The *Journal of Cotton Science 23:131–140 (2019)*
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WEED SCIENCE

Impact of Cereal Rye Seeding Rate and Planting Method on Weed Control in Cotton

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ABSTRACT

Costs related to herbicide use have increased greatly due to evolution and proliferation of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri* S.). The use of cover crops in conservation tillage offers advantages such as weed suppression through physical and allelopathic effects. A field study was initiated in fall 2013 and 2014 in Fayetteville, AR to determine the impact of cereal rye (*Secale cereal* L.) seeding rate and planting method on weed control and cotton (*Gossypium hirsutum* L.) yield. Cereal rye seeding rates were 56, 112, and 168 kg ha^{-1} in absence or presence of a herbicide program. Planting methods consisted of drilled and broadcast. No differences were observed between planting methods in any parameter evaluated. In both years, cereal rye biomass production increased as seeding rate increased. When herbicides were not applied, cereal rye at 56 kg ha^{-1} provided the least weed control. Cereal rye at 112 and 168 kg ha^{-1} provided comparable levels of Palmer amaranth control. At 8 wk after cotton planting, all plots treated with a commonly used herbicide program had 99% or greater grass control, regardless of the seeding rate. Yields from plots with a standard herbicide program were greater than from plots without herbicide. Yield improvement was observed due to use of cereal cover crop compared to no cover crop in 2014, whereas no differences were observed in 2015.

Cotton growers today struggle with weed management mainly because of herbicide-resistant weeds (Sosnoskie and Culpepper, 2014). The recent confirmation of protoporphyrinogen oxidase (PPO)-resistant Palmer amaranth (*Amaranthus palmeri* S.) in the Mid-South region of the U.S. along with widespread glyphosate-resistant (GR) Palmer amaranth have increased concerns about sustainability of weed management in cotton production systems (Salas et al., 2016). Relying only on herbicides, especially one mode of action, is no longer a sustainable option for controlling Palmer amaranth. Hence, integrating herbicide programs with cultural practices is necessary to preserve existing technologies and herbicides. The use of cover crops in conservation tillage is of interest to growers who intend to capitalize on federal conservation payments and incorporate sustainable practices into agricultural systems. Weed suppression as well as nitrogen credits are two of the most desirable short-term benefits realized by farmers when using cover crops in row crops (Snapp et al., 2005). Long-term effects, such as increased organic matter, reduced soil erosion, and carbon sequestration, are also significant; however, they are often overlooked because these benefits are cumulative and difficult to measure (Mazzoncini et al., 2011; Sainju et al., 2002).

Extensive research has been conducted to evaluate the impact of cover crops on weed control in several crops (Mirsky et al., 2011; Snapp, 2005). Results measuring the level of weed suppression offered by cover crops are variable (Reddy, 2001). However, most research conducted on this subject indicated that cover crops have the potential to suppress weeds and aid most weed control programs. Cover crops can provide weed suppression through several means: cover crop residues can act as a physical barrier to weed seed germination and weed growth, limit the amount of light transmitted to the soil, lead to production of allelochemical substances that are toxic to weed seed, and narrow the temperature amplitude that can reduce weed seed germination (Teasdale and Mohler, 1993).

Cereal rye (*Secale cereal* L.) is an important cover crop in a large array of cropping systems because it can contribute to organic matter, reduce soil erosion, suppress weeds, and enhance water infiltration and conservation (Dabney et al., 2001; Korres

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and Norsworthy, 2015; Putman et al., 1983). Cereal rye has been used widely because it can be grown on soils having low fertility and low pH, and it has high frost and drought resistance compared to other cereal cover crops such as wheat (*Triticum aestivum* L.) and oats (*Avena sativa* L.) (Bushuk, 2001; Clark, 2008; Fowler et al., 1999). Cereal rye also can germinate in untilled soil as well as at many soil moisture and soil temperature levels (Blackshaw, 1991).

When using a cover crop to achieve weed suppression, maximum biomass production is preferred because there is a positive correlation between biomass production and weed suppression (Teasdale and Mohler, 2000). Based on the available literature, cereal rye can produce a wide range of biomass. Price et al. (2012) reported that in Tennessee, cereal rye biomass production ranged from 4,177 to 10,886 kg ha^{-1}. In South Carolina, Bauer and Reeves (1999) reported cereal rye biomass production of 2,390 to 4,130 kg ha^{-1}, and in Arkansas, Norsworthy et al. (2011) reported cereal rye biomass production of 7,880 to 8,460 kg ha^{-1}. Among all fall-seeded cereal cover crops, cereal rye appears to have the greatest potential biomass production (Bauer and Reeves, 1999; Prabhakara et al., 2015). It is also important that the cover crop residue has thorough soil coverage to better suppress weed emergence. Nelson et al. (1991) stated that among several cover crops, cereal rye provided the greatest soil coverage ranging from 65 to 93% at vegetable planting.

