, 1989; Rickerl et al., 1989). However, if residues are trapped within the seed furrow (especially if row cleaning attachments are not used), these residues may cause damage to young cotton roots.

Growing winter cereals as winter cover crops can result in N deficiency of the succeeding cotton crop. The cereal cover crop scavenges N from the soil throughout the winter months, reducing soil-available N to the succeeding cotton crop. Subsequently, the high C:N ratios of winter cereal residues causes N immobilization (Aulakh et al., 1991; Doran and Smith, 1991; Somda et al., 1991; Torbert and Reeves, 1991). For cotton grown without fertilizer N, Bauer et al. (1993) found lower petiole NO_3-N levels in cotton following green-manured rye than in cotton following winter fallow. Because of this, higher rates of N fertilizer has been recommended for cotton following winter cereals (Reeves et al., 1993).

Cotton plant morphology may be influenced by the presence of winter cereal residues on the soil surface. Stevens et al. (1992) reported 11% fewer cotton floral buds (squares) on the lower fruiting nodes of cotton seeded directly into wheat stubble than of cotton grown with conventional tillage. The light environment surrounding plants affects seedling growth (reviewed by Schopfer, 1984) and residues affect the photosynthetic photon quantity and wavelength composition of light reflected from the soil surface (Kasperbauer, 1994; Hunt et al., 1989). Kasperbauer (1998) found a lower root: shoot ratio in 7-d-old greenhouse-grown cotton plants that were grown over wheat straw compared with plants grown over bare soil.

The species and planting date of winter cereals partially determine biomass production of a cover crop, and conservation tillage crop production in the southeastern USA can be improved with large biomass inputs to the soil (Langdale et al., 1990). Since cotton crop development and yield may be affected by the presence of winter cereal residues, a characterization of these effects may be useful in designing conservation tillage management techniques. This may especially be needed for potentially new cover crops like black oat. Our objectives were (i) to compare black oat to adapted winter cereals for growth and N accumulation when planted at different times in the fall; and (ii) to determine how the species and quantity of winter cereal residue affect cotton growth, N status, and yield.

P.J. Bauer, USDA-ARS Coastal Plains Soil, Water, and Plant Research Center, 2611 West Lucas Street, Florence, SC 29501; D.W. Reeves, USDA-ARS National Soil Dynamics Lab., Auburn, AL. Received 25 Jan. 1999. *Corresponding author (bauer@florence.ars.usda.gov).

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MATERIALS AND METHODS

Greenhouse Study

A greenhouse study was conducted to compare soil-incorporated black oat residues to rye residues for inhibition of cotton and radish seedling emergence and tap root extension. Besides the two cereals, two control treatments were included. One control was soil without a green manure. Because of its known detrimental effects on cotton (Pieters and McKee, 1938), the other control was crimson clover (*Trifolium incarnatum* L.), which was included in the experiment as a check of environmental conditions to ensure that decomposition was occurring. Aboveground plant material of black oat, rye, and crimson clover was collected from field plots in April and immediately mixed with soil [collected from the surface 30 cm of a Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Kandiudult)] and placed in pots on greenhouse benches. The plant residues were added so that each pot contained 5% fresh plant material, by weight. The pots were then watered and loosely covered with newspaper to reduce soil evaporation. The plant material was allowed to decompose in the pots for one week. After one week, five cotton seeds ('Coker 315') or 10 radish seeds were planted into each pot. At 7 d after seeding, emergence and taproot length of the seedlings were determined. The cotton and radish experiments were conducted separately, but simultaneously. The experimental design for each was a randomized complete block. Each treatment in each experiment was replicated five times and the experiments were conducted twice.

Field Study

A field study was conducted at Clemson University's Pee Dee Research and Education Center near Florence, SC, from October 1994 through cotton harvest in 1995 and from October 1995 through cotton harvest in 1996. The soil type was Goldsboro loamy sand. Each year the experiment followed corn. Treatments were winter cereal species (black oat, oat, rye, and wheat) and winter cereal planting date (early October, early November, early December). Treatments were in a factorial arrangement in a randomized complete block experimental design with four replicates each year. Each plot was 3.86 m wide (four 0.96-m wide rows) and 15.24 m long.

