Weed Technology

www.cambridge.org/wet

Research Article

Cite this article: Price KJ, Li X, Price A (2020) Cover crop response to residual herbicides in peanut-cotton rotation. Weed Technol. **34**: 534–539. doi: 10.1017/wet.2020.5

Received: 13 September 2019
Revised: 5 December 2019
Accepted: 31 December 2019
First published online: 13 January 2020

Associate Editor:
Lawrence E. Steckel, University of Tennessee

Keywords:
Biomass; establishment; herbicide carryover; stand reduction

Nomenclature:
Acetochlor; acifluorfen; bentazon; chlorimuron-ethyl; diclosulam; diuron; flumioxazin; imazapic; prometryn; pyroxasulfone; pyrithiobac-sodium; *S*-metolachlor; trifloxysulfuron-sodium; cereal rye; *Secale cereal* L.; common vetch; *Vicia villosa* L.; cotton, Gossypium hirsutum L.; crimson clover, *Trifolium incarnatum* L.; daikon radish, *Raphanus sativis* L.; oat, *Avena sativa* L.; peanut, *Arachis hypogaea* L.; winter wheat, *Triticum aestivum* L.

Author for correspondence:
Xiao Li, 201 Funchess Hall, Auburn University, Auburn, AL 36849. Email: steveli@auburn.edu

Cover crop response to residual herbicides in peanut-cotton rotation

Katilyn J. Price[1], Xiao Li[2] and Andrew Price[3]

[1]Research Associate, Department of Crop Soil and Environmental Sciences, Auburn University, Auburn, AL, USA; [2]Assistant Professor, Department of Crop Soil and Environmental Sciences, Auburn University, Auburn, AL, USA and [3]Plant Physiologist, National Soil Dynamics Laboratory, U.S. Department of Agriculture–Agricultural Research Service, Auburn, AL, USA

Abstract

Cover crops can provide many benefits to peanut and cotton crops planted in rotation including suppressing weeds, conserving soil moisture after termination, increasing soil organic matter, and reducing soil erosion. However, herbicide carryover can affect cover crop establishment. The objective of this study was to investigate the responses of 6 cover crops (daikon radish, cereal rye, oat, crimson clover, winter wheat, and common vetch) to 12 soil residual herbicides. A multiyear (2016–2018), multilocation study was conducted in Macon and Henry counties, Alabama. Herbicide treatments included *S*-metolachlor, acetochlor, pyroxasulfone, diclosulam, imazapic, chlorimuron-ethyl, bentazon plus acifluorfen, pyrithiobac-sodium, trifloxysulfuron-sodium, diuron, prometryn, and flumioxazin, each applied at 10% of the full-labeled rate. At 42 to 52 and 145 to 149 d after planting (DAP), cover crop plant heights and stand counts were evaluated, as was biomass at 145 to 149 DAP. Treatments varied from year to year but not locations. In 2016, significant stand reductions ($P \leq 0.10$) of 36% to 43% in rye and 44% to 75% in wheat were observed at 48 to 52 DAP for *S*-metolachlor, acetochlor, pyroxasulfone, imazapic, and bentazon plus acifluorfen compared with nontreated plants. Vetch had stand reductions ranging from 14% to 80% for all treatments 50 DAP except for plants treated with prometryn. *S*-metolachlor, pyroxasulfone, and acetochlor reduced stands of rye, wheat, and vetch more than any other herbicides. In 2017, at 147 to 149 DAP, clover stands were reduced by 29% with diclosulam and by 38% with trifloxysulfuron-sodium. Similarly, radish stands were reduced by 64% with diclosulam treatment. No significant biomass reductions were observed for any cover crop species either year. Oat showed the most tolerance with no treatments reducing any growth parameters either year. Although initial injury and stunting may occur, biomass at termination of cover crops were not affected by herbicide residues evaluated in this study.

Cover crops can provide many benefits to a peanut and cotton rotation including suppressing weeds, conserving soil moisture after termination, increasing soil organic matter, and reducing soil erosion (Clark 2007; Dabney et al. 2001; Kasper and Singer 2011; Lu et al. 2000). High-residue cover crops have been shown to suppress weeds in no-till or strip-till cropping systems through resource competition, alleopathic affects, physical impediment, and light suppression (Aulakh et al. 2011; Dabney et al. 2001; Price and Norsworthy 2013; Reberg-Horton et al. 2011; Reeves et al. 2005). In recent years, throughout the Southeastern United States there has been an increasing practice of using cover crops and conservation tillage (Claassen et al. 2018; SARE CTIC 2017). Producers often use residual herbicides during the growing season to extend the period of weed control and provide another control method to herbicide programs especially to manage herbicide-resistant weeds. However, residual herbicides can prevent the successful establishment of fall-seeded cover crops, thus reducing biomass and subsequent weed suppression and achieving longer-term benefits provided by cover crops (Curran et al. 2006; Rogers et al. 1986; Yu et al. 2015).