Increasing cover crop density can improve biomass production and planting uniformity, which can enhance the weed suppression capacity of the cover crop residue. In California, Boyd et al. (2009) found that population density increased linearly as the seeding rate of cereal rye (90, 180, and 270 kg ha^{-1}) increased. They also evaluated cereal rye biomass production at three different harvest dates over a two year study.At first harvest on 1 December 2003 and 29 November 2004, biomass production increased as the seeding rate increased, resulting in a significant decrease in weed biomass production at the highest seeding rate. Conversely, no differences were observed among seeding rates on the last harvest (17 February 2004 and 1 March 2005) with cereal rye biomass production both years producing an average biomass of 7,300 kg ha^{-1}.

Akemo et al. (2000) investigated the impact of cereal rye seeding rate (29, 57, and 114 kg ha^{-1}) on biomass production and weed control in Ohio. Results also showed increased biomass production of cereal rye with higher seeding rate, resulting in weed biomass reduction.

Planting method also can affect biomass production and ground coverage of cover crops. Broadcast (commonly performed using airplanes or spreaders implements), no-till drill, and conventional tillage with drill seeding are commonly used methods to establish cover crops. Reports on the effectiveness of these planting methods have shown that drill seeding appears to provide superior cereal cover crop establishment due to the lack of soil coverage when broadcasting. Keisling et al. (1997) reported that using a broadcast planting method reduced wheat emergence compared to a drill planting method. However, Wilson et al. (2013) found that broadcasting cereal rye can be effective if a rainfall event occurs within a week of broadcast seeding.

Cereal rye has become an important option for weed suppression in conservation tillage in cotton production (McCarty et al., 2003; Monks and Patterson, 1996). Although there are many reports on weed suppression by cereal rye residue, not many have investigated the effect of seeding rate and planting method on weed management and yield in cotton. Increasing the cereal rye biomass production through increased seeding rate should provide higher weed suppression. In addition, the level of weed suppression can differ by planting method. Hence, research was conducted to investigate the impact of cereal rye seeding rate and planting method on weed control and cotton yield.

MATERIAL AND METHODS

A field experiment was conducted on separate sites beginning in fall 2013 and 2014 at the University of Arkansas Research and Extension Center in Fayetteville, AR. The soil series was a Leaf silt loam (fine, mixed, active, thermic Typic Albaquults) with 34% sand, 53% silt, 13% clay, 1.1% organic matter, and a pH of 6.9. The experiment was conducted under overhead irrigation system. The amounts of rainfall and irrigation supplied during the growing season are provided in Table 1. The experimental design was a two-factor factorial, randomized complete block with a strip-plot structure. One factor was the four cereal rye seeding rates (0, 56, 112, and 168 kg ha^{-1}) and the other was the herbicide program (presence and absence of a standard herbicide program) The strip-plot factor was drill and broadcast seeding of cereal rye. Herbicide treatments were applied using a CO_2-pressurized backpack sprayer equipped with a handheld boom that contained AIXR 110015 flat-fan nozzles

(TeeJet Technologies, Springfield, IL). Nozzles were spaced 50-cm apart and calibrated to deliver 140 L ha^{-1} at 276 kPa. For the post-direct application, herbicides were applied with CO_2-pressurized backpack sprayer equipped with a handheld boom that contained even-fan nozzle. Herbicides used in the program are listed in Table 2. Four replications were used with plot sizes of 3.6 by 9.9 m. Cereal rye was sown on 8 October 2013 and 12 September 2014. For the drill-seeded portion of the plot, an Almaco Light-Duty Grain Drill with a single drop cone (Almaco Headquarters, Nevada, IA) was used, and for the broadcast seeded portion, the cereal rye was distributed by hand over the broadcast portion of the main plot. Prior to cereal rye sowing, the field was fertilized with 34 kg ha^{-1} of N, P, and K, and tilled to an approximate 15-cm depth using a disk harrow followed by two passes of a field cultivator at a 5-cm depth to allow for a smooth seedbed.

