Chapter 6

Cover-Crop Management Influences Residue Biomass and Subsequent Weed Suppression in a Conservation Agriculture Corn and Cotton Rotation

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Additional information is available at the end of the chapter

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Abstract

The use of winter cover crops is an integral component of conservation systems in a corn and cotton conservation agriculture rotation. Field experiments were conducted from the autumn of 2003 through cash crop harvest in 2006 at three locations. The treatments were five cover-crop-planting timings each fall and four cover-crop termination timings each spring. Five crimson clover or cereal rye planting timings occurred: on the average first 0°C temperature date, 4 and 2 weeks prior and 4 and 2 weeks after the average 0°C temperature date. Termination dates were 1–4 weeks prior to the average optimum soil temperature date for the establishment of each cash crop. Results showed that biomass production by winter covers decreased with even a week's delay in winter cover-crop seeding and resulted in a corresponding increase in summer annual weed biomass. More than 10 times difference in biomass produced by clover was observed when clover was planted on the earliest date and terminated on the last date compared to late planting and early termination, rye eight times. Correspondingly, weed biomass was 556 kg ha^{-1} in the treatment with least rye biomass, eight times higher compared to the treatment with greatest rye biomass.

Keywords: alternative weed control, conservation tillage, cover crops, crop rotation, weed biomass

1. Introduction

Resistance management has become the dominating weed science research and extension focus. In the Southeastern and Mid-South United States, questions concerning management of herbicide resistant *Amaranthus* species, horseweed (*Conyza Canadensis* L.), and Italian ryegrass (*Lolium multiflorum* Lam.), comprise the majority of Cooperative Extension Service (CES) calls in these regions. Conservation agriculture (CA) practices are especially threatened by the emergence and rapid spread of glyphosate-resistant Palmer amaranth (*A. palmeri* S. Wats.). Hundreds of thousands of CA hectares are at risk of being converted to higher-intensity tillage systems due to the inability to reliably control herbicide-resistant weeds in CA systems, especially dry land systems where soil applied herbicides risk non-activation [1]. Currently, the integration of high-residue cover-crop systems, inversion of the soil profile facilitating burial of the surface seedbank, and overlapping residual herbicides are increasingly being recommended by state CES throughout the Southeastern Coastal Plain and Mid-South Delta for herbicide-resistance management [1–3]. The CES in the Southeastern and Mid-South United States is also more frequently recommending tillage to enable increased pre-planting and pre-emergence herbicide use [3–5]. Between-row cultivation is also a proven method of controlling many troublesome and resistant weed species [4, 6]. However, conventional tillage practices decrease soil and water quality and may exclude producers from participating in government loan, insurance, and incentive programs designed to promote soil conservation stewardship. With the rapid spread of acetolactate synthase (ALS) and glyphosate-resistant Palmer amaranth, the hectares in CA could potentially decline further without the development of new, effective weed-control strategies [1].

In the 2012 Weed Science special issue "Herbicide Resistant Weeds", authors describe the need to understand a diverse best management practices (BMPs), including "emphasizing cultural management techniques that suppress weeds by using crop competitiveness" and "using mechanical and biological management practices where appropriate" [7]. Specific examples among many BMPs include crop rotation and cover-crops mulches, respectively. Interest in utilizing high-residue cover crops as a weed management tool is continually increasing from both producers and conservation organizations such as the Soil and Water Conservation Society and USDA Natural Resource Conservation Service among others who both actively support conservation practices through outreach programs and fiscal incentives. This special issue manuscript also states that the appropriate time for cover-crop termination is complex and that the optimum planting and termination timing will be regional and often farm-specific, and concludes "the greatest challenge to the use of any cover crop is the added complexity associated with integration into existing cropping systems."

To reduce the use of intensive tillage practices in integrated weed management systems for controlling problematic weeds, further evaluation of alternative control strategies is necessary. High-residue cover crops, which have been shown to provide early-season weed control, may be utilized in cotton along with other management tactics to suppress *Amaranthus* growth [8–18]. Although early-season weed control is possible with cover crops, season-long control has required the use of herbicides [14, 16, 19–21]. In addition, the quantity of mulch needed to physically suppress weeds has been evaluated [22].

In the past, cover-crop termination has been facilitated utilizing pre-plant (PP) burndown herbicides before planting. The CES recommends terminating winter covers relatively early in the spring, due to concerns for excessive cover-crop biomass interfering with planting operations or excessive soil moisture depletion [23, 24]. However, planting into residue is commonplace (**Figure 1**) and it is well known that planting date affects subsequent residue cover [25].