Previous studies have evaluated soybean and corn herbicide carryover onto fall-seeded cover crops with varied results. One study observed pyroxasulfone caused a 12%, 16%, and 11% reduction in plant density for cereal rye, hairy vetch, and wheat, respectively; however, the reduction in plant density did not lead to significant biomass reductions (Palhano et al. 2018). The same study found crimson clover biomass reductions of 13%, 12%, and 11% for atrazine, pyroxasulfone, and *S*-metolachlor, respectively, when applied during the growing season; however, there were no significant reductions in plant density (Palhano et al. 2018). Yu et al. (2015) found imazethapyr, *S*-metolachlor + atrazine + mesotrione, and saflufenacil + dimethenamid-p did not cause any significant injury or biomass reductions to oat, hairy vetch, and cereal rye when planted 3 mo after application at the labeled rates. One study evaluating the carryover effects of cotton herbicides (fluometuron, MSMA, trifluralin, linuron) on hairy vetch and wheat found ground cover reductions varied greatly by soil type, with more injury found in Dundee silty clay than the silt loam soils (Rogers et al. 1986). Cornelius and Bradley (2017) found cereal rye to be the most tolerant cover crop to all of the corn and soybean herbicides evaluated, with cloransulam-methyl, flumioxazin, fomesafen + *S*-metolachlor, and metribuzin causing reductions in cover crop stands or biomass. The study also found that crimson clover and Austrian winter pea (*Pisum sativum* L.) were the most sensitive to herbicide carryover (Cornelius and Bradley 2017). In addition, pyroxasulfone, imazethapyr, fomesafen, and flumetsulam carryover reduced stand and cover crop biomass more than other herbicides evaluated (Cornelius and Bradley 2017). A greenhouse study in Iowa showed radish was the most sensitive to corn and soybean herbicide carryover, whereas cereal rye was the most tolerant (Hartzler and Anderson 2015). All of these previous studies have shown there are cases in which herbicide carryover can affect the establishment and biomass of fall-seeded cover crops; however, there is not a comprehensive understanding of the effects of cotton and peanut herbicides on Southeastern and mid-South cover crops.

Herbicide carryover can reduce cover crop biomass and subsequent weed suppressive qualities. It can increase expenses associated with cover crop establishment if replanting is needed in the fall or more herbicide applications the following season are needed for weeds. Herbicide chemistry and soil properties including pH, texture, organic matter, clay content, temperature, and moisture determine herbicide persistence in the soil. Overall, few of the previous studies evaluated commonly used peanut and cotton residual herbicides and limited research has been conducted in the Southeast, which has different environmental conditions and soil compared with other regions. Therefore, the objective of this study was to investigate the responses of 6 cover crops (daikon radish, cereal rye, oat, crimson clover, winter wheat, and common vetch) to simulated carryover from 12 common soil residual herbicides used in peanut and cotton.

Materials and Methods

Field trials were conducted in Macon County (32.4939°N, 85.8903°W)), and Henry County (31.3512°N, 85.3146°W), Alabama, in 2016–17 and 2017–18. The Macon County trial had a Kalmia sandy loam soil (fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Typic Hapludults) and the Henry County trial had a Dothan fine sandy loam soil (fine-loamy, kaolinitic, thermic Plinthic Kandiudults). Soil composition and pH for each location are listed in Table 1. At each location, soil was conventionally tilled 1 wk prior to herbicide application to provide ideal soil seeding conditions and prevent previous crop residue interference with herbicide application. The study was set up as a completely randomized block design with herbicide treatments in each block applied in strips, and the cover crops planted in perpendicular strips across the herbicide treatment. Plots were 1.8 m by 3.7 m with four replications in Henry County and three replications in Macon County each year. Herbicide rates were set at 10% of full-labeled rate and all treatments were applied prior to cover crop planting (Table 2). The treatment rate of 10% of the full-labeled rate was selected to simulate high concentrations of herbicide residue carryover beyond cotton or peanut harvest. Herbicide treatments were applied November 18, 2016 and October 30, 2017 in Macon County and November 3, 2016 and October 30, 2017 in Henry County. Herbicide treatments were applied using a backpack sprayer with a six-nozzle boom (Teejet TT110025 flat-fan nozzles in Henry County and Teejet XR11002VS extended-range flat-fan spray tips in Macon County; Teejet®, Spraying Systems Co., Wheaton, IL 60187) propelled by compressed CO_2 at a spray volume of 187 L ha^{-1}. Plots were immediately irrigated with 1.3 cm after herbicide applications to ensure activation. Six cover crops were planted: Daikon radish, Wrens Abruzzi cereal rye, Coker 227 oat, crimson clover, Pembroke 2017 winter wheat, and AU Olympic vetch. Cover crops were drill-seeded with a Hege plot grain drill November 21, 2016 and November 7, 2017 in Macon County, and November 7, 2016 and November 3, 2017 in Henry County with a Great Plains 1205 no-till drill. Rye, oat, and wheat were planted at 100 kg ha^{-1}. Clover and vetch were planted at 22 kg ha^{-1}. Radish was planted at 11 kg ha^{-1}. No rain was received for 7 d after planting (DAP) either year at either location.