The entire experiment was desiccated 21 d prior to cotton planting with glyphosate (potassium salt) and dicamba (diglycoamine salt) at 870 g ae ha^{-1} and 280 g ae ha^{-1}, respectively, followed by an application of paraquat at 480 g ai ha^{-1} 1 d prior to planting. In addition, N was applied at 34 kg ha^{-1} at cotton planting followed by another application of 43 kg ha^{-1} at 45 d after planting. Aboveground cover crop biomass was sampled from two random 1-m^2 quadrats in each main plot at planting. Biomass of desiccated natural vegetation was also collected in the no cover crop plots. Cotton (*Gossypium hirsutum* L.) 'ST 4946 GLB2' (Stoneville, Bayer Research Triangle Park, NC) was planted with a four-row planter (John Deere 6403, Deere and Company, Moline, IL) equipped with double-disk openers and coulters set to a 91-cm row spacing at a seeding rate of 123,000 seeds ha^{-1}. Cotton was planted on 23 May 2014 and 3 June 2015.

Table 1. Monthly rainfall plus irrigation data for season 2013/2014 and 2014/2015

Year		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
		mm												
2013/2014[y]	Rain[z]	33	58	89	7	3	97	87	137	104	35	65	91	184
	Irrig[z]	0	0	0	0	0	0	0	26	0	91	26	0	0
2014/2015[x]	Rain	184	78	75	14	1	82	81	167	172	268	67	58	48
	Irrig	0	0	0	0	0	0	0	0	0	0	65	13	0

[z] Abbreviations: Rain, rainfall; Irrig, irrigation

[y] Planting date: 23 May 2014

[x] Planting date: 3 June 2015

Table 2. Source of all herbicides used in the experiment to evaluate the impact of cereal rye on weed control in cotton

Common name	Trade name	Formulation[z]	Rate	Application timing[z]	Manufacturer	Location
			g ai or ae ha^{-1}			
Glyphosate	Roundup PowerMax	SL	870	3 WBP	Monsanto Company	St. Louis, MO
Dicamba	Clarity	SL	280	3 WBP	BASF Corporation	Research Triangle Park, NC
Paraquat	Gramoxone	SL	700	1 DBP	Syngenta Crop Protection	Greensboro, NC
Fluometuron	Cotoran	FL	1120	PRE	Makhteshim Agan of North America	Raleigh, NC
Glufosinate	Liberty	SL	595	2 and 4 WAP	Bayer CropScience	Research Triangle Park, NC
S-metolachlor	Dual Magnum	EC	1070	2 and 4 WAP	Syngenta Crop Protection	Greensboro, NC
Flumioxazin	Valor[y]	WDG	71	8 WAP	Valent	Walnut Creek, CA
Monosodium acid methanearsonate	MSMA[y]	SL	2240	8 WAP	Drexel Chemical Company	Memphis, TN

[z] Abbreviations: SL, soluble liquid; EC, emulsifiable concentrate; WDG, water dispersible granule; WBP, weeks before planting; DBP, day before planting; PRE, preemergence; WAP, weeks after planting.

[y] Post-directed application

After cotton emergence, cotton stand was assessed on 2 m of row randomly selected within the plot. Palmer amaranth density was measured in two 0.5-m^2 quadrats marked with flags randomly placed within the drill and broadcast planting side of each plot. Palmer amaranth emergence was monitored in the two quadrants every 2 wk until 8 wk after planting (WAP). Palmer amaranth seedlings were manually removed after each emergence assessment, and herbicide treatments were applied immediately after emergence assessment (see Table 2 for herbicide treatment information). Control of Palmer amaranth, broadleaf signalgrass [*Urochloa platyphylla* (Nash) RD Webster], and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] was visually evaluated 2, 4, 6, and 8 WAP. Seed cotton was hand-harvested from 6.6 m of the center rows in each subplot. Seed cotton yields were determined by weighing the seed cotton and converting the weights to kg ha^{-1}.

Data were subjected to ANOVA using the MIXED procedure in JMP 12 PRO (JMP, Version 12. SAS Institute Inc., Cary, NC). The significance of main effects and potential interactions were tested for biomass production, cotton stand, grass control (broadleaf signalgrass and barnyardgrass), cumulative Palmer amaranth emergence, and seed cotton yield at α = 0.05. Palmer amaranth emergence data were also fit with a repeated measures model using the MIXED procedure in JMP 12 PRO to describe the number of individuals emerging during an emergence period. A first-order autoregressive (AR[1]) covariance structure was assumed because observations closer in time are expected to have a higher correlation than treatments further apart in time. Hence, Palmer amaranth emergence was analyzed by cereal rye seeding rate as well as by assessment timing and means were separated by Fisher's protected LSD (α = 0.05).

