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Spring-applied corn herbicides impact fall-planted cover crops in South Dakota

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Abstract

Early spring herbicide applications can have residuals that impede fall-planted cover crop growth. A greenhouse study examined radish (*Raphanus sativus* L.) or rye (*Secale cereale* L.) growth in silty clay loam (southeastern South Dakota) and silt loam (north-central South Dakota) where corn herbicides had been applied about 120 d prior to collection. *S*-metolachlor, acetochlor, flumetsulam, metribuzin, bicyclopyrone + mesotrione + *S*-metolachlor + atrazine, and primisulfuron-methyl + prosulfuron (northern site only) were applied at the suggested timing and highest recommended rate and planted to corn (*Zea mays* L.). Two 11-cm diam. soil cores to a 10-cm depth were collected per plot after silage harvest, with nontreated soils also collected. Soil was mixed within each core and two subsamples were placed into conetainers and planted with four seeds of the crop species. Plant height, and fresh shoot and root weights were quantified after 6 wk and compared to growth in nontreated soil. Radish was unaffected by any herbicide in either soil. Rye growth was influenced by soil and herbicide. In the silt loam, rye shoot biomass was reduced 15–25% by flumetsulam, acetochlor, and primisulfuron + prosulfuron; and acetochlor reduced root biomass by 44%. In the silty clay loam, acetochor reduced shoot biomass by 59%; and all treatments reduced root biomass by 35% or more. These data suggest that spring herbicide applications and cover crop species should be carefully matched to help in cover crop success.

1 | INTRODUCTION

Pre-emergence soil-applied herbicides can control weed seedlings for 2–6 wk after a single application. While these herbicide residuals are desirable for in-season weed control (Horvath et al., 2018; Page et al., 2012; Tursun et al., 2016), residuals may be problematic if sensitive species are planted too soon after initial application (Cornelius & Bradley, 2017; Hartzler & Anderson, 2020; Palhano, Norsworthy, & Barber, 2018). Cover crops are being planted more frequently after a cash crop, with 6.2 million ha planted to a cover crop in 2017, which is 49% greater than the number of hectares planted in 2012 (SARE, 2017). If the cover crop is grazed or used as forage, there may be planting interval restrictions on labels that must be followed. However, a cover crop may be planted for conservation only purposes (e.g., erosion control, water use,

Abbreviations: DAA, days after application; GDD, growing degree days.

nutrient scavenging), but the grower assumes responsibility if herbicide residuals interfere with stand establishment or impede growth (Hartzler & Anderson, 2020).

In the northern Great Plains, planting cover crops after a full-season cash crop (soybean or corn for grain, harvested in mid-October or later) often results in a poor or marginal stand due to low temperatures and/or dry soils (Bauder, Karki, & Bly, 2019). Greater stand establishment and growth has been obtained if the cover crop follows a short season crop (such as wheat, harvested about 1 August; or silage corn, harvested in early/mid-September) or if it is interseeded into corn at or after V7 (Brooker, Renner, & Sprague, 2020) or soybean in mid-July (Hively & Cox, 2001). Planting cover crops in these situations is when herbicide residuals may be the most hazardous for cover crop establishment.

However, herbicide selection in spring is based typically on expected weeds and needed control and typically not on future cover crop establishment. While past herbicide history is mentioned as a consideration for selecting species of cover crops (Bauder et al., 2019; Hartzler & Anderson, 2020), there is a paucity of research on the impact of corn herbicides, with known residual activity applied in early spring, on early fall-planted cover crops in the northern Great Plains region.

Herbicide dissipation (leaching and microbial breakdown) and carryover are influenced by multiple factors. These include, but are not limited to, the inherent herbicide chemistry, environmental factors, and soil chemical and physical factors (Clay, 2000; Koskinen & Clay, 1997). In addition, the bioavailability of the remaining chemical (whether tightly sorbed or desorbable from clay or organic matter, due in part to the ionic charge of the herbicide) (Zabaloy, Zanini, Bianchinotti, Gomez, & Garland, 2011) and the sensitivity of the plant to the herbicide also will influence if the plant will sustain injury (Whalen et al., 2019).