Table 1. Locations and soil information of field trials conducted in 2016–17 and 2017–18.[a]

Location (county)	City, State	Soil texture	pH	OM%[b]	Sand	Silt	Clay
Henry	Headland, AL	Dothan fine sandy loam[c]	6.2	1.2	82	1	17
Macon	Shorter, AL	Kalmia sandy loam[d]	6.1	0.9	72	11	18

[a]Soil information was provided by Auburn University Soil Testing Laboratory (Auburn AL).
[b]Abbreviation: OM, organic matter.
[c]Fine-loamy, kaolinitic, thermic Plinthic Kandiudults.
[d]Fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Typic Hapludults.

Plant stands and heights for 10 random plants were collected for each herbicide-by-cover crop treatment at 42 to 52 DAP and 145 to 149 DAP. Stand counts were taken in two linear 1-m rows in broadleaf cover crops and three 30-cm linear row stand counts were collected from the cereal grain cover crops. Heights were measured from the base of the plants at the soil to the highest growing point. A fresh weight biomass was recorded for each plot at 146 to 149 and 148 to 150 DAP in 2017 and 2018, respectively. In Henry County, cover crops were harvested with a hay cutter then two 1-m^2 quadrats were raked and weighed onsite. In Macon County, a Carter® flail forage harvester was utilized to harvest and weigh the center 1.5-m by 3-m of the plot.

All data were converted to a percentage of the nontreated (NT) prior to statistical analysis for each individual cover crop. Then, converted data were processed with the PROC GLIMMIX procedure in SAS® 9.4 (SAS Institute Inc., Cary, NC 27513). Year, treatment, location, and block were subjected to ANOVA for a randomized complete block design. Each cover crop species was analyzed separately because the objective of the study was not to compare the different cover crops to each other but to evaluate the effects of different residual herbicides on each species individually. Treatment and location were considered fixed effects, while block was a random effect. If treatment by location was not significant, then location was used as a random effect and data were combined over location for analysis. If the interaction was significant, data were analyzed and presented by location. All means were separated using Tukey's honestly significant difference test with $P < 0.10$ to reveal statistical difference. This significance level was used because differences in cover crop injury and growth are difficult to distinguish, and $P < 0.10$ will, without question, reveal biologically significant differences among treatments.

Results and Discussion

There was a year-by-treatment interaction ($P < 0.10$) for each cover crop species; therefore, 2016–17 and 2017–18 were analyzed separately for stand counts and plant heights. Data were combined over both locations for stand counts because there were no location-by-treatment differences for each year. Stand counts were evaluated at 48 to 52 DAP and 145 to 148 DAP at each location in

Table 2. Herbicide treatments and rates.