Before the first planting of the winter cereals each year, a fertilizer application containing 28 kg N ha^{-1}, 24 kg P ha^{-1}, and 46 kg K ha^{-1} was broadcast-applied to the entire experimental area. Lime was applied at this time on the basis of soil test results (Anonymous, 1982). The area was then disked twice and leveled with a harrow equipped with S-shaped tines. The cereals were planted with a grain drill on 12 October, 9 November, and 8 December in 1994 and 12 October, 6 November, and 6 December in 1995. Seeding rates were 54 kg ha^{-1} for the black oat and oat, 94 kg ha^{-1} for the rye, and 101 kg ha^{-1} for the wheat. Cultivars used were 'IAPAR-61' black oat, 'Coker 716' oat, 'Gurley Grazer' rye, and 'Coker 9835' wheat.

Winter cereal biomass samples were collected on 19 April 1995 and 23 April 1996. Each year, all of the aboveground plant material in a 0.57 m^2 area of each plot was collected, dried at 70°C for 3 d, and then weighed. Samples were ground to pass a 100-mesh screen and then stored until analyzed for N. Winter weeds that were present in the sampling area were collected, dried, weighed, and analyzed for N separately from the winter cereal plant material. The effect of these weeds on N and biomass of the winter cover treatments was negligible and did not influence any conclusions of the study, so that data is not presented.

After the biomass samples were collected, glyphosate [*N*-(phosphonomethyl)glycine] (1.12 kg a.i. ha^{-1}) was applied to the entire experimental area. Then, a fertilizer application containing S (11.2 kg ha^{-1}) and B (0.56 kg ha^{-1}) was made. Plots were in-row subsoiled just prior to cotton planting. Cotton ('Stoneville 453') was planted on 3 May both years with a four-row planter equipped with wavy coulters. Seeding rate was approximately 9 seeds per m of row. Weeds were controlled by applying recommended pre- and post-emergence herbicides and by handweeding. An in-furrow application of aldicarb [2-methyl-2-(methylthio) propionaldehyde *O*-(methylcarbamoyl)oxime] (0.84 kg a.i. ha^{-1}) was made at planting for early-season insect control. Aerial applications of insecticides were applied when pest insect thresholds for economic damage (Roof et al., 1994) were exceeded.

Fertilizer N (total of 90 kg ha^{-1}) was applied to the cotton in a split-application of NH_4NO_3. With a four-row applicator equipped with fertilizer coulters, 45 kg N ha^{-1} was knifed-in beside each row after planting and again on 14 June 1995 and 18 June 1996. Cotton leaf blade N and petiole NO_3-N were determined three times during the growing season. Ten uppermost fully expanded leaf blades and petioles from each plot at each sampling date. The first sampling was made on 14 June 1995 and 17 June 1996, which was prior to first bloom and just before the second application of fertilizer N was made. Subsequently, samples were collected at first bloom on 7 July in 1995 and 2 July in 1996 and again after first bloom at 20 July in 1995 and 16 July in 1996. Samples were dried and ground as described for the winter cereal plant samples and then stored until they were analyzed for N.

Winter cereal plant tissue and cotton leaf blade N analysis was conducted by the Clemson University Extension Agriculture Service Laboratory. Nitrogen concentration of the tissues was determined with a Kjeltec System 2300 Distilling Unit1 (Tecator Company, Hoganas, Sweden)[1] after block digestion. Petiole NO_3-N was determined with an ion-specific electrode after extraction with $Al_2(SO_4)$ solution (Baker and Thompson, 1992).

Throughout both cotton growing seasons, height (from the soil surface to the top of the plants) was measured on five consecutive plants in one row of each plot. At harvest time, all plants in the two center rows were counted to determine plant density and mainstem node number and height of lowest boll were measured at this time on five consecutive plants in one row of each plot.

The two center rows of each plot were harvested with a spindle picker on 17 October in 1995 and 14 October in 1996. After weighing the bags of seed cotton, samples were taken from the harvest bags for determination of lint percentage and fiber property analysis. The samples were then ginned in a 10-saw laboratory gin. Yield was determined by multiplying lint percent by harvested seed cotton weight. Samples of fibers were sent to Starlab, Inc. (Knoxville, TN) for high volume instrumentation analysis of fiber length, bundle strength, elongation, micronaire, and color.

All data were subjected to analysis of variance (ANOVA). Variances for winter cover biomass and N content were not equal among planting dates, so separate ANOVAs were done for each planting date for these variables. Except for plant height in the field experiment, data were combined over both trials in the greenhouse study and over both years in the field study for analysis. Sources of variation were considered significant when the probability of greater *F* values were

[1] Mention of trade names is for information purposes only. No endorsement is implied by the USDA.

Table 1. Cotton and radish emergence and taproot length 7 d after being planted into soil with different green manures that had been decomposing for 1 wk. In each test, five cotton seeds were planted in each pot while 10 radish seeds were planted per pot. Data are averages of two trials of the experiment, with five replicates in each trial.