This study examined a broadleaf (radish, *Raphanus sativus* L.) and grass (rye, *Secale cereale* L.) species growth in soils sampled about 120 d after spring herbicide application at two South Dakota locations. The two South Dakota sites had different climate conditions (rainfall and temperatures) and soil types (one with more clay, the other with more sand). The herbicides chosen had varying residual activity, different expected half-lives (all longer than 30 d), different modes-of-action, and controlled different weed control spectrums (Table 1) (Bosak & Davis, 2014; Shaner, 2014). All of these factors could lead to susceptible plant injury after a short-season crop. Indeed, cover crop planting dates based on labeled recommendations range from 90 to 540 d (Table 1). Cereal rye and radish were chosen as the target plants, as these are commonly grown cover crops in the United States (SARE, 2017). The information gained in this study can be used to help inform growers about how choosing herbicide treatments early in the season may influence later season decisions.

Core Ideas

- Spring-applied herbicides may influence fall-planted cover crop growth.
- Fall-planted radish planted after spring herbicide treatment was not impacted by herbicide.
- Rye biomass was reduced with most herbicides at the southern South Dakota location.
- Spring herbicides and cover crop must be matched for successful fall establishment.

2 | MATERIALS AND METHODS

Field studies were established in 2018 at southeastern (Beresford; 43°4′50″ N, 96°46′25″ W) and northeastern (Groton; 45°26′51″ N, 98°5′55″ W) South Dakota sites. Soil series at Beresford site was an Egan–Trent silty clay loam (fine-silty, mixed, superactive, mesic Udic Haplustolls) (~30% clay, 48% silt, 12% sand), whereas soil series at Groton site was a Beotia silt loam (fine-silty, mixed, superactive, frigid Pachic Hapludolls) (~23% clay, 57% silt, 20% sand).

The pre-emergence herbicides used at the maximum labelled rate for South Dakota (Table 1) were metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(1-methoxypropan-2-yl)acetamide]; metribuzin [4-amino-6-tert-butyl-3-1,2,4-triazin-5(4H)-one]; flumetsulam {*N*-(2,6-difluorophenyl)-5-methyl-[1,2,4]triazolo[1,5-a]pyrimidine-2-sulfonamide}; acetochlor {*N*-(2,6-difluorophenyl)-5-methyl-[1,2,4]triazolo[1,5-a]pyrimidine-2-sulfonamide} (encapsulated formulation); and the premix combination of S-metolachlor + atrazine (1-chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine) + mesotrione [2-(4-methylsulfonyl-2-nitrobenzoyl)cyclohexane-1,3-dione] + bicyclopyrone {4-hydroxy-3-[2-(2-methoxy-ethoxymethyl)-6-trifluoromethyl- pyridine-3-carbonyl]-bicyclo[3.2.1]oct-3-en-2-one}. The premix combination of primisulfuron-methyl {methyl 2-[[4,6-bis(difluoromethoxy)pyrimidin-2-yl]carbamoylsulfamoyl]benzoate} + prosulfuron {1-(4-methoxy-6-methyl-1,3,5-triazin-2-yl)-3-[2-(3,3,3-trifluoropropyl)phenyl] sulfonylurea} was applied post-emergence at Groton. The experiment was laid out in a randomized complete block design with four replications per location, with herbicides as the fixed treatment and

TABLE 1 Herbicides and active ingredient (a.i.) rates of application, Weed Science Society of America [WSSA] group and mode of action, site of action, estimated half-life of each herbicide (based on Shaner, 2014), and labelled suggested cover crop planting interval (days after application, DAA) (when provided)

Common chemical name	Rate applied	WSSA group and mode of action	Site of action	Estimated half-life	Suggested cover crop planting interval
	kg a.i. ha^{-1}			d	DAA
S-metolachlor	2.24	15/seedling shoot growth inhibitor	Long chain fatty acid synthesis	91–152	135 (rye)[a]
Metribuzin	0.27	5/photosynthesis inhibitor	Photosystem II	14–28	120 (rye)[b]
540 (radish)					
Acetochlor	2.52	15/seedling shoot growth inhibitor	Long chain fatty acid synthesis	56–84	120 (rye)[c]
flumetsulam	0.07	2/Amino acid synthesis inhibitor	Acetolactate synthetase	60	120 (rye)[d]
270 (radish)					
S-metolachlor + atrazine + mesotrione + bicyclopyrone	1.80 + 0.84 + 0.21 + 0.05	15/5/27/27; seedling growth inhibitor; photosynthesis inhibitor; pigment inhibitors	Long chain fatty acid synthesis; photosystem II; HPPD inhibitors	91–152; 30; 5–15; 213	120 (rye) and field test recommended[e]
Primisulfuron + prosulfuron	+ 0.03	2/2;amino acid synthesis inhibitor	Acetolactate synthetase	30; 19	90 (rye)[f] 540 (radish)