Common name	Trade name	Manufacturer	City, State; website	Rate[a] (g ai ha^{-1})
Acetochlor	Warrant	Monsanto Company	St. Louis, MO; www.monsanto.com	126
Aciflurofen + Bentazon	Storm	United Phosphorus, Inc.	King of Prussia, PA; http://www.upi-usa.com	28 + 56
Chlorimuron-Ethyl	Classic	DuPont Crop Protection	Wilmington, DE; www.corteva.us.com	0.88
Diclosulam	Strongarm	Dow AgroSciences, LLC	Indianapolis, IN; www.corteva.us.com	0.33
Diuron	Direx	Drexel Chemical Company	Memphis, TN; www.drexchem.com	84
Flumioxazin	Valor	DuPont Crop Protection	Wilmington, DE; www.corteva.us.com	11
Imazapic	Cadre	BASF Corporation	Research Triangle Park, NC; www.BASF.com/us	7
Prometryn	Caparol	Syngenta Crop Protection, LLC	Greensboro, NC; www.syngenta-us.com	224
Pyrithiobac	Staple LX	DuPont Crop Protection	Wilmington, DE; www.corteva.us.com	11
Pyroxasulfone	Zidua	BASF Corporation	Research Triangle Park, NC; www.BASF.com/us	2.2
S-metolachlor	Dual Magnum	Syngenta Crop Protection, LLC	Greensboro, NC; www.syngenta-us.com	207
Trifloxysulfuron-sodium	Envoke	Syngenta Crop Protection, LLC	Greensboro, NC; www.syngenta-us.com	2.4
Nontreated				

[a]All treatments are 10% of the full-labeled rate to simulate carryover.

Table 3. Plant stand response to residual herbicides in peanut and cotton rotation in 2016–2017.[a]

		Plant stands[bcd]					
		Rye		Wheat		Vetch	
Herbicide treatment	Rate	48–52 DAP	145–148 DAP	48–52 DAP	145–148 DAP	48–52 DAP	145–148 DAP
	g ai ha^{-1}	% (NT)					
Acetochlor	126	56 d	78 a	33 fg	73 a	26 jk	85 a
Aciflurofen + Bentazon	28 + 56	69 abcd	87 a	72 abcde	98 a	61 ef	93 a
Chlorimuron-Ethyl	0.88	70 abcd	101 a	64 bcdef	102 a	54 fg	81 a
Diclosulam	0.33	65 abcd	76 a	49 defg	109 a	41 hi	90 a
Diuron	84	93 ab	127 a	95 ab	91 a	81 bc	87 a
Flumioxazin	11	87 abc	100 a	103 a	82 a	86 bc	107 a
Imazapic	7	57 bcd	86 a	56 cdefg	81 a	47 hg	76 a
Prometryn	224	87 abc	109 a	103 a	110 a	87 ab	98 a
Pyrithiobac	11	80 abcd	82 a	80 abcd	99 a	67 de	79 a
Pyroxasulfone	1.8	55 bc	80 a	41 efg	93 a	34 ij	86 a
S-metolachlor	138	48 d	75 a	25 g	87 a	20 k	101 a
Trifloxysulfuron-sodium	2.4	84 abcd	77 a	87 abc	106 a	74 dc	72 a
Nontreated		100 a	100 a	100 a	100 a	100 a	100 a

[a]Abbreviations: NT, nontreated; DAP, days after planting.
[b]Data collected in Henry County December 12, 2016 and March 20, 2017. Collected in Macon County January 12, 2017 and April 18, 2017.
[c]Clover, radish, and oat did not have any significant stand reductions, and therefore were not included in this table.
[d]Means followed by the same letter in the same column do not differ based on a mixed model analysis of variance of a randomized complete block (P = 0.1). Data are expressed as percentage of nontreated.

2016–17 (Table 3). Stand reductions of 43%–52% in rye and 44%–75% in wheat, respectively, were observed at 48 to 52 DAP for *S*-metolachlor, acetochlor, pyroxasulfone, imazapic, and bentazon plus acifluorfen over both locations. Wheat also had stand reductions of 36% with chlorimuron-ethyl use and 52% with diclosulam use at both locations. Vetch had significant stand reductions for all herbicide treatments, except for prometryn, at 48 to 52 DAP, ranging from 14% to 80% over both locations. The sensitivity of vetch to residual herbicides was not observed in two previous studies that evaluated corn and soybean herbicides (Bradley et al. 2016; Yu et al. 2015). However, two other studies found significant vetch injury or biomass reductions, indicating that environmental or soil composition factors are likely playing a role in herbicide carryover effecting vetch establishment (Bryan 2014; Palhano et al. 2018). *S*-metolachlor, pyroxasulfone, and acetochlor had the largest negative impacts on stand counts for rye (52%, 45%, 44%), wheat (75%, 59%, 67%), and vetch (80%, 66%, 74%) at 48 to 52 DAP. Similarly, Palhano et al. (2018) saw stand reductions 14 DAP of 12% and 11% with pyroxasulfone used with rye and wheat, respectively. Clover, radish, and oat were not affected by any herbicide treatment at 48 to 52 DAP. By 145 to 148 DAP, there were no stand reductions for any of the cover crops evaluated in 2016–17. The stand recovery was due to late-season germination of the affected cover crops. In 2017–18, stand counts were evaluated at 42 to 45 DAP and 147 to 149 DAP at each location (Table 4). At 147 to 149 DAP, diclosulam and trioxysulfuron-sodium reduced clover stand by 29% and 38%, respectively. Diclosulam reduced radish stand by 64% at 147 to 149 DAP. Chlorosis and stunting were observed for clover and radish plants following herbicide treatments that had stand reductions at 147 to 149 DAP. Oat, rye, and vetch did not have any stand reductions at either 42 to 45 DAP or 147 to 149 DAP. Overall, more stand reductions were observed at 147 to 149 DAP than at 42 to 45 DAP, which was different from 2016–17, when by 145 to 148 DAP there were no observed stand reductions. Conditions in 2016–17 favored more stand reductions by herbicides than in 2017–18. In 2016–17 there was more rainfall and lower soil temperatures than 2017–18 (Table 5). These environmental factors may have slowed cover crop germination and emergence allowing the seedling to be exposed to herbicide for a longer period compared with 2017–18, especially for herbicides that are not very water-soluble.