RESULTS AND DISCUSSION

Biomass. No differences were observed in planting method for cereal rye biomass production in all seeding rates evaluated. Hence, the biomass production was averaged over drill and broadcast planting method (data not shown). The effect of seeding rate on biomass production interacted with year (p < 0.0012), with biomass production in 2014 being greater than 2015 (Table 3). In both years, cereal biomass was greater as the seeding rate increased. These results agree with those of Boyd et al. (2009) where they reported biomass production from cereal rye at seeding rates of 90, 180, and 270 kg ha^{-1} increased linearly as the seeding rate increased. The nonsignificant effect of planting method on biomass production is similar to that observed by Abbas et al. (2009) who observed no differences in biomass production between drill- and broadcast-seeded wheat.

Table 3. Biomass production and cotton density as function of cereal rye seeding rates in 2014 and 2015

Seeding rate	Biomass		Cotton stand count	
	2014	2015	2014	2015
kg ha^{-1}	--------- kg ha^{-1} ---------		thousand plants ha^{-1}	
0	840[z]	690[z]	113	116
56	3,060	2,460	104	113
112	4,000	3,310	96	103
168	4,460	3,620	94	98
LSD (0.05)	390	290	7	5

[z] Biomass of natural vegetation occurred in the field.

Cereal rye biomass ranged from 3,060 to 4,460 kg ha^{-1} and 2,460 to 3,620 kg ha^{-1} in 2014 and 2015, respectively (Table 3). These results sharply contrast with results observed at Marianna, AR by Norsworthy et al. (2011), where there was an average biomass production of 8,170 kg ha^{-1} of cereal rye. Such discrepancy in biomass production could be due to differences in environmental conditions in Fayetteville and Marianna as well as cereal rye management. The performance of a winter cover crop is difficult to predict because a variety of factors, including cover crop cultivar, soil properties, and growing conditions, can interact and influence the growth of cover crops (Bushuk, 2001). Analysis of the growing degree days for both years showed that 2014 to 2015 had more growing degrees units (GDU) than 2013 to 2014 (Fig. 1). However, the amount of GDU in both years should have been sufficient for maximum biomass production (Mirsky et al., 2011).

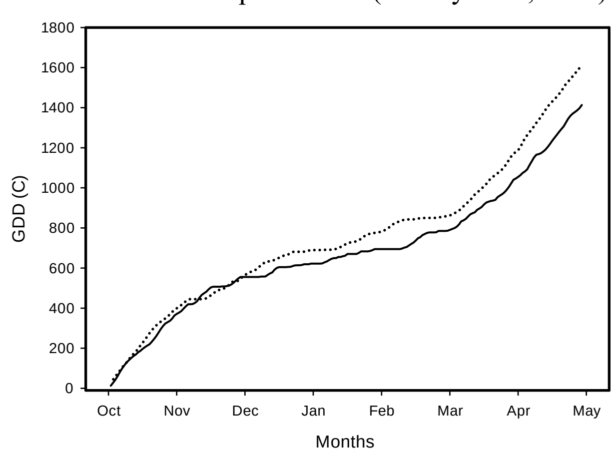

Figure 1. Cumulative growing degrees day (GDD) data from 2013-2014 (solid line) and 2014-2015 (dotted line). Temperature base of 0°C.

Cotton Density. Years are presented separately because of a significant year-by-seeding rate interaction (Table 3). The interaction of planting method by cereal rye seeding rate was not significant for cotton density, but the main effect of seeding rate was significant ($p < 0.0344$). Hence, cotton density was averaged over drill and broadcast planting methods.

All seeding rates decreased cotton density relative to the no cover crop treatment in 2014. The 56-kg ha^{-1} cereal rye seeding rate was the least detrimental, with 8% cotton stand reduction. Both the 112- and 168-kg ha^{-1} cereal rye seeding rates provided the highest cotton density at 15 and 17%, respectively (Table 4). In 2015, the 56-kg ha^{-1} cereal rye seeding rate did not show any significant negative effect compared to the no cover crop treatment. However, cereal rye at 112 and 168 kg ha^{-1} reduced the cotton stand by 11 and 14%, respectively. The slight improvement in cotton density in the cover crop plots in 2015 is likely due to the lower amount of biomass present at planting, which is similar to findings in other research (Kornecki et al., 2005). A more appropriate cotton planting method to better plant into standing cereal rye might have improved cotton stands because others have observed that it is possible to plant cotton into greater amounts of cereal rye biomass than present in this research without a negative effect on crop emergence (Mirsky et al., 2013; Raimbult et al., 1990).

