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Influence of Six Herbicides Applied to Silage Corn on Fall Planted Rye and Radish Cover Crop Growth in South Dakota Soils

Sydney Pridie
South Dakota State University

INFLUENCE OF SIX HERBICIDES APPLIED TO SILAGE CORN ON FALL PLANTED RYE AND RADISH COVER CROP GROWTH IN SOUTH DAKOTA SOILS

Author: Sydney Pridie
Faculty Sponsor: Dr. Sharon Clay
Department: Plant Science

Abstract

Spring preemergence herbicide applications are often used for burndown of existing weeds and residual control, eliminating weed presence during early season crop growth. There has been an increased interest in planting cover crops soon after cash crop removal, due to the potential soil and production benefits. However, soil herbicide residuals may result in poor cover crop growth. This study examined the growth of radish (*Raphanus sativa*) and rye (*Secale cereal*), species often used as cover crops, in soils treated with residual herbicides about 100 days prior to cover crop planting. The herbicides were applied at recommended rates to silage corn in mid-May to early June at two sites, a southern site near Beresford, SD (Egan-Trent Silty Clay Loam soil), and a northern site near Groton, SD (Beotia Silt Loam soil). Soil samples were collected in mid-September, and greenhouse studies were conducted to examine if herbicide activity was great enough to injure the cover crops. Plant height and fresh weights of shoots and roots were compared to these parameters in plants grown in herbicide-free soil after six weeks of growth using a one-way paired t-test. Radish growth was unaffected by any herbicide. Several herbicides applied to the Groton soil reduced rye shoot weight, whereas in the Beresford soil several herbicides reduced rye shoot height and root weight. Rye shoot weight was reduced by 59% in Warrant treated soil at Beresford, however, at Groton, three herbicides reduced shoot weight by about 25% (Python, Warrant, and Spirit). Rye shoot height was reduced by about 23% by two herbicides (Parallel, Warrant) in Groton soil and by about 16% by three herbicides (Glory, Python, Acuron) in the Beresford soil. Rye root weight was reduced by 35% or more by five herbicides (Parallel, Glory, Python, Warrant, and Acuron) in the Beresford soil, but only by Warrant (44%) in the Groton soil. This data indicates that herbicide residuals can be present in high enough concentrations after a short season crop to injure fall planted cover crops and that injury is herbicide, crop species, and soil specific. Further studies are needed to understand the influence of specific soil, herbicide, climatic conditions, and cover crop species where herbicide injury is possible. The results can be used by growers to select herbicide/cover crop species combinations that will be most successful for farms.

Introduction

Herbicides are a large part of agriculture today, providing a relatively simple solution to control weed problems. They must be effective to kill the weeds, but not harmful to present or future crops. Soil applied pre-emergence herbicides are used for their ability to kill germinating seeds for four- to six-weeks after a single application, allowing the crop to become established. While herbicide residual can be good for continued weed control, it can become a problem if the grower wants to plant a cover crop, especially following the harvest of a short-season cash crop. The herbicide residual may remain in the soil at too high a concentration or be at a high enough activity level to kill or injure specific sensitive cover crop species. This project examined rye and radish response in the fall to several corn herbicides known to have different lengths of residual activities and different spectrums of weed species controlled that were applied in the spring (Bosak and Davis, 2014).

Cover crops are defined as “crops planted between cash crops to cover and protect the soil,” which benefit the soil through “reduced soil erosion, increased soil organic matter, increased biological diversity, increased nitrogen supply, and weed control” (Wang, 2018). A variety of different plants can be used as cover crops, and while legumes and grasses are the most widely used, there has recently been an increase in use of brassicas. Brassica cover crops have a wide array of available types, depending on the season during which the cover crop will be used (SARE, 2010). In South Dakota, most growers will use winter annuals between their spring cash crop rotations. Cool season brassicas and mustards that would survive the climactic conditions include rapeseed (*Brassica napus*), turnip (*Brassica rapa* subsp. *rapa*), radish (*Raphanus raphanistrum* subsp. *sativus*), crambe (*Crambe L.*), kale (*Brassica oleracea* var. *sabellica*), swede (*Brassica napobrassica*), and mustard (*Brassica rapa* subsp. *oleifera*). Additional cool season nonlegume broadleaves include sugar beet (*Beta vulgaris* subsp. *vulgaris*) and flax (*Linum usitatissimum*). Cool season legume broadleaf options include alfalfa (*Medicago sativa*), sweet clover (*Melilotus officinalis*), red clover (*Trifolium pratense*), white clover (*Trifolium repens*), alsike clover (*Trifolium hybridum*), hairy vetch (*Vicia villosa*), chickling vetch (*Lathyrus sativus*), field pea (*Pisum sativum*), and lentils (*Lens culinaris*). Cool season grasses include rye (*Secale cereale*), wheat (*Triticum*), barley (*Hordeum vulgare*), oats (*Avena sativa*), triticale (*Triticosecale*), annual ryegrass (*Lolium multiflorum*), and tall wheatgrass (*Thinopyrum ponticum*) (USDA-NRCS, undated). The grower must select a cover crop based on their cropping rotation, the cost of implementing the cover crop, seed and planting cost, the benefits they want to obtain by using the cover crop, and how they plan on terminating the cover crop prior to planting the next cash crop.