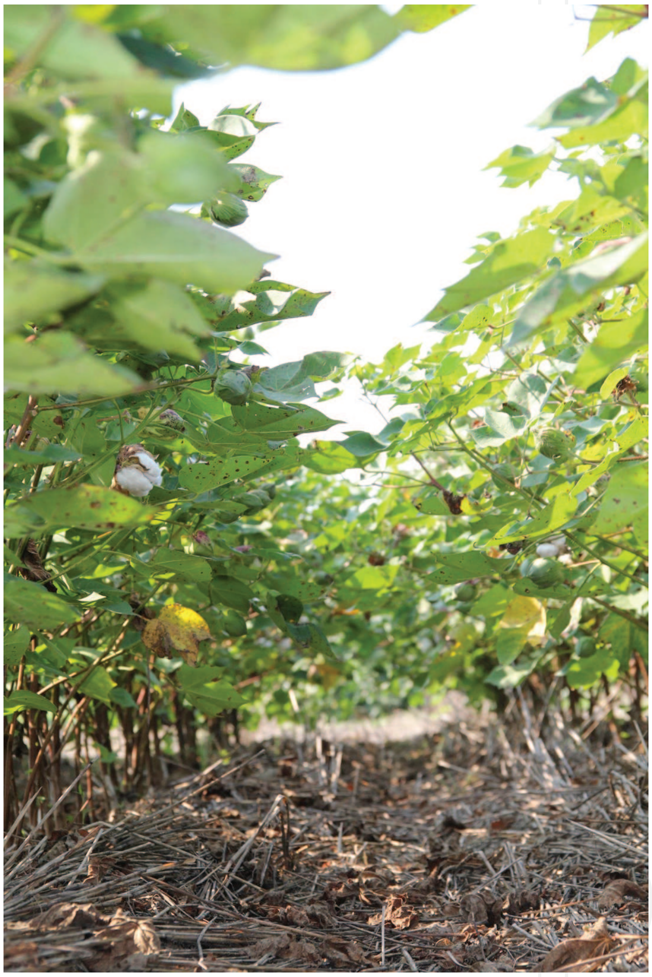

Figure 1. Cotton planted into cereal rye cover crop for weed suppression.

Cooperative extension service recommendations also generally recommend waiting approximately 2–4 weeks after desiccating cereal winter covers before planting cotton to avoid allelopathic effects [26, 27]. However, little research has been conducted evaluating how management of high-residue cover-crop biomass production in situ affects biomass amounts attained as well as weed and crop response. Thus, the objective of this research was to determine how cover-crop planting and termination timing influence subsequent residue and weed biomass and crop yield responses.

2. Materials and methods

Field experiments were conducted at the Alabama Agricultural Experiment Station's E.V. Smith Research Center at Shorter, AL, and Tennessee Valley Research and Extension Center at Belle Mina, AL, from autumn of 2003 through cash crop harvest in 2006. The experiment was also conducted at the University of Florida West Florida Education and Research Center at Jay, FL, from autumn of 2004 to cash crop harvest in 2006. The three locations were selected due to their relatively distant latitude positions and differing soil types, which, according to previous observations concerning forage biomass yield, would influence winter cover-crop growth. Latitude ranged from Belle Mina at 34.689595, E.V. Smith at 32.427626 to Jay, FL, at 30.777618. The soil types were Compass loamy sand (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) at E.V. Smith, Decatur silty loam (fine, kaolinitic, thermic, Rhodic Paleudult) at Tennessee Valley, and a Dothan sandy loam (fine-loamy, siliceous, thermic Plinthic Kandiudults) at Jay.

The treatments were five cover-crop-planting timings each fall and four cover-crop termination timings each spring. The five crimson clover or cereal rye-planting timings occurred on the average 30 year first 0°C temperature date, 4 and 2 weeks prior and 4 and 2 weeks after the average 30 year 0°C temperature date. Termination dates were 1–4 weeks prior to the average 30-year optimum soil temperature date for the establishment of corn or cotton (**Table 1** and **2**). Termination dates were 4, 3, 2, and 1 week prior to the chosen date for corn and cotton establishment, which we based on the long-term average date of the minimum soil temperature ideal for corn (*Zea mays L.*) or cotton (*Gossypium hirsutum* L.) seeding as recommended by the Auburn University CES recommendations (**Tables 1** and **2**).

Belle Mina, AL			**Shorter, AL**		**Jay, FL**		
2003/2004	**2004/2005**	**2005/2006**	**2003/2004**	**2004/2005**	**2005/2006**	**2004/2005**	**2005/2006**
Seeding dates							
25-Sep	27-Sep	25-Sep	09-Oct	08-Oct	12-Oct	29-Oct	04-Nov
09-Oct	11-Oct	11-Oct	20-Oct	21-Oct	25-Oct	10-Nov	17-Nov
22-Oct	26-Oct	24-Oct	10-Nov	10-Nov	07-Nov	29-Nov	02-Dec
04-Nov	08-Nov	07-Nov	21-Nov	03-Dec	22-Nov	13-Dec	12-Dec
18-Nov	18-Nov	18-Nov	08-Dec	16-Dec	07-Dec	20-Dec	22-Dec
Termination dates							
23-Feb	23-Feb	22-Feb	23-Feb	23-Feb	22-Feb	03-Feb	10-Feb
01-Mar	01-Mar	01-Mar	01-Mar	01-Mar	01-Mar	10-Feb	17-Feb
08-Mar	09-Mar	08-Mar	08-Mar	09-Mar	08-Mar	17-Feb	24-Feb
15-Mar	18-Mar	15-Mar	15-Mar	18-Mar	15-Mar	24-Feb	03-Mar

Table 1. Crimson clover seeding and termination dates.