	Cotton		Radish	
Species	Plants	Root length	Plants	Root length
	per pot	cm	per pot	cm
None	4.1	8.6	9.4	8.6
Black oat	3.6	6.6	8.7	3.0
Rye	3.9	7.9	8.3	3.8
Clover	3.4	2.5	7.2	2.0
$LSD_{0.05}$	0.6	1.0	ns†	0.8

† ns indicates treatment means did not differ.

<0.05. Mean separations were made with an LSD ($P = 0.05$) when sources of variation from the ANOVA were significant.

RESULTS AND DISCUSSION

Greenhouse Study

In this study, we constructed the treatments so that the cotton and radish seedlings would be exposed to a relatively high amount of decomposition products. The ephemeral nature of the release of these products from soil-incorporated plant tissues has been known for a long time, and the recommendation for cotton planting after a legume green manure has been to wait about 3 wk after legume incorporation before planting cotton (Pieters and McKee, 1938). Plant emergence and tap root length of cotton and radish planted in soil containing decomposing cover crop tissues is shown in Table 1. The deleterious effects of the clover residue on both the cotton and the radish seedlings were substantial. Cotton emergence (but not radish) was lower when planted into the soil containing the crimson clover residue than when planted into the soil that did not contain a cover crop. Root length of both cotton and radish was greatly reduced when grown in the presence of decomposing clover (Table 1). Residues from the cereal species were less detrimental to the cotton and radish seedlings than crimson clover residues. Cotton and radish emergence was the same for the black oat, rye, and the soil-only control treatments (Table 1). Black oat residue inhibited root elongation of both cotton and radish more than rye residue did.

Table 3. Winter cover N concentration in mid-April as influenced by winter cereal species and planting date. Data are averaged over 2 yr.

	Winter cereal planting date		
Species	October	November	December
		g kg^{-1}	
Black oat	10.5	10.1	17.8
Rye	8.0	7.9	12.9
Oat	8.7	9.0	11.7
Wheat	8.2	9.3	12.6
$LSD_{0.05}$	1.5	1.0	2.4

Field Study

Cover Crop Biomass and N Content

A year × species interaction occurred for winter cereal biomass when the winter cereals were planted in October and December, while only the year and species main effects were significant for biomass production when the cereals were planted in November. For the October planting date, wheat had lower production than oat in 1995, while there were no differences among the other three species that year (Table 2). In 1996, the superior cold tolerance of rye was evident as it was the only species not visibly damaged when nighttime low temperatures reached −12.2°C in early February. For the October planting date, rye had the highest biomass

Table 2. Winter cover aboveground biomass and N content in mid-April of 1995 and 1996.

		Biomass			N content		
Planting date	Species	1995	1996	Mean	1995	1996	Mean
		kg ha^{-1}					
October	Black oat	3480	2490	2980	32	30	31
	Rye	3250	7340	5300	20	72	46
	Oat	4330	3990	4160	38	35	36
	Wheat	3150	2880	3010	22	27	24
	Mean	3550	4170		28	41*	
$LSD_{0.05}$ (Species)				840			12
$LSD_{0.05}$ (Year × Species)†		1180			17		
November	Black oat	1720	2480	2100	16	27	21
	Rye	2390	4130	3250	16	27	21
	Oat	1860	2970	2410	17	36	27
	Wheat	1040	2560	1800	9	25	17
	Mean	1750	3035**		15	29**	
$LSD_{0.05}$ (Species)				800		ns	
$LSD_{0.05}$ (Year × Species)		ns‡			ns		
December	Black oat	320	700	510	5	12	8
	Rye	460	2350	1400	6	31	19
	Oat	300	860	580	3	10	7
	Wheat	360	530	450	5	7	6
	Mean	360	1110**		5	15*	
$LSD_{0.05}$ (Species)				390			6
$LSD_{0.05}$ (Year × Species)		550			9		

*, ** indicate means between years at $P = 0.05$, $P = 0.01$, respectively.
† The year × species LSD is for comparing species means within a year.
‡ ns indicates species or year × species interaction terms were not significant ($P < 0.05$) from analysis of variance.