[a] Adama Essentials (2012).
[b] Adama Essentials (2011).
[c] Monsanto (2014).
[d] DowAgro Sciences (2017).
[e] Syngenta (2018).
[f] Syngenta (2013).

blocks as a random effect. Corn at both locations was planted just prior to the pre-emergence applications and was cut for silage in August.

The pre-emergence applications at Beresford were applied on 16 May and sampled on 16 September (122 days after application, DAA). At Groton, all applications but the post-emergence herbicide were applied on 4 May and sampled 18 September (136 DAA). The post-emergent treatment was on applied 6 June and sampled 18 September (102 DAA).

Due to the uncertainty of timely fall rains to establish a cover crop, soil samples were taken using a 11-cm diam. soil core (R&R Products) to a 10-cm depth at two areas per plot (Rashid, Sharma, & Evans, 2001). Soil was placed in a cold room (5 °C) until processing. Soil for each core was mixed (akin to a surface cultivation), about 100 g was placed in a conetainer, seeded with four seeds of either tillage radish or rye and placed in the greenhouse with a 12-h day/night cycle. Samples were done in duplicate and there were four field replicates, so that each treatment had eight replicated samples. Containers were checked every 2 d and 15–20 ml of water was added from the top as needed. Radish was thinned to two plants soon after emergence.

Six weeks after planting, plants were harvested with shoots clipped at soil level and roots carefully washed. Measurements included shoot length, fresh shoot weight, and, after patting dry, fresh root weight.

The greenhouse experiment was replicated using the same protocols and soil for a second repetition in time, starting about 8 wk after the first planting. Data were similar between runs. Data were analyzed by location using a one-way paired *t* test to compare plant growth parameters in the herbicide-treated soil to plants grown in soil taken from the same location but from a nontreated area.

3 | RESULTS

3.1 | Climate and soil

Conditions at Beresford were warmer and wetter than at Groton. At Beresford, rainfall was 443 mm and there were a total of 1,470 growing degree days (GDD) (base 10 °C) from application to soil sampling. At Groton, rainfall was almost 50% less than at Beresford (266 mm) and GDD totaled 1,393 between the pre-emergence application and

FIGURE 1 Herbicide injury to (a) radish (with hydroxyphenylpyruvate dioxygenase [HPPD] inhibitor) and (b) rye (with acetolactate synthase [ALS] inhibitor), seen within the first 3 wk after planting

soil sampling, whereas rainfall was 236 mm and GDD total was 1,096 between the post-emergence application and soil sampling.

The soil at Beresford had a higher clay content than Groton, which should increase herbicide sorption (Clay, 2000). The higher sand content in the Groton soil would limit soil sorption, which could make the herbicide more subject microbial breakdown (Zabaloy et al., 2011). However, fewer GDD may, in fact, lessen microbial activity and result in higher bioavailability of the herbicides from the soil. Nevertheless based on the reported half-lives (see Table 1) and suggested planting intervals for the cover crops that were selected for this study, we expected that some of the chosen herbicides would limit growth of these plants in both soils.

3.2 | Plant injury

A few radish plants had interveinal bleaching, typical of hydroxyphenylpyruvate dioxygenase (HPPD) inhibitor-type symptoms, (Shumway & Scott, 2016) within 2 wk after emergence (Figure 1a), although this symptom was not consistent among replications or soil types. However, by the 6-wk harvest, radish appearance and measured parameters were similar to radish growth in the nontreated soil for both locations (data not shown).

Rye was more sensitive to herbicide injury than radish. Stunting and purpling of the plants (Figure 1b), akin to symptoms observed with acetolactate synthase (ALS) disruptors (Weed Science Society of America [WSSA] Group 2 herbicides) such as flumetsulam and the sulfonylurea types, were seen during development. At harvest, rye response differences were herbicide and location specific (Table 2), with greater shoot height and root weight reductions observed in the Beresford soil.