The experiment for each location was a randomized complete block design ($r = 3$) with a split-block restriction on randomization. This design was chosen for practical reasons because it enabled us to handle seeding and termination operations for the cover crop efficiently. We assigned cover-crop-planting dates (5) to horizontal and termination dates (4) to vertical strips. For each location *x*-year combination, therefore, we had three different sizes of experimental units (Steel and Torrie, 1987). The largest experimental unit (TD) equals one-quarter of the block size, the second largest (PD) equals one-fifth of the block size, and the smallest (PD × TD combinations) equals 1/20 of the block size. This design also led to three different sources of experimental errors catering to each experimental unit. Depending on location, the smallest experimental unit (henceforth called plot) was 4 m wide and 8 m long containing four rows of corn and cotton with a 1-m row spacing.

Belle Mina, AL			**Shorter, AL**		**Jay, FL**		
2003/2004	**2004/2005**	**2005/2006**	**2003/2004**	**2004/2005**	**2005/2006**	**2004/2005**	**2005/2006**
Seeding dates							
25-Sep	27-Sep	25-Sep	09-Oct	08-Oct	12-Oct	29-Oct	04-Nov
09-Oct	11-Oct	11-Oct	20-Oct	21-Oct	25-Oct	10-Nov	17-Nov
22-Oct	26-Oct	24-Oct	10-Nov	10-Nov	07-Nov	29-Nov	02-Dec
04-Nov	08-Nov	07-Nov	21-Nov	03-Dec	22-Nov	13-Dec	12-Dec
18-Nov	18-Nov	18-Nov	08-Dec	16-Dec	07-Dec	20-Dec	22-Dec
Termination dates							
02-Apr	04-Apr	05-Apr	23-Mar	23-Mar	22-Mar	10-Mar	16-Mar
09-Apr	11-Apr	10-Apr	31-Mar	30-Mar	29-Mar	17-Mar	24-Mar
16-Apr	18-Apr	17-Apr	07-Apr	06-Apr	04-Apr	24-Mar	31-Mar
22-Apr	28-Apr	24-Apr	13-Apr	13-Apr	12-Apr	29-Mar	07-Apr

Table 2. Cereal rye seeding and termination dates.

Winter cover crops included crimson clover (*Trifolium incarnatum* L.) cv. AU Robin preceding corn and cereal rye (*Secale cereale* L.) cv. Elbon preceding cotton. Both the phases of rotation were present on adjacent areas within the same field tier. Crimson clover and cereal rye were established with a no-till drill at a seeding rate of 28 and 100 kg ha^{-1}, respectively, at the times described previously. In the spring, cover-crop biomass samples were collected immediately prior to termination by clipping all aboveground plant parts close to the soil surface from one randomly selected 0.25-m^2 section in each plot. Plant material was dried at 60°C for 72 h and weighed. Each plot was mechanically rolled/crimped at the timings described previously immediately prior to chemical termination, as described by Ashford and Reeves [28], to aid in cover-crop desiccation and the process leaves a uniform mat of residue on the soil surface. Clover was then sprayed with glyphosate (N-(phosphonomethyl) glycine) at 1.12 kg ae ha^{-1} plus 2,4-D amine (2,4-D-dimethylammonium) at 0.20 kg ai ha^{-1}, while rye was terminated with glyphosate alone, utilizing a compressed CO_2 backpack sprayer delivering 140 L ha^{-1} at 147 kPa.

Because the central Alabama and West Florida sites had a well-developed hardpan, the experimental areas were in-row subsoiled within the week prior to corn and cotton planting with a narrow-shank parabolic subsoiler equipped with pneumatic tires to close the subsoil channel (KMC, Tifton GA, USA). Corn hybrid cv. Dekalb 69-72RR and cotton cultivars DP 444 BG/RR, ST 5242 BR and DP555BRR were planted at Shorter, Belle Mina, and Jay Florida, respectively. Each cash crop was planted 1 week after the final termination date for winter cover crops at each location with a four-row planter equipped with row cleaners and double-disk openers (Great Plains Mfg., Inc. Salina, KS, USA).

At the corn eight-leaf or cotton four-leaf growth stage, all aboveground biomass for all weeds were harvested from two between the row randomly selected 0.25-m^2 sections per plot and treated in a similar manner as to cover-crop samples described above. Immediately after weed sampling, glyphosate was applied at 1.12 kg ae ha^{-1}. Plots were then kept weed-free until harvest utilizing Alabama CES-recommended herbicide applications. For the determination of corn grain yield, the two center rows of each plot were harvested with a plot combine, dried to constant moisture (150 g H_2O kg^{-1}), and weighed. Seed cotton yield was determined by machine harvesting the middle two rows of each plot with a spindle picker.