Table 4. The main effect of cereal rye seeding rate on Palmer amaranth emergence in 2014 and 2015, and the main effect of assessment timing on Palmer amaranth emergence in absence of herbicide application[z]

Seeding rate	Density		Assessment timing[w]	Density
	2014	2015		
kg ha^{-1} [y]	------- plants m^{-2} -------		weeks after planting	plants m^{-2}
0	5.4 (0)[x]	4.3 (0)	0 – 2	1.6
56	2.8 (48)	2.9 (36)	2 – 4	3.3
112	1.6 (70)	1.8 (58)	4 – 6	3.1
168	1.1 (80)	1.1 (74)	6 – 8	2.4
LSD (0.05)	1.3	1.4		1.1

[z] All means within a year can be compared using Fisher's protected LSD at $\alpha \leq 0.05$.

[y] Years presented separately due to the interaction of seeding rate and year.

[x] Numbers in parentheses represent the percentage reduction in total Palmer amaranth emergence relative to the no cover crop treatment without herbicide.

[w] Emergence was averaged over years.

Palmer Amaranth Emergence. Similar to cotton density, there was no effect of planting method on Palmer amaranth emergence in both years, and the effect of seeding rate on Palmer amaranth density interacted with year. However, the effect of assessment timing on Palmer amaranth density did not interact with year; hence, data were averaged over 2014 and 2015 (Table 4).

All seeding rates decreased Palmer amaranth emergence over the four assessment timings compared to the no cover crop treatment (Table 4). However, cereal rye seeded at 168 kg ha^{-1} was superior to 56 kg ha^{-1} in suppressing Palmer amaranth emergence. In 2015 over the four assessment timings, the 56-kg ha^{-1} seeding rate did not differ from the no cover crop treatment, and emergence from the 112- and 168-kg ha^{-1} seeding rates were 58 and 74% lower than the no cover crop.

Suppression of Palmer amaranth emergence by the cereal cover crop was most effective at the earliest evaluations. Averaged over seeding rate, Palmer amaranth emergence at the first assessment timing was lower than second and third assessment timings (Table 4). The 2 to 4 and 4 to 6 WAP period allowed the highest Palmer amaranth emergence with 3.3 and 3.1 plants m^{-2}, respectively. These results agree with other reports that convey cover crops are most effective in suppressing weeds early in the growing season. Reddy (2001) reported that browntop millet (*Urochloa ramosa* L.) suppression provided by cereal rye in soybean at 3 WAP averaged 77%, but by 6 WAP control had declined to 62%.

The effect of cereal rye seeding rate in combination with herbicide application on total Palmer amaranth emergence is described in Table 5. In 2014, the seeding rate of 112 kg ha^{-1} did not show differences in Palmer amaranth emergence between plots with and without herbicide application. This was an exception because in all the remaining seeding rate treatments the combination of a cereal rye cover crop with a herbicide program resulted in lower Palmer amaranth emergence compared to plots without herbicide application. The same effect was observed in 2015 within each cereal rye seeding rate where the herbicide application proved to be beneficial to suppression of Palmer amaranth emergence (Table 5). These results support the concept that the utilization of cover crops ought to be performed with a herbicide program. Hence, one of purpose of using cover crops is to diminish the weed density during growing season to decrease herbicide selection pressure on weeds.

Table 5. Total Palmer amaranth emergence as a function of seeding rate and herbicide application in 2014 and 2015[z,y]

Seeding rate	Total Palmer amaranth emergence			
	2014 Herbicide application		2015 Herbicide application	
	Yes	No	Yes	No
kg ha^{-1}	plants m^{-2}			
0	2.5 (88)[x]	21.7 (0)	2.3 (87)	17.3 (0)
56	2.9 (87)	11.2 (48)	0.5 (97)	9.2 (47)
112	2.4 (89)	5.6 (74)	0.9 (95)	7.3 (58)
168	1.3 (94)	5.9 (73)	0.5 (97)	6.0 (65)
LSD	3.7		2.6	

[z] All means within a year can be compared using Fisher's protected LSD at $\alpha \leq 0.05$.