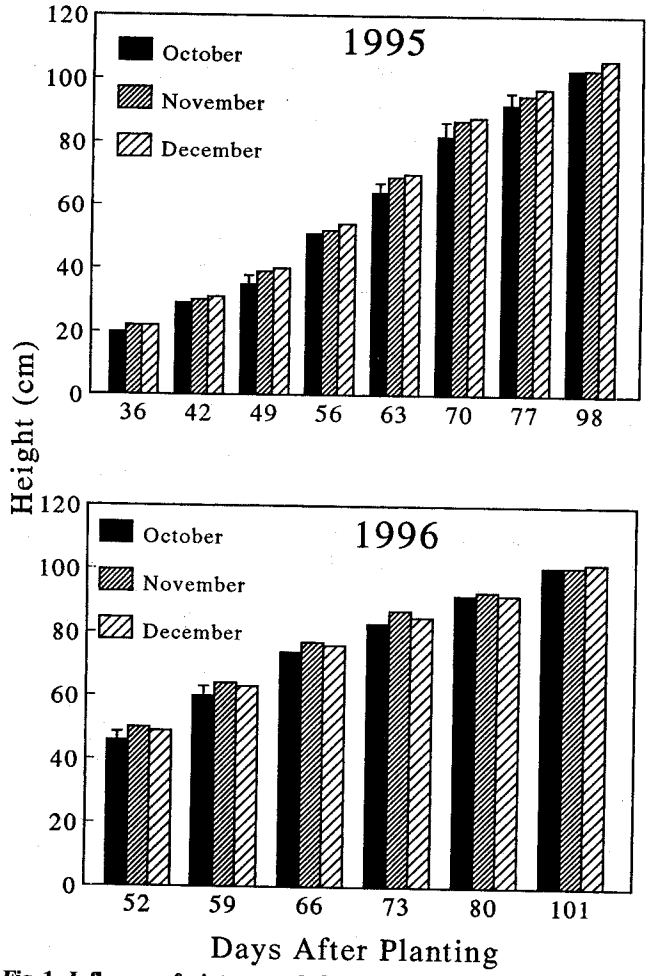

Fig. 1. Influence of winter cereal planting date on cotton plant height throughout the 1995 and 1996 cotton growing seasons. Error bars indicate LSD(0.05) value for comparing means at that sampling date. Lack of error bars indicates means did not differ.

effect of immobilization of N by the decomposing residues (Reeves et al., 1993). Even though residue levels of the black oat at times were lower than for rye (Table 2) and the C:N ratio of the black oat was lower (indicating that N availability would be greater from those residues), there were no difference among the four winter cereals for cotton petiole NO_3-N or leaf blade N at any sampling date. Averaged across both years and all winter cereal planting dates, cotton leaf N at the first sampling date (prior to addition of the second fertilizer N application) was 40 g kg^{-1} for black oat and wheat, 39 g kg^{-1} for oat, and 38 g kg^{-1} for rye. The petiole NO_3-N concentration at that same sampling date was 15.7 g kg^{-1} for black oat and oat, 16.0 g kg^{-1} for wheat, and 15.1 g kg^{-1} for rye.

At the two cotton leaf samplings after the second fertilizer N application was made, cotton had higher petiole NO_3-N when it followed the October winter cereal planting date than when grown following the other two planting dates (Table 5). Since the winter cereals planted in October had higher N accumulation (Table 2) than the other two winter cereal planting dates, the greater petiole NO_3-N probably was the result of the N in the cereal tissues being mineralized by this time, making it available to the cotton crop. Leaf blade N prior to first bloom was lower for cotton following the October and November winter cereal planting dates than for cotton following the winter cereals planted in December, which also suggests that the large amounts of residues reduced N availability early in the season. However, since yield differences did not occur because of N immobilization, and leaf N concentrations were not deficient (Roof et al., 1986), N management did not appear to affect lint yield.

Our results contrast with earlier studies that indicated that increased N fertilization was needed for optimal production following large amounts of high C:N ratio organic amendments. Reeves et al. (1993) recommended that an extra 34 kg N ha^{-1} may be needed for optimal production when planting cotton in cereal residues. In a 3-yr study comparing five N rates (0–160 kg N ha^{-1} in 40 kg ha^{-1} increments), Hutchinson et al. (1994) found the optimum N rate for seedcotton yield following native vegetation was 80 kg ha^{-1}, while the optimum N rate following a wheat cover crop was 120 kg ha^{-1}. They band-applied all of the fertilizer N at one time, about 3 wk after cotton planting. In this study, we made a split-application of N and placed 45 kg ha^{-1} of the N in a band below and to the side of each row at planting. This relatively large amount of N fertilizer at planting, coupled with it being placed in a relatively small area, may have overcome the immobilization problem so that N availability was adequate throughout the entire spring season. Further N rate × placement studies with cereal cover crops are needed to verify this.

Winter cereal species and planting date had only a small effect on mainstem node number and height of the lowest boll on the cotton plants (Table 6). The response to winter cereal planting date for node number was not consistent across winter cereal species. For black

Table 5. Cotton leaf petiole NO_3–N and blade N at three sampling times as influenced by planting date of winter cereal cover crops. Data are averaged over all cover crop species and 2 yr.