Data were analyzed separately for each location using generalized linear-mixed models methodology as implemented in SAS® PROC GLIMMIX. Year, planting date and termination date, and all their interactions were considered fixed effects. Interaction of reps with planting date and termination date was considered random effects. Interaction effects were considered to be important whenever the calculated *P*-value was less than 0.10. Treatment differences were calculated by Dunnett's single degree-of-freedom contrasts.

3. Results and discussion

3.1. Crimson clover cover-crop biomass

Climatic conditions encountered at the three locations resulted in large differences in biomass production. The maximum biomass production (5447 kg ha^{-1}) was observed at Shorter, AL, when crimson clover was seeded 4 weeks prior to the average first 0°C temperature and terminated 1 week prior to planting the corn cash crop (data not shown). The least biomass production (24 kg ha^{-1}) was observed at Belle Mina, AL, when the clover was seeded at the last establishment date (4 weeks post 0°C temperature) and terminated 1 week prior to corn planting (data not shown).

The most general model for this type of study is a classification model that treats seeding and termination dates as categorical variables resulting in a 5 by 4 factorial arrangement. The three-way interaction was significant (P = 0.051) only for the Bella Mina location (data not shown). The two-way interactions termination date by year was significant for the northern and southernmost locations only ($P \leq 0.001$), whereas seeding date interacted significantly with years for all three locations ($P < 0.0001$). The seeding by termination date interaction was significant only for Belle Mina and Jay ($P < 0.026$). Main effects for seeding and termination dates were significant at all locations except for termination date at Shorter.

Cover crop seeding date	**Growing season**		
	2003–2004	**2004–2005**	**2005–2006**
	Clover biomass (kg ha^{-1})		
	Belle Mina, AL		
−4 weeks	2861	1928	1904
−2 weeks	1435	2336	1753
Median date	604	945	757
+2 weeks	304	263	381
+4 weeks	76	121	85
SE	172		
Dunnett's *P* versus median-seeding date			
−4 weeks	<0.0001	<0.0001	<0.0001
−2 weeks	<0.0001	<0.0001	<0.0001
+2 weeks	<0.0001	0.009	0.265
+4 weeks	<0.0001	0.001	0.010
	Shorter, AL		
−4 weeks	1808	4750	4511
−2 weeks	2135	3827	3935
Median date	1223	1061	1958
+2 weeks	1321	359	805
+4 weeks	914	414	425
SE	332		
Dunnett's *P* versus median-seeding date			
−4 weeks	0.462	<0.0001	<0.0001
−2 weeks	0.117	<0.0001	<0.0001
+2 weeks	0.998	0.302	0.030
+4 weeks	0.884	0.373	0.002
	Jay, FL		
−4 weeks	NA	601	2123
−2 weeks	NA	468	979
Median date	NA	230	465

Cover crop seeding date	Growing season		
	2003–2004	2004–2005	2005–2006
	Clover biomass (kg ha^{-1})		
	Belle Mina, AL		
+2 weeks	NA	103	205
+4 weeks	NA	90	132
SE	86		
Dunnett's *P* versus median-seeding date			
−4 weeks	NA	0.011	<0.0001
−2 weeks	NA	0.164	<0.0001
+2 weeks	NA	0.683	0.113
+4 weeks	NA	0.605	0.026

Table 3. Clover biomass (kg ha^{-1}) by location and year as influenced by cover-crop seeding date, which were based on the 30-year average day of first frost at each location. Further seeding dates were either 2 or 4 weeks prior (−) or later (+) than that date. Data are averaged over termination dates.

Crimson clover dry biomass yield was significantly reduced by the delay in seeding date at all locations and years (**Table 3**).

In 2003–2004 at Belle Mina, crimson clover planted 4 and 2 weeks prior to the average 0°C date yielded 2257 and 831 kg ha^{-1} higher, respectively, than plots planted on the average 0°C date (604 kg ha^{-1}), and 2785 and 1359 kg ha^{-1} higher, respectively, than the latest planting date. Similar trends were observed in 2004–2005 and 2005–2006 except for one comparison. Belle Mina is the coldest of the three experiment locations with an average temperature of 10, 5.5, and 3.8°C during November, December, and January, respectively. These observations indicate that it is very important to plant a legume cover crop such as crimson clover early enough to get sufficient growth before cooler temperatures reduce growing degree days. Less than 400 kg ha^{-1} of biomass was produced when crimson clover was seeded 2 weeks after the average 0°C temperature at Belle Mina in any year. At Belle Mina in 2003–2004 and 2005–2006, clover biomass was maximized by waiting until 1 week prior to planting to terminate the cover crop gaining an additional 521 and 195 kg ha^{-1}, respectively, compared to terminating at the CES recommended 2 weeks prior to planting.

At Shorter, the variability in crimson clover biomass production among the years was very pronounced; biomass production was less in 2003 compared to 2004 and 2005. Significant reduction in crimson clover biomass production was observed with an advanced seeding date only in 2004 and 2005, as indicated by contrasts. If the seeding of crimson clover was delayed by 4 weeks compared to the earliest date, 3689 and 2553 kg ha^{-1} less biomass were produced in 2004 and 2005, respectively. No significant differences in crimson clover biomass production were, however, observed with early or delayed termination in 2004 and 2005 (**Table 4**).