Location by treatment was different for radish height and was analyzed by each location in 2016–17 (Table 6). Treatments

Table 4. Plant stand response to residual herbicides in peanut and cotton rotation in 2017–2018.[a]

		Plant stands[bcd]			
		Clover		Radish	
Herbicide treatment	Rate	42–45 DAP	147–149 DAP	42–45 DAP	147–149 DAP
	g ai ha^{-1}	———————% (NT)———————			
Acetochlor	126	95 a	93 ab	106 a	111 a
Aciflurofen + Bentazon	28 + 56	92 a	85 ab	97 a	113 a
Chlorimuron-Ethyl	0.88	87 a	87 ab	96 a	87 ab
Diclosulam	0.33	80 a	71 bc	109 a	36 b
Diuron	84	95 a	93 ab	99 a	83 ab
Flumioxazin	11	92 a	99 ab	95 a	123 a
Imazapic	7	89 a	106 a	89 a	67 ab
Prometryn	224	84 a	94 ab	97 a	115 a
Pyrithiobac	11	89 a	91 ab	99 a	102 a
Pyroxasulfone	1.8	94 a	93 ab	101 a	120 a
S-metolachlor	138	95 a	94 ab	109 a	126 a
Trifloxysulfuron-sodium	2.4	76 a	62 c	109 a	86 ab
Nontreated		100 a	100 a	100 a	100 a

[a]Abbreviations: NT, nontreated; DAP, days after planting.
[b]Data collected in Henry County on December 18, 2017 and March 29, 2018. Collected in Macon County on December 19, 2017 and April 5, 2018.
[c]Rye, vetch, and oat did not have any significant stand reductions, and therefore were not included in this table.
[d]Means followed by the same letter in the same column do not differ based on a mixed model analysis of variance of a randomized complete block (P = 0.01). Data are expressed as percentage of nontreated.

applied in Henry County did not result in any height reductions for radish at 48 or 145 DAP. In Macon County, height reductions of radish were reduced by 31% at 52 DAP when imazapic was used. This was the only time and location to show radish plant height reduction. Radish sensitivity was also observed in other studies in which radish had more injury from herbicide carryover than any other cover crop evaluated (Anderson 2014; Bradley et al. 2016; Bryan 2014; Hartzler and Anderson 2015). By 147 DAP, radish had recovered and there was no height differences compared with NT plants. Radish did not have height reductions at either timing in 2017–18. Again, no other cover crop had height reductions in either year or location of this study. Previous studies have not considered height as a potential growth parameter to evaluate for herbicide carryover onto fall-seeded cover crops. Based on the results of this study, plant height reductions are not a good visual indicator of herbicide carryover. Because radish was the only cover crop to have a plant height reduction, this was likely due to radish being sensitive to environmental factors or, possibly, to higher clay content in the soil in Macon County in 2016–17. Overall, based on these data, stand reductions are a better indicator of herbicide carryover compared to height reductions. Although stand losses were observed for some cover crops each year, this did not lead to biomass reduction at the end of the growing season either year. Also, the average biomass of all treated plots was not different from the average NT plots for each cover crop. Oat had the largest average biomass of the evaluated grass species in both treated and NT plots both years (Table 7). Although vetch had stand reductions for all but one herbicide in 2016–17 at the beginning of the season, it had the greatest average amount of biomass of the broadleaf species evaluated in the treated and NT plots. Even though clover did not exhibit any reductions, it did not have the largest amount of biomass of the broadleaf plants in 2016–17. Therefore, if a