[y] See Table 2 for specific herbicides, rates, and timings associated with each designation.

[x] Numbers in parentheses represent the percentage reduction in total Palmer amaranth emergence relative to the no cover crop treatment without herbicide.

Cumulative Palmer Amaranth Emergence. In 2014, cereal rye residue from all seeding rates reduced Palmer amaranth emergence throughout the season (Fig. 2). At 2 WAP cotton, cereal rye seeded at 56, 112, and 168 kg ha^{-1} decreased Palmer amaranth emergence by 76, 86, and 90% compared to no cover crop. The highest Palmer amaranth emergence in the no cover crop plots occurred between 2 and 4 WAP averaging 8.8 plants m^{-2}. During this period, cereal rye plots at 56-, 112-, and 168-kg ha^{-1} seeding rate reduced Palmer amaranth emergence by 49, 74, and 91%, respectively. After all assessments, cumulative Palmer amaranth emergence in the no cover crop plots was 21.7 plants m^{-2}. The greatest Palmer amaranth emergence reduction occurred in the 112- and 168-kg ha^{-1} seeding rates (74 and 73%, respectively) compared to no cover crop. The reduction provided by 56-kg ha^{-1} seeding rate was lower than the 112 and 168 kg ha^{-1} with 48% reduction in Palmer amaranth emergence. Similar results were obtained by DeVore et al. (2012) where cereal rye reduced Palmer amaranth emergence by 74% at 3 WAP, and cereal rye residue reduced Palmer amaranth emergence by 67% at 12 WAP.

In 2015, all the seeding rates reduced Palmer amaranth emergence compared to no cover crop up to 8 WAP (Fig. 3). At first assessment, the 56-kg ha^{-1} seeding rate was not as effective as 112 and 168 kg ha^{-1}. Reductions of Palmer amaranth emergence at the 112- and 168-kg ha^{-1} seeding rates were 80 and 93%, respectively, compared to no cover crop. At 8 WAP, cumulative Palmer amaranth emergence showed that tseeding rates of 56, 112, and 168 kg ha^{-1} reduced Palmer amaranth emergence by 47, 58, and 65%, respectively. The inferior Palmer amaranth suppression in 2015 is attributed to the overall lower biomass production of cereal rye. According to Teasdale and Mohler (2000), the success of weed suppression by cover crops is directly related to the amount of biomass produced, because higher quantities of residue would reduce the ability of weed seedlings to grow through the mulch.

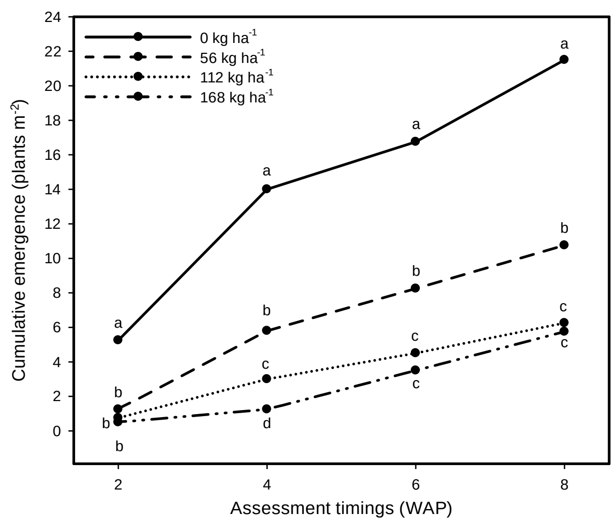

Figure 2. Cumulative Palmer amaranth emergence in the no herbicide plots as a function of cereal rye seeding rate in 2014. Means with the same letter within each assessment timings are not significantly different according to Fisher's protected LSD (α = 0.05). Abbreviations: WAP, weeks after planting.

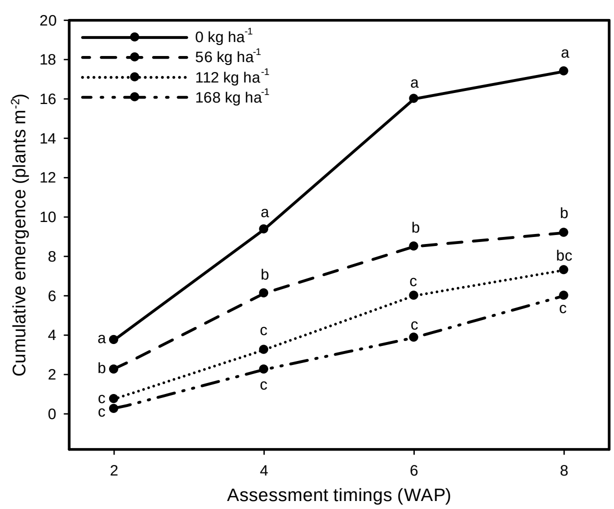

Figure 3. Cumulative Palmer amaranth emergence in the no herbicide plot as a function of cereal rye seeding rate in 2015. Means with the same letter within each assessment timings are not significantly different according to Fisher's protected LSD (α = 0.05). Abbreviations: WAP, weeks after planting.