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Cover crop seeding date	Growing season		
	2003–2004	**2004–2005**	**2005–2006**
	Clover biomass (kg ha^{-1})		
	Belle Mina, AL		
−1 week prior	1637	1015	1323
−2 week prior	1116	1364	1131
−3 week prior	832	1119	833
−4 week prior	639	977	617
SE	144		
Dunnett's *P* versus first termination date			
−1 week prior	<0.0001	0.991	<0.0001
−2 week prior	0.022	0.059	0.007
−3 week prior	0.550	0.729	0.431
	Shorter, AL		
−1 week prior	1860	2348	2827
−2 week prior	1315	2005	2385
−3 week prior	1691	1813	2389
−4 week prior	1054	2162	1706
SE	335		
Dunnett's *P* versus first termination date			
−1 week prior	0.187	0.956	0.039
−2 week prior	0.891	0.972	0.310
−3 week prior	0.360	0.781	0.306
	Jay, FL		
−1 week prior	NA	474	1144
−2 week prior	NA	217	945
−3 week prior	NA	201	588
−4 week prior	NA	300	446
SE	77		
Dunnett's *P* versus first termination date			
−1 week prior	NA	0.264	<0.0001
−2 week prior	NA	0.787	<0.0001
−3 week prior	NA	0.687	0.426

Table 4. Clover biomass (kg ha^{-1}) by location and year as influenced by cover-crop termination date, which were 4, 3, 2, and 1 week prior to corn planting. Termination dates were based on a 30-year average soil temperature. Data are averaged over seeding dates.

Dry biomass accumulation was maximized if crimson clover was allowed to grow until 1 week prior to corn planting compared in 2006.

At the southernmost location Jay, except the three-way interaction, all other main and interaction effects were significant for crimson clover biomass production. Significant differences among years were observed, with biomass production less in 2004–2005 compared to 2005–2006. In 2004–2005 and 2005–2006, the earliest planting date resulted in 601 and 2123, respectively. With every 2-week delay in seeding, the cover-crop biomass production was reduced by more than half in almost all comparisons (**Table 3**). Significantly high biomass was accumulated when crimson clover was terminated only a week or 2 prior to the corn planting in 2005–2006 compared with the earliest termination date (**Table 4**).

3.2. Weed biomass in corn

The three-way interaction (year by PD by KD) was not significant for any location. The interaction of termination date with year was significant for both Belle Mina and Shorter locations ($P \leq 0.04$). Interactions of seeding date with year as well as with termination date were not significant ($P \geq 0.11$). Years did not have a significant effect at any of the locations ($P \geq 0.12$). The effect of termination date ($P \leq 0.05$) and seeding date ($P = 0.09$) was significant at Belle Mina and Shorter only.

At Belle Mina, weed biomass was only 81 kg ha^{-1} in 2003/2004 growing season corresponding to crimson clover biomass of 2861 kg ha^{-1} when the cover crop was seeded 4 weeks prior to the average 0°C temperature (data not shown). Weed biomass increased with delay in cover-crop seeding date indicating that a greater amount of crimson clover residue produced by earlier seeding dates suppressed early-season weed biomass production in corn. However, contrasts indicate no significant reduction in weed biomass if crimson clover was planted 4 or 2 weeks after the average 0°C temperature. In the 2004–2005 growing season, weed biomass production was significantly reduced by seeding crimson clover 4 and 2 weeks prior to the average 0°C temperature; again, the higher biomass production resulted in less weed biomass. No significant differences in weed biomass production were observed if crimson clover was seeded on the average 0°C temperature or thereafter. In 2005/2006, seeding dates had no significant effect on weed biomass production. No significant effect of delayed termination on weed biomass production was observed in 2003–2004 and 2004/2005 growing seasons compared to the first termination date (4 weeks prior to average 0°C temperature). However, in 2005/2006 growing season, a significant reduction in weed biomass was observed with only a week's delay in crimson clover termination. This could be attributed to the increase in crimson clover biomass production with delayed termination, which in turn resulted in early season weed suppression.

At Shorter location, no significant increase or decrease in weed biomass production was observed with seeding of crimson clover earlier or later than the average 0°C temperature date. However, weed biomass production in general increased with delay in crimson clover seeding date; in 2003/2004 and 2005/2006 growing seasons, weed biomass ranged from 16 to 28 kg ha^{-1} for the first two crimson clover seeding dates, whereas the final seeding date plots averaged nearly 109 kg ha^{-1} weed biomass during both the growing seasons. The effect of termination dates was pronounced only in 2005/2006; significantly less weed biomass was produced if the termination was delayed by even a week (data not shown).

At Jay location, our southernmost location, no definite trend in weed biomass production was observed with earlier seeding or termination of the crimson clover (data not shown). This could be due to rapid decomposition of residue due to warmer temperatures and higher rainfall at this location compared to the northern locations.