Table 5. Average monthly rainfall, temperature, and soil temperatures

	2016–2017						2017–2018					
	Henry			Macon			Henry			Macon[b]		
Month	Rainfall (cm)	Temperature (C)	Soil Temperature[a] (C)	Rainfall (cm)	Temperature (C)	Soil temperature (C)	Rainfall (cm)	Temperature (C)	Soil Temperature (C)	Rainfall (cm)	Temperature (C)	Soil temperature C
November	0.03	16	19	5	14	16	1	15	27	3	13	17
December	21	13	19	16	10	12	5	11	24	7	9	12
January	30	13	18	20	11	11	3	6	19	12	5	9
February	11	15	18	9	12	12	18	16	22	10	16	15
March	4	16	20	6	14	13	10	14	24	12	13	15
April	-	-	-	8	19.2	17	-	-	-	9	16	18

[a]Soil temperatures were taken at 10-cm depth.
[b]Soil temperature data was missing from November 25, 2017 to December 14, 2017 because the Macon County weather station soil sensor was down for repairs. Soil temperature data for the missing days came from Natural Resources Conservation Service Weather Station on Morris Farms, an Alabama SCAN site, approximately 10 miles away.

Table 6. Radish plant height response to residual herbicides in peanut and cotton rotation in Macon County in 2016–17.[a]

Herbicide treatment	Rate	Radish[bc]	
		52 DAP	148 DAP
	g ai ha^{-1}	——% (NT)——	
Acetochlor	126	93 def	105 a
Aciflurofen + Bentazon	28 + 56	120 ab	81 a
Chlorimuron-Ethyl	0.88	85 fg	105 a
Diclosulam	0.33	106 abcdef	91 a
Diuron	84	91 ef	105 a
Flumioxazin	11	118 abc	82 a
Imazapic	7	69 g	97 a
Prometryn	224	125 a	91 a
Pyrithiobac	11	108 abcde	82 a
Pyroxasulfone	1.8	95 edf	112 a
S-metolachlor	138	113 abcd	106 a
Trifloxysulfuron-sodium	2.4	99 cdef	108 a
Nontreated		100 bcdef	100 a

[a]Abbreviations: NT, nontreated; DAP, days after planting.
[b]Data collected in Macon County on January 12, 2017 and April 18, 2017.
[c]Means followed by the same letter in the same column do not differ based on a mixed model analysis of variance of a randomized complete block (P = 0.1). Data are expressed as percentage of nontreated.

Table 7. Average wet weight cover crop biomass in nontreated and all treated plots.[a]

	Wet weight of biomass			
	Treated plots[b]	NT[c]	Treated plots	NT
Cover crop	2016–17	2016–17	2017–18	2017–18
	——kg ha^{-1}——			
Clover	16,660	14,020	6,480	7,050
Oat	11,590	10,500	6,550	6,440
Radish	11,400	13,840	8,630	10,290
Rye	4,930	6,080	4,350	5,110
Vetch	17,760	16,950	7,280	7,920
Wheat	4,040	4,900	3,000	4,440

[a]Data collected in Henry County March 31, 2017 and March 30, 2018. Collected in Macon County April 19, 2017 and April 6, 2018.
[b]Treated plots are the average of all plots treated with herbicides across both locations.
[c]Abbreviation: NT, nontreated.

producer is growing a cover crop for biomass, then species selection and herbicide carryover need to be considered. Clover did not show any stand reductions but did not have the greatest amount of biomass at the end of the growing season in 2016–17 of the broadleaf plants evaluated. In 2017–18 radish exhibited the largest average biomass of the broadleaf species in the treated and NT plots. Overall, some cover crops had stand reductions; however, the new plants that did emerge were able to compensate for the reduced population and produce a biomass similar to that of the NT plots with a full growing season for each cover crop evaluated in this study. Cover crop response to herbicides varied from year to year, even though the same amount of herbicides were applied each year they did not vary between locations, suggesting environmental factors favored certain herbicide persistence each year and not soil composition. Although this study applied low rates of herbicides prior to planting to simulate carryover, in field settings, these herbicides would be applied weeks to months before planting fall-seeded cover crops. Environmental factors including soil pH, soil composition, microbial activity, soil temperatures, air temperatures, and other conditions can extend soil herbicide residual persistence, thus increasing carryover chances on to fall-seeded cover crops (Curran 2016). In addition to herbicide chemistry, how it degrades, and its half-life can affect how long an herbicide will be persistent in a soil. Overall in this study, diclosulam caused more stand reductions than any other herbicide by affecting all cover crops with the exception of oat and rye. Trifloxysulfuron-sodium, diuron, flumioxazin, pyrithiobac, and prometryn did not affect the establishment of any grass cover crop stands either year. Prometryn was the only herbicide to not affect broadleaf cover crops. Although injury and/or stand reduction is possible with residual herbicide use, producers should likely expect cover crops to recover and produce full biomass potential.