Grass Control. Broadleaf signalgrass and barnyardgrass control were averaged due to the similar response of both weeds to the herbicide treatment and cereal rye. The density of both grass weeds was slightly higher in 2015 than in 2014. In 2014, at 8 WAP the grass density in the no herbicide and no cover crop plots averaged 12 broadleaf signalgrass and 4 barnyardgrass plants m^{-2}. At the same period in 2015, densities of broadleaf signalgrass and barnyardgrass were 28 and 6 plants m^{-2}, respectively (data not shown).

The application of a standard herbicide program resulted in excellent grass control in all plots, regardless of the cereal rye seeding rate in 2014 (Table 6). Plots treated with the standard herbicide program averaged at least 97% grass control for each of the four evaluations, regardless of cereal rye seeding rate. Grass control diminished over the course of the growing season in plots that had no cereal rye or cereal rye seeded at 56 kg ha^{-1}. However, cereal rye seeded at 112 and 168 kg ha^{-1} was comparable to plots with herbicide application.

In 2015, except for the first evaluation where grass control in herbicide-treated plots was not acceptable, the overall grass control at 4, 6, and 8 WAP was excellent in the herbicide-treated plots (Table 6). At 2 WAP, the 168-kg ha^{-1} seeding rate in combination with the standard herbicide program provided superior grass control compared to no cover crop treatment with herbicide. Similar results were obtained by Reeves et al. (2005) where the addition of cereal rye provided enhanced weed control compared to a herbicide program alone. The low grass control observed at 2 WAP in the herbicide plots in 2015 is likely due to above average rainfall after PRE-herbicide application, which could have led to leaching of the herbicide out of the zone in which weed germination typically occurs (Stewart et al., 2010). Following POST herbicide applied at 2 WAP, grass control averaged 95% or higher through 8 WAP. The improved grass control with the herbicide program in combination with the cereal rye was evident at 8 WAP, proving again that grass control is partially attributable to the cereal rye cover crop.

Table 6. Grass control (broadleaf signalgrass and barnyardgrass) as function of cereal rye seeding rate and herbicide application in 2014 and 2015[z]

Seeding rate	Herbicide application	Control[y,x]							
		2 WAP		4 WAP		6 WAP		8 WAP	
kg ha^{-1}		%	SE	%	SE	%	SE	%	SE
2014									
0	No	0	0	0	0	0	0	0	0
	Yes	98	1	100	0	100	0	100	0
56	No	97	1	92	1	81	2	72	1
	Yes	99	1	98	1	98	1	99	1
112	No	98	1	92	1	83	1	77	2
	Yes	100	0	100	0	99	0	99	0
168	No	99	1	95	1	89	1	80	1
	Yes	100	0	100	0	99	0	99	0
2015									
0	No	0	0	0	0	0	0	0	0
	Yes	83	2	99	0	100	0	100	0
56	No	64	2	54	2	49	1	42	2
	Yes	82	1	99	0	100	0	100	0
112	No	65	1	54	1	52	1	49	2
	Yes	82	1	99	0	100	0	100	1
168	No	77	1	75	2	65	2	66	1
	Yes	93	1	95	2	100	0	100	0

[z] Seeding rates that did not meet the assumptions of ANOVA are reported as means followed by the standard error (SE) of the mean.

[y] See Table 2 for specific herbicides, rates, and timings associated with the herbicide application.