3.3. Corn grain yield

Corn grain yield was not affected by crimson clover seeding and termination dates at Belle Mina. Though no statistically significant differences were observed, plots with the earliest seeding of the crimson clover yielded numerically highest at this location. At both Shorter and Belle Mina, significant differences in corn grain yield were observed across years (**Tables 5** and **6**).

Cover crop seeding date	Growing season		
	2003–2004	2004–2005	2005–2006
	Corn grain yield (kg ha^{-1})		
	Belle Mina, AL		
−4 weeks	10,471	9262	4646
−2 weeks	9474	8712	4686
Median date	9963	8684	5228
+2 weeks	10,054	8434	4607
+4 weeks	9344	8414	4831
SE	370		
Dunnett's *P* versus median-seeding date			
−4 weeks	0.501	0.386	0.380
−2 weeks	0.534	1.000	0.445
+2 weeks	0.998	0.919	0.324
+4 weeks	0.326	0.897	0.702
	Shorter, AL		
−4 weeks	11,986	7631	5703
−2 weeks	11,701	7701	5709
Median date	12,429	7333	5629
+2 weeks	11,325	7363	5840

Cover crop seeding date	Growing season		
	2003–2004	2004–2005	2005–2006
	Corn grain yield (kg ha^{-1})		
	Belle Mina, AL		
+4 weeks	11,533	7864	5296
SE	379		
Dunnett's *P* versus median-seeding date			
−4 weeks	0.592	0.847	0.999
−2 weeks	0.175	0.731	0.999
+2 weeks	0.015	1.000	0.949
+4 weeks	0.065	0.431	0.792
	Jay, FL		
−4 weeks	NA	5582	13520
−2 weeks	NA	6259	14328
Median date	NA	5236	12982
+2 weeks	NA	6318	12083
+4 weeks	NA	6432	12694
SE	945		
Dunnett's *P* versus median-seeding date			
−4 weeks	NA	0.972	0.878
−2 weeks	NA	0.446	0.216
+2 weeks	NA	0.397	0.560
+4 weeks	NA	0.310	0.986

Table 5. Corn grain yield (kg ha^{-1}) by location and year as influenced by cover-crop seeding date, which were based on the 30-year average day of first frost at each location. Further seeding dates were either 2 or 4 week prior (−) or later (+) than that date. Data are averaged over termination dates.

Grain yield decreased with the progression of the experiment. Weather conditions were different among the years, 2004 being a normal rainfall year whereas in 2005 majority of the rainfall was received in July at Belle Mina (6 in.) and Shorter (8.5 in.); 2006 was a drought year at both the locations throughout the summer. These differences in rainfall events can likely explain some of the yield differences observed among years at both the locations. Corn is most sensitive to water stress during silking or flowering, and pollination stages of growth and drought stress during this period can result in poor grain development and yield losses.

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Cover crop seeding date	Growing season		
	2003–2004	**2004–2005**	**2005–2006**
	Corn grain yield (kg ha⁻¹)		
	Belle Mina, AL		
−1 week prior	9880	8389	4946
−2 week prior	9707	8392	5201
−3 week prior	10,117	9196	4842
−4 week prior	9741	8827	4209
SE	425		
Dunnett's *P* versus first termination date			
−1 week prior	0.988	0.745	0.370
−2 week prior	1.000	0.748	0.155
−3 week prior	0.818	0.827	0.491
	Shorter, AL		
−1 week prior	10,916	7579	4382
−2 week prior	12,094	7424	5949
−3 week prior	12,453	8225	6933
−4 week prior	11,717	7085	5278
SE	500		
Dunnett's *P* versus first termination date			
−1 week prior	0.482	0.797	0.392
−2 week prior	0.895	0.920	0.616
−3 week prior	0.547	0.209	0.037
	Jay, FL		
−1 week prior	NA	5615	12,565
−2 week prior	NA	5867	12,872
−3 week prior	NA	6225	13,468
−4 week prior	NA	6155	13,581
SE	784		
Dunnett's *P* versus first termination date			
−1 week prior	NA	0.926	0.673
−2 week prior	NA	0.987	0.853
−3 week prior	NA	1.000	0.999

Table 6. Corn grain yield (kg ha^{-1}) by location and year as influenced by cover-crop termination date, which were 4, 3, 2, and 1 week prior to corn planting. Termination dates were based on 30-year average soil temperature. Data are averaged over seeding dates.

3.4. Cereal rye cover-crop biomass

When analyzed by location, the three-way interaction was not significant at Belle Mina. The interaction of experiment years with seeding date was significant. The main effect of seeding date, termination date, and year was also significant. In general, rye biomass production declined with every 2-week delay in seeding the cover crop (**Table 7**).