Rye shoot height and root weight were the most negatively impacted parameters in the Beresford soil. Shoot heights were reduced by about 23% in soil treated with metolachlor or acetochlor, 19% for metribuzin, 15% for flumetsulam and the premix containing *S*-metolachlor + atrazine + mesotrione + bicyclopyrone, relative to the nontreated check. In contrast, only acetochlor reduced rye shoot weight (59% decrease) in the Beresford soil. Rye root weight was sensitive to the herbicide residual at Beresford with all treatments having less biomass than the nontreated control reductions were most severe with acetochlor (54%) and flumetsulam (49%); whereas metolachlor, metribuzin, and the premix containing *S*-metolachlor + atrazine + mesotrione + bicyclopyrone, each reduced fresh root weight by about 36%.

In the Groton soil, rye shoot heights were all similar to the nontreated control. Fresh shoot and root weights in the nontreated soil was almost double the weight of those grown in the Beresford nontreated soil. Higher plant biomass in the Groton soil may be due to higher sand content, which may have facilitated water movement through the soil or provided for better aeration. However, fresh shoot weight was reduced in soil that had been treated with flumetsulam (31%), acetochlor (23%), and primisulfuron + prosulfuron (27%). Unlike the results from the Beresford

TABLE 2 Rye shoot height and fresh weight and root fresh weight 6 wk after planting in Beresford and Groton soils treated with herbicides about 120 d before collection

Treatment	Shoot				Root	
	Height	P value[a]	Fresh weight	P value	Fresh weight	P value
	cm		mg		mg	
Beresford						
Nontreated soil	17.3		560		300	
S-Metolachor	13.4	.02	520	ns	190	.02
Metribuzin	14.1	.005	460	ns	180	.01
Flumetsulam	14.7	.008	380	ns	150	.004
Acetochlor	13.5	.002	230	.001	140	.004
S-Metolachlor + atrazine + mesotrione + bicyclopryone	14.7	.008	420	ns	190	.007
Groton						
Nontreated soil	19.7		1,030		630	
S-Metolachor	18.2	ns	1,030	ns	600	ns
Metribuzin	20	ns	1,130	ns	430	ns
Flumetsulam	19	ns	720	.03	2,140	ns
Acetochlor	19.2	ns	790	.03	350	.02
S-Metolachlor + atrazine + mesotrione + bicyclopryone	19.7	ns	1,000	ns	470	ns
Primisulfuron + Prosulfuron	19.6	ns	750	.04	690	ns

[a]Note. ns, not significant.

[a]*P* value is based on one-way paired *t* test for the parameter compared to rye grown in nontreated soil for the location.

soil where all treatments reduced fresh root weight, only acetochlor reduced root weight (by 44%) in the Groton soil.

4 | DISCUSSION

This study examined several commonly used corn herbicides that are known to provide residual control (Table 1). These are labeled for application in a silage corn crop. The use of cover crops after silage harvest would be ideal as there is time to plant cover crops in September. This timing would provide early fall rains and warm enough temperatures in the northern Great Plains to aid in stand establishment and growth. However, based on label recommendations, the cover crop planting may be just at or before the planting interval. Because producers can assume the risk of cover crop injury if planted before the suggested timing, they need the information of which herbicide residuals from early-season applications may impede either cover crop emergence, growth, or both.

We found that radish growth was not impacted by any of the pre-emergence herbicides applied at either a northern or southern South Dakota location when sampled in the fall just prior to cover crop planting. However, rye growth, as measured by shoot height and root weights, was reduced by all five herbicides applied at the southern location. At the northern locations, the injury was less with only one of six reducing root weight and three of six reducing shoot weight. Acetochlor, which was applied at the highest rate of any of this study's herbicides, and is microencapsulated to limit mobility and extend residual control (Vasilakoglou & Eleftherohorinos, 1997), resulted in the greatest injury at both locations.