[x] Abbreviations: WAP, weeks after planting

Seed Cotton Yield. Only the main effects of seeding rate and herbicide program impacted seed cotton yield in 2014. All seeding rates increased yields compared to no cover crop, with yield increasing as the cereal rye seeding rate increased (Table 7). Seed cotton yield improvement due to use of cereal rye has been reported previously. Sainju et al. (2006) reported that in a no-till system, cotton plots with cereal rye had a cotton lint yield of 1,110 kg ha^{-1} compared to 814 kg ha^{-1} in winter fallow. Herbicide application also had a significant effect on seed cotton yield. Plots that received the standard herbicide program had an average seed cotton yield of 1,400 kg ha^{-1}, whereas plots with no herbicide had a seed cotton yield of 940 kg ha^{-1}. Similar results were reported by Reeves et al. (2005) where cereal rye cover crop plots with no herbicide application resulted in reduced seed cotton yield compared to plots where herbicides were applied.

Table 7. The main effect of seeding rate and herbicide application on seed cotton yield in 2014 and 2015

Main effect	Seed cotton yield[z]	
	2014	2015
Seeding rate	-------------- kg ha^{-1} --------------	
0	1,030	1,200
56	1,160	1,260
112	1,200	1,240
168	1,290	1,210
LSD (0.05)	90	NS
Herbicide application[y]		
Yes	1,400	1,790
No	940	570
LSD (0.05)	50	50

[z] All means within a year and seeding rate or herbicide application can be compared using Fisher's protected LSD at $\alpha = 0.05$.

[y] See Table 2 for specific herbicides, rates, and timings associated with the herbicide application.

The effect of cereal rye seeding rate on seed cotton yield was not significant in 2015 (Table 7). Seed cotton yield ranged from 1,200 to 1,260 kg ha^{-1} among seeding rates, including the absence of cereal rye (Table 7). Others have reported similar seed cotton yields in the presence and absence of a cereal rye cover crop in Arkansas (DeVore et al., 2012; Korres and Norsworthy, 2015; Norsworthy et al., 2011). The effect of herbicide program did impact seed cotton yield in 2015 (Table 7). Averaged over cereal rye seeding rates, plots that received the standard herbicide program produced a seed cotton yield of 1,790 kg ha^{-1}. In contrast, plots that lacked an in-crop herbicide application had an average seed cotton yield of 570 kg ha^{-1}, likely because of the poor grass control by cereal rye alone.

The impact of cereal rye residue on seed cotton yield has been widely investigated. However, inconsistent results have been reported. The large array of environmental factors that can influence cotton yield in a cover crop system could be the reason for such inconsistencies. Nitrogen management has proven to be an important factor in a cereal cover crop system in cotton (Bouquet et al., 2004). Cereal rye is known to scavenge nitrogen with its extensive fibrous root system (Meisinger et al., 1991). Hence, it is likely that cereal rye might deplete inorganic nitrogen in the soil during fall and winter months. The decomposition and consequently mineralization of nitrogen in cereal rye residue can take a long time because the rate of decomposition of cereal rye residue is low due to the high C:N ratio (Creamer and Baldwin, 2000; Rosecrance et al., 2000; Sainju et al., 2006). Another factor to consider is rainfall and irrigation regime. Under well-watered or irrigated conditions, differences in cotton yield between no cover and cover crop plots are less likely. It is known that cover crops increase moisture infiltration and conservation (Unger and Vigil, 1998). Hence, the positive effect of cover crop residues on cotton yield might be more likely in areas with low summer rainfall or inadequate irrigation management (Dabney et al., 2001).

Practical Implications. Neither of the planting methods evaluated in this experiment appear to have an advantage for any parameter evaluated. The similar biomass production between the two planting methods in this study compare favorably to the findings of Fisher et al. (2011) where they concluded that broadcast seeding is an effective planting method for cereal rye. Increasing the seeding rate appears to be a worthy option to increase biomass production of cereal rye. However, based on the Palmer amaranth emergence, the highest seeding rate might not be warranted because there were no differences in emergence between the two highest seeding rates. The application of a standard herbicide program resulted in superior Palmer amaranth and grass control compared to the no herbicide program, regardless of the cereal rye seeding rate. However, having a cereal residue to give early weed suppression in cases where PRE herbicides fail to be activated would be a worthy practice and likewise reduce the number of weeds needing to be controlled with POST herbicides. These results support the concept that, even though cover crops can provide a high level of weed suppression early in the cotton growing season, the use of herbicides is still essential for adequate control throughout the entire growing season (Price et al., 2012). Further investigations on the effect of seeding rate on biomass production in different locations and environments should be considered. Environmental effects along with different soil fertilizer regimes for cereal rye might change the response of Palmer amaranth emergence and cotton yield to seeding rate and planting methods.

ACKNOWLEDGMENTS

Supported by Cotton Incorporated and University of Arkansas.

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