Cover crop seeding date	**Growing season**		
	2003–2004	**2004–2005**	**2005–2006**
	Rye biomass (kg ha^{-1})		
	Belle Mina, AL		
−4 weeks	8878	5062	6396
−2 weeks	7852	5232	4078
Median date	6584	2863	2479
+2 weeks	4500	2149	3085
+4 weeks	2649	913	2066
SE	611		
Dunnett's *P* versus median-seeding date			
−4 weeks	0.004	0.006	<0.0001
−2 weeks	0.200	0.003	0.070
+2 weeks	0.010	0.701	0.788
+4 weeks	<0.0001	0.018	0.933
	Shorter, AL		
−4 weeks	5566	5331	6177
−2 weeks	5053	4893	6269
Median date	4344	2610	5372
+2 weeks	2779	518	2553
+4 weeks	1276	213	1370
SE	356		
Dunnett's *P* versus median-seeding date			
−4 weeks	0.020	<0.0001	0.198
−2 weeks	0.298	<0.0001	0.128
+2 weeks	0.002	<0.0001	<0.0001
+4 weeks	<0.0001	<0.0001	<0.0001
	Jay, FL		
−4 weeks	NA	3605	5006

Cover crop seeding date	Growing season		
	2003–2004	2004–2005	2005–2006
	Rye biomass (kg ha^{-1})		
	Belle Mina, AL		
−2 weeks	NA	2982	5341
Median date	NA	2559	4695
+2 weeks	NA	1687	3349
+4 weeks	NA	1545	2706
SE	253		
Dunnett's *P* versus median-seeding date			
−4 weeks	NA	0.005	0.727
−2 weeks	NA	0.480	0.142
+2 weeks	NA	0.026	<0.0001
+4 weeks	NA	0.007	<0.0001

Table 7. Rye biomass (kg ha^{-1}) by location and year as influenced by cover-crop seeding date, which were based on the 30-year average day of first frost at each location. Further seeding dates were either 2 or 4 week prior (−) or later (+) than that date. Data are averaged over termination dates.

Delaying cereal rye planting 4 weeks significantly lowered the rye biomass yield in all the years. Biomass production was in general less at this location in 2003/2004 and 2004/2005 growing seasons. Earlier termination of rye also significantly reduced biomass. Biomass production in all the years was increased if rye was terminated a week or 2 prior to cotton planting (**Table 7**). However, no significant differences in biomass production were observed if rye was terminated 3 or 4 weeks prior to cotton planting.

At Shorter location, all the interactions and main effects were significant for rye biomass production. Delayed seeding of rye significantly reduced dry biomass accumulation (**Table 7**). In 2004–2005, no significant differences in rye dry biomass accumulation occurred if rye was seeded on the third seeding date or later. Significant planting and termination date interaction were also observed at this location. The maximum biomass production was 8523 kg ha^{-1} in year 2006 when rye was planted 2 weeks before the 0°C temperature date and terminated a week prior to cash crop planting. The least biomass produced at Shorter was 140 kg ha^{-1} when covers were planted on the last planting date and terminated on the first planting date (data not shown).

At our southernmost location Jay, all two-way interactions and main effects were significant. Rye biomass production was better in year 2006 compared to year 2005. As observed at other two locations, delayed seeding or earlier termination reduced dry biomass accumulation by rye (data not shown). The maximum observed rye biomass at this location was 7468 kg ha^{-1} produced when rye was planted 4 weeks prior to the average 0°C temperature and terminated 2 weeks before the seeding of cotton.

3.5. Weed biomass in cotton

Dry weights of weeds were more in cotton compared to corn at all site years due to the earlier sampling time in corn when fewer summer annual weeds had emerged. The cover-crop biomass observed at each location was reflected in the subsequent results observed for weed control. The three-way interaction was not significant at any of the locations. The interaction of year with seeding and termination date was significant at all the locations except at Jay. The seeding by termination date interaction was not significant at any location.

In general, there was an increase in weed biomass in cotton with earlier termination and late planting of the rye cover crop. At Belle Mina, numerically less weed dry biomass was observed corresponding to a high rye cover-crop residue (**Table 8**).

Cover crop seeding date	Growing season		
	2003–2004	2004–2005	2005–2006
	Belle Mina, AL		
−4 weeks	31	133	214
−2 weeks	54	182	455
Median date	406	275	945
+2 weeks	250	297	368
+4 weeks	345	478	664
SE	102		
Dunnett's *P* versus median-seeding date			
−4 weeks	0.010	0.601	<0.0001
−2 weeks	0.017	0.865	<0.0001
+2 weeks	0.519	0.999	<0.0001
+4 weeks	0.965	0.283	0.077
	Shorter, AL		
−4 weeks	316	289	62
−2 weeks	318	381	53
Median date	470	440	58
+2 weeks	474	467	81
+4 weeks	970	378	88
SE	101		
Dunnett's *P* versus median-seeding date			
−4 weeks	0.425	0.438	1.000
−2 weeks	0.437	0.953	1.000
+2 weeks	1.000	0.997	0.998

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Cover crop seeding date	Growing season		
	2003–2004	2004–2005	2005–2006
	Belle Mina, AL		
+4 weeks	<0.0001	0.944	0.996
	Jay, FL		
−4 weeks	NA	48	53
−2 weeks	NA	50	48
Median date	NA	80	88
+2 weeks	NA	53	85
+4 weeks	NA	87	65
SE	14		
Dunnett's *P* versus median-seeding date			
−4 weeks	NA	0.338	0.259
−2 weeks	NA	0.390	0.160
+2 weeks	NA	0.495	1.000
+4 weeks	NA	0.993	0.626

Table 8. Weed dry biomass (kg ha^{-1}) in cotton by location and year as influenced by cover-crop seeding date, which were based on the 30-year average day of first frost at each location. Further seeding dates were either 2 or 4 week prior (−) or later (+) than that date. Data are averaged over termination dates.