Other studies have reported cover crop injury in field studies using the same or related herbicides. For example, Palhano et al. (2018) conducted similar studies with metolachlor, mesotrione, and atrazine in Arkansas; and Cornelius and Bradley (2017) used atrazine, acetochlor, flumetsulam, metribuzin, mesotrione, and *S*-metolachlor in Missouri to examine the carryover potential to fall-planted cover crops following corn harvest. Several cover crop species at these more southerly locations, which have a longer growing season and greater in-season rainfall than South Dakota, were sensitive to residual herbicides. Small-seeded broadleaf species were more likely to be affected than monocots or larger-seeded broadleaf species. In the Arkansas study, atrazine reduced cover crop density of Austrian winter pea (*Pisum sativum* L. var. *arvense*), crimson clover (*Trifolium incarnatum* L.), and hairy vetch (*Vicia villosa* Roth), emergence of berseem clover (*Trifolium alexandrinum* L.), and biomass of all cover crops evaluated. Mesotrione reduced the density of Austrian winter pea, cereal rye, and oat (*Avena sativa* L.), and the emergence of berseem clover. *S*-Metolachlor reduced density of crimson clover and emergence of barley (*Hordeum vulgare* L.), oat, and wheat (*Triticum aestivum* L.) (Palhano et al., 2018). In the Missouri study (Cornelius & Bradley, 2017), atrazine reduced the biomass of winter wheat, crimson clover, and Italian ryegrass (*Lolium multiflorum* Lam.). Flumetsulam reduced the biomass of winter wheat and hairy vetch and reduced the stand density and biomass of oilseed radish. Mesotrione also reduced biomass of Austrian winter pea and hairy vetch. Acetochlor, *S*-metolachlor, and metribuzin reduced crimson clover, Austrian winter pea, and hairy vetch biomass.

Our data support the previously observed injury reported from Arkansas and Missouri with herbicide residuals negatively impacting fall-seeded cover crops. The spring-applied herbicide should be considered when choosing a cover crop that will establish well to provide soil conservation services (Bauder et al., 2019; Hartzler & Anderson, 2020; USDA-NRCS, n.d.). However, due to climate and soil differences impacts on herbicide residuals, and differences in species sensitivity to herbicide carryover, these types of studies are appropriate for the diverse environments and species evaluations where cover crops are used. In addition, the length of this study was 6 wk, which, in South Dakota, may be at, or beyond, when a killing frost would occur. In more southern trials, a longer time frame may be appropriate and should be considered.

Another consideration is the injury symptoms, including when, or if, any occur, and if the plant survives, recovers, and thrives. For example, we observed injury symptoms on radish with some herbicides within the first few weeks of this trial, but the plants outgrew them, so that by the 6-wk harvest, no differences in root or shoot biomass were observed between the treatment and nontreated control. Rye, on the other hand, with some herbicides emerged, grew, but never outgrew the injury by harvest.

5 | CONCLUSION

Soil residual herbicides are applied in the spring to lessen weed problems, especially during the critical weed-free period, which occurs early in crop establishment. However, these herbicides may be present in soil at high enough concentrations to impact cover crop growth and establishment, especially after short season crops. This study showed that several of the commonly used herbicides did have residual activity and affected rye growth. It was unexpected that the Beresford site had all herbicides impeding rye growth, as this location had more GDD, higher precipitation, and a higher clay content in the soil than the Groton site. The clay may have resulted in more herbicide sorption, and thus, slower degradation, which resulted in greater bioavailabilty at the end of the season.

These types of information are needed to inform producers who want to maximize cover crop growth and minimize cost of planting seed that will not perform under their conditions. As there were no deleterious effects from these herbicides on tillage radish growth, it would be suggested as a cover crop following silage corn at either location that had been treated with these herbicides.

There are many reasons to plant a cover crop. In South Dakota, one criteria for success is to have at least 30% green cover on the soil prior to a killing frost to minimize wind erosion before snow cover. At Groton, radish or rye, at proper seeding rates and having typical fall rain events, could be established to meet this goal following applications of all the herbicides used in the study, except rye following acetochlor. At Beresford, radish was not influenced by these herbicides, however, all of these herbicides may reduce rye growth and a different cover crop species may be used to optimize fall growth. In addition, other species should be tested to provide more choices for a fall cover crop.

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CONFLICT OF INTEREST

The authors do not have any conflicts of interest regarding this manuscript.

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