Winter cereal planting date	Petiole NO_3–N			Leaf blade N		
	Prior to first† bloom	At first bloom	After first bloom	Prior to first bloom	At first bloom	After first bloom
	g kg^{-1}					
October	15.6	10.5	5.1	38.6	40.6	37.2
November	14.9	9.4	4.2	38.8	40.6	37.2
December	16.5	9.0	4.0	40.0	40.5	37.7
$LSD_{0.05}$	ns‡	1.2	0.7	1.0	ns	ns

† Actual sampling dates were 14 June, 7 July, and 20 July in 1995 and 17 June, 2 July, and 16 July in 1996.
‡ ns indicates means within that column did not differ.

Table 6. Effect of winter cover species and winter cover planting date on cotton plant morphology at Florence, SC. Data are averaged over 2 yr.

	Node of lowest fruiting branch				Height of lowest fruiting branch node			
	Winter cereal planting date				Winter cereal planting date			
Winter cereal	October	November	December	Mean	October	November	December	Mean
	Node no.				cm			
Black oat	6.5	6.1	6.4	6.3	28.5	26.4	27.8	27.5
Oat	6.6	6.3	5.9	6.2	29.2	28.1	27.2	28.2
Rye	6.4	6.4	6.2	6.3	29.9	30.1	28.1	29.3
Wheat	6.4	6.0	6.3	6.2	28.8	28.6	26.2	27.9
Mean	6.5	6.2	6.2		29.1	28.3	27.3	
$LSD_{0.05}$ (Species)				ns†				ns
$LSD_{0.05}$ (Planting date)				0.2				1.4
$LSD_{0.05}$ (Species × Planting date)‡				0.4				ns

† ns indicates means within that column did not differ.
‡ The species × planting date LSD is for comparing species means within a planting date.

oat and wheat, the mainstem node number of the branch with the lowest boll was highest for the October winter cereal planting date and lowest for the November winter cereal planting date (Table 6). For oat, both the October and November winter cereal planting dates resulted in an increase in the node of lowest fruiting branch compared with the December winter cereal planting date, while no differences occurred among planting dates for rye. The tendency for the October winter cereal planting date to have a higher node number for the branch with the lowest boll resulted in that planting date having a higher height for the lowest fruiting branch node than the December planting date (Table 6). There were no differences among the winter cereals for height of the branch with the lowest boll.

The treatments in this study also had only a small effect on fiber properties. Cotton fiber strength was influenced by winter cereal planting date. Means were 239, 235, and 232 kN m kg^{-1} for the October, November, and December winter cereal planting dates, respectively [LSD(0.05) = 1.4 kN m kg^{-1}]. Winter cereal planting date also had a small impact on fiber micronaire, but the response was almost opposite for the 2 yr. In 1995, micronaire values were 3.7, 3.6, and 3.6 for the October, November, and December winter cereal planting dates while in 1996 values were 3.5, 3.6, and 3.7 for those planting dates [LSD(0.05) = 0.1 micronaire units]. Neither winter cereal species nor winter cereal planting date affected the other fiber properties. Averaged over all treatments and years, fiber length was 2.80 cm, elongation was 9.3%, whiteness (Rd) was 65.4%, and yellowness (Hunters' +b) was 7.4. Previously, Bauer and Busscher (1996) found conservation tillage to have a higher lint percentage than conventional tillage. No differences occurred for lint percent among the conservation tillage treatments in this study.

Black oat has potential as a winter cereal cover crop for cotton in the southeastern USA. Black oat had a greater inhibitory effect on root elongation of radish than rye which suggests it may be a better mulch for weed control than rye. Previous studies in Brazil found weed biomass and density of some weed species were lower following black oat than following rye (Derpsch, 1990). Additionally, black oat had the highest N concentration (and lowest C:N ratio) of the four cereals we tested. Cotton yields following black oat were equal to or greater than those of the other three winter cereals. When differences occurred for the cotton growth, morphological characteristics, and fiber properties that we measured, they were generally due more to winter cereal planting date (thus, residue amount) than to the species of the winter cereal. However, blackoat was more detrimental to cotton seedlings than was rye in the greenhouse study (even though stands in the field did not differ), and the lack of cold-hardiness in the cultivar that we evaluated may limit its geographic range. Research efforts are needed to improve cold hardiness and reduce the deleterious effects of decomposing residues on cotton seedlings to improve the utility of black oat as a cover crop for cotton.

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