Overall, oat showed the most herbicide tolerance with no treatments reducing stands, heights, or biomass in either year. This aligns with other studies that found oat to be tolerant to many corn and soybean herbicides, including *S*-metolachlor, imazethapyr, atrazine, and mesotrione (Hartzler and Anderson 2015; Yu et al. 2015). Previous studies have shown rye to be more tolerant than oat to residual herbicides (Bryan 2014; Cornelius and Bradley 2017). One study found cereal rye had the most tolerance out of all the cover crops tested, with stand and biomass reductions caused by only a few herbicides, including by flumioxazin, cloransulam, sulfentrazone, metribuzin, and fomesafen + *S*-metolachlor (Cornelius and Bradley 2017). Another study also found rye to be the most tolerant to commonly used corn herbicides including *S*-metolachlor (Bryan 2014). However, this study did observe rye stand losses with a number of herbicides including *S*-metolachlor in 2016–17. Wheat exhibited the most sensitivity to herbicide carryover out of the grasses evaluated as more stands were reduced compared with other grasses. Rogers et al. (1986) observed significant cover reductions of wheat to cotton herbicides (fluometuron, MSMA, trifluralin) in three different soil types. Broadleaf cover crops showed more sensitivity to herbicide carryover compared to grass species. Vetch response was variable in that it had the most sensitivity to herbicide carryover of all the broadleaf plants with all but one herbicide effecting stand establishment in 2016–17; however, it did not exhibit a stand reduction the following year. Some studies have shown hairy vetch to be the most tolerant cover crop to herbicide carryover, whereas other studies showed it to be the most sensitive (Bryan 2014; Hartzler and Anderson 2015; Rogers et al. 1986; Stahl 2016; Yu et al. 2015). Palhano et al. (2018) found clover had reduced biomass in a field study from residual herbicides but emergence reductions were not observed, whereas the opposite occurred in this study. Another study found acetochlor and *S*-metolachlor caused biomass reductions of clover during one year of the study; however, neither herbicide caused injury in this study (Cornelius and Bradley 2017). Previous studies indicated radish, similar to clover and vetch, had both tolerance and susceptibility to carryover (Cornelius and Bradley 2017; Yu et al. 2015). One study evaluating oilseed radish tolerance found it to be sensitive to a number of residual herbicides, including fomesafen, *S*-metolachlor/fomesafen, and imazethapyr but was not affected by them the following year, likely due to increased rainfall (Cornelius and Bradley 2017). Another study that also had varying results from year to year did not recommend planting oilseed radish within 3 mo of an imazethapyr application but did not report injury with *S*-metolachlaor + atrazine and saflufienacil + dimethenamid-P (Yu et al. 2015). The results of this study and all previous studies indicate that residual herbicides have the potential to reduce fall-seeded cover crop establishment; however, weather conditions, soil textures, application timings, and other environmental factors affect the severity of damage observed.

Overall, cover crop stand establishment varied over the years but not locations, similar to previous studies with other row crop

https://doi.org/10.1017/wet.2020.5 Published online by Cambridge University Press

residual herbicides, likely due to environmental factors affecting herbicide persistence (Cornelius and Bradley 2017; Tharp and Kells 2000; Yu et al. 2015). Fall-seeded cover crop should be planted based on the residual herbicides applied to row crops the previous season, when the last application of residuals occurred and based on the biomass goal and nutrient needs of the field. Although initial injury and stunting may occur, cover crop biomass was not affected by the residual herbicides evaluated in this study and producers can still expect the full benefits offered by cover crops. Further research needs to be conducted to determine the minimum plant-back interval needed for fall-seeded cover crops after herbicide applications in the previous crop, especially as the utilization of cover crops increases in the Southeast.

Acknowledgments. We thank the National Peanut Board for funding support and the Alabama Agricultural Experimental Stations for trial initiation and management. No conflicts of interest have been declared.