Weed biomass averaged only 31 kg ha^{-1} corresponding to rye biomass of 8878 kg ha^{-1} in plots seeded with rye 4 weeks before the average 0°C temperature in 2003. No significant differences in weed biomass production were observed in 2004 among different seeding dates. In 2005, weed biomass was maximum in plots seeded with rye on the median seeding date averaging 945 kg ha^{-1} and less in the later-seeded plots. This is likely due to less rye biomass (2479 kg ha^{-1}) production in these plots. No significant differences in the weed biomass production were observed among the termination dates in 2003 and 2004 (data not shown). In 2005, however, the plots terminated on the final termination date had the least weed biomass.

At Shorter, no significant differences in weed biomass production were observed among seeding dates in 2004 and 2005 (**Table 8**). The maximum observed weed biomass was 970 kg ha^{-1} corresponding to rye biomass of 1276 kg ha^{-1} in 2005, when rye was seeded 4 weeks after 0°C freeze. The effect of termination dates on weed biomass production was significant in 2003; weed biomass decreased with delay in rye cover-crop termination date (**Table 9**).

At Jay location, weed biomass production was less compared to other two locations. No differences in weed biomass production were observed among seeding dates at this location (**Table 8**). The delay in rye termination decreased weed biomass production. In 2004, however, plots terminated a week before cotton planting had more weed biomass than plots terminated 2 and 3 weeks prior to cotton planting (**Table 9**).

Cover crop seeding date	Growing season		
	2003–2004	2004–2005	2005–2006
	Belle Mina, AL		
−1 week prior	287	201	272
−2 week prior	153	150	424
−3 week prior	165	397	755
−4 week prior	265	345	665
SE	116		
Dunnett's *P* versus first termination date			
−1 week prior	0.998	0.678	0.035
−2 week prior	0.815	0.456	0.288
−3 week prior	0.858	0.975	0.890
	Shorter, AL		
−1 week prior	104	141	17
−2 week prior	341	389	74
−3 week prior	532	430	64
−4 week prior	1061	603	118
SE	24		
Dunnett's *P* versus first termination date			
−1 week prior	<0.0001	0.001	0.771
−2 week prior	<0.0001	0.228	0.973
−3 week prior	<0.0001	0.392	0.952
	Jay, FL		
−1 week prior	NA	64	20
−2 week prior	NA	51	51
−3 week prior	NA	48	83
−4 week prior	NA	91	118
SE	77		
Dunnett's *P* versus first termination date			
−1 week prior	NA	0.322	<0.0001
−2 week prior	NA	0.070	0.001
−3 week prior	NA	0.052	0.125

Table 9. Weed dry biomass (kg ha^{-1}) in cotton by location and year as influenced by cover-crop termination date, which were 4, 3, 2, and 1 week prior to cotton planting. Termination dates were based on 30-year average soil temperature. Data are averaged over seeding dates.

The decrease in dry weed biomass with corresponding increase in rye biomass is in accordance with the previous studies. Teasdale [29] concluded that weed biomass production is correlated with the cover-crop biomass. Smeda and Weller [30] also reported an increase in residual weed suppression by no-till-rye residues when the time between cover-crop desiccation and crop planting was reduced, probably due to allelopathic effects.

3.6. Cotton seed lint yield

There were differences in cotton seed lint yield among the years likely due to weather conditions but cotton lint yield was not affected by the rye cover-crop seeding and termination dates at any site year (data not shown). Cotton seed lint yield averaged 3784 kg ha^{-1} in 2003, 4269 kg ha^{-1} in 2004 to 2252 kg ha^{-1} in 2005 at Belle Mina. At Shorter, the maximum seed cotton lint yield was obtained in the year 2004 averaging 4065 kg ha^{-1}. At Jay, yield was less in 2005 but was comparable to other two locations in 2005. Thus, cover-crop biomass did not interfere with attaining yields, and it reflects current knowledge on residue management at planting.

4. Conclusions

In this study, early planting of the cover crop with its later termination for subsequent corn and cotton plantings has increased cover-crop biomass accumulation compared to the late planting and early termination of the cover crop. Increased cover-crop biomass suppressed subsequent total weed dry biomass. These findings indicate that high-residue cover crops have predictable potential for suppressing early-season weeds in corn and cotton. If farmers are utilizing glyphosate-resistant corn-cotton rotation systems, these findings hold particular importance with current glyphosate-resistant weed-control issues. Because corn and cotton yields were not negatively impacted, we can conclude that high residue obtained by planting crimson clover or rye cover crops timely and terminating either a week or 2 prior to cash crop planting is feasible. Ideal management will result in maximum cover-crop biomass production and subsequent weed suppression.

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