References

Anderson MJ (2014) Interactions between cover crops and weed management in Iowa's conventional cropping systems. Master's Thesis 14087. 72 p

Aulakh JS, Price AJ, Balkcom KP (2011) Weed management and cotton yield under two row spacings in conventional and conservation tillage systems utilizing conventional, glufosinate, and glyphosate-based weed management systems. Weed Technol 25:542–547

Bradley K, Hoorman R, Ellis C, Shannon K, Broz B (2016) The effects of corn herbicide carryover on Missouri cover crops:cover crop integration. Columbia: University of Missouri Extension. http://crops.missouri.edu/covercrops/cornherbicide.pdf. Accessed: Febuary 23, 2019

Bryan M (2014) Field crops research: herbicide carryover injury to cover crops. Practical Farmers of Iowa pp1-3. https://practicalfarmers.org/research/herbicide-carryover-injury-cover-crops Accessed: Febuary 23, 2019

Clark A (2007) Managing cover crops profitably. Page 212 in Sustainable Agriculture Network Handbook Series 9. Beltsville, MD: Sustainable Agriculture Network

Claassen R, Bowman M, Mcfadden J, Smith D, Wallander S (2018) Tillage intensity and conservation cropping in the United States. Econominc Information Bulletin 197. Beltsville, MD: U.S. Department of Agriculture–Agricultural Research Srvice. 27 p

Cornelius CD, Bradley KW (2017) Carryover of common corn and soybean herbicides to various cover crop species. Weed Technol 31:21–31

Curran WS, Lingenfelter DD, Garling L, Wagoner P (2006) Cover crops for conservation tillage systems. University Park, PA: Penn State Cooperate Extension. https://extension.psu.edu/cover-crops-for-conservation-tillage-systems. Accessed: Febuary 23, 2019

Dabney SM, Delgado JA, Reeves DW (2001) Using winter cover crops to improve soil and water quality. Soil Sci Plant Anal 32:221–250

Hartzler B, Anderson M (2015) Effect of residual herbicides on cover crop establishment. Ames: Iowa State Extension and Outreach. https://crops.extension.iastate.edu/effect-residual-herbicides-cover-crop-establishment. Accessed: Febuary 23, 2019

Kasper TC, Singer JW (2011) The use of cover crops to manage soil. Pages 321–337 in Hatfield JL and Sauer TJ, eds. Soil management: building a stable base for agriculture. American Madison, WI: Society of Agronomy

Lu Y, Watkins K, Teasdale J, Abdul-Baki A (2000) Cover crops in sustainable food production, Food Rev Int 16:121–157

Palhano MG, Norsworthy JK, Barber T (2018) Sensitivity and likelihood of residual herbicide carryover to cover crops. Weed Technol 32:236–243

Price AJ, Norsworthy JK (2013) Cover crops for weed management in southern reduced-tillage vegetable cropping systems. Weed Technol 27: 212–217

Reeves DW, Price AJ, Patterson MG (2005) Evaluation of three winter cereals for weed control in conservation-tillage nontransgenic cotton. Weed Technol 19:731–736

Reberg-Horton SC, Grossman JM, Kornecki TS, Meijer AD, Price AJ, Place GT, Webster TM (2011) Utilizing cover crop mulches to reduce tillage in organic systems in the southeastern USA. Renew Agr Food Syst 27:41–48

Rogers BC, Talbert R, Frans R (1986) Effect of cotton (Gossypium birsutum) herbicide carryover on subsequent crops. Weed Sci 34:756–760

SARE CTIC (2017) Annual report 2016–2017 cover crop survey. Joint Publication: Conserv Technol Inf Center, North Cent Reg Sustain Agric Res Educ Program, Am Seed Trade Assoc. https://www.sare.org/Learning-Center/From-the-Field/North-Central-SARE-From-the-Field/2017-Cover-Crop-Survey-Analysis. Accessed: February 23, 2019. 46 p

Stahl L (2016) Managing risk when using herbicides and cover crops in corn and soybean. Commodity Crops and Soil Health. St. Paul: University of Minnesota Extension Publication. https://extension.umn.edu/herbicides/managing-risk-when-using-herbicides-and-cover-crops-corn-and-soybean. Accessed: February 27, 2019

Tharp BE, Kells JJ (2000) Effect of soil applied herbicides on establishment of cover crop species. Weed Technol 14:596–601

Yu L, Van Eerd LL, O'Halloran I, Sikkema PH, Robinson DE (2015) Response of four fall-seeded cover crops to residues of selected herbicides. Crop Prot 75:11–17

https://doi.org/10.1017/wet.2020.5 Published online by Cambridge University Press