Termination of the cover crop in the spring prior to or at planting of the cash crop cannot be overlooked and growers should be concerned about this important step. If spring conditions are not conducive to termination, or if the cover crop vigorously regrows if not totally controlled, the cover crop then acts as a weed. Most crops have a critical weed free period, which is different for each crop species and is affected by factors such as weed community, cropping practices, and environment (Hartzler, undated). The critical weed free period is the length of time that the crop must remain weed free to prevent yield loss at a certain level (Tursun et al., 2016). This critical time period is an important aspect to consider when planning for effective weed control. The critical weed free period for corn is from V3-V8, or from the third leaf stage to approximately the eighth leaf stage (Page et al., 2012). Weeds that are removed during or just after this period can still have negative effect on crop growth and yield that are not recoverable (Horvath et al., 2018). If weeds (or cover crops) are present, crop losses can range from 0% to nearly 100%, depending on the timing and density of the competing plants.

The Sustainable Research and Education (SARE) program conducted their fifth annual cover crop survey in 2016 and obtained feedback from 2,102 farmers. The respondents reported that 88% were using cover crops across the United States. Cereal rye was the most used cover crop, followed by oats and radish. The survey asked farmers about perceived benefits of using cover crops, and their explanations were important for understanding why they adopted cover crops into their cropping systems. The primary benefit was improved soil health, with yield benefits and economic returns also listed as most desired potential benefits. The responses indicated that while yield and economic benefits are a strong factor, they're not as widespread as the belief in improved soil health. The three major concerns among growers who were not using cover crops included time and labor for implementing them in their system, fear of no economic return, and concerns that the cover crop could become a weed. Additional concerns were increased production risks, getting a good cover crop stand, fear of yield reduction, and selecting the right cover crop species. The survey had eight supplementary questions for 178 non-users about what factors had the biggest influence on their decision to plant cover crops and asked them to rate their agreement level with each statement. Cost share or incentives received the highest positive associations, with free technical assistance being close behind. More information on cover crop species and more knowledge of cover crop benefits were also positively associated answers. Tax credit and discounted insurance premiums received lower positive rankings, concluding that other than cost share or incentives, the factors that received the highest responses were about information (CTIC, 2017).

Although South Dakota cover crop usage has increased over the last decade, low commodity prices have growers trying to reduce input costs, especially inputs that have varying or unknown return. In order to see a quicker return, South Dakota State University has started researching livestock integration. In the spring of 2017, a study about adoption of conservation practices and precision technologies was conducted in South Dakota, with almost 200 participants, most of whom were from eastern South Dakota. The survey results showed that 51% raised either dairy or beef cattle, and of those with livestock, 94% grazed residue, and only 39% reported grazing cover crops. Within the total respondents, 31.3% used cover crops in their operation during 2016, with 64.5% using cover crops when livestock was integrated into their production system. The survey also included questions about why they did or did not use cover crops in their operations. "Improves soil health," "Increases farm productivity," and "Improves water availability/water conservation" were the highest reasons for adopters. "Planting time conflicts with harvest of cash crops" and "Satisfied with current practices" were the highest ranked responses among non-users. The results for cover crop producers and those using livestock were then compared to analyze the difference in adoption reasoning. Although the top three reasons for adoptions remained the same between the two groups, "Helps with livestock integration" increased by 18% and "Increases farm profitability" increased by over 52%. While other variable expenses need to be considered, such as seed cost and planting, fencing, and labor, additional costs may be offset by not having cattle in the yard and reducing time spent feeding, bedding, and cleaning (SDSU Extension, 2019).

According to the 2018 State Agriculture Overview for South Dakota, there were 360,000 harvested acres of silage corn (USDA-NASS, 2019). Silage corn is a high-quality forage crop used on dairy and beef cattle farms. It's a popular feed choice for livestock as it becomes high in energy and easily digestible when the entire plant is chopped (South Dakota Corn, 2015). Silage corn is harvested based on percent moisture content of the corn and the type of ensiling used (bunker, bag, or tower silo), but often starts in mid to late August (University of Wisconsin Extension, 2016). Grain corn, in comparison, is harvested at physiological maturity in mid to late October. The early harvest of silage corn allows for planting and establishment of cover crops in the fall in northern climates, whereas cover crops after grain corn harvest often cannot be successfully incorporated into crop production management.

When deciding to plant cover crops, another aspect to consider is the herbicides that are used in season for the cash crop. Long residual pre-emergent or early post-emergent herbicides, while providing needed weed control, may cause stand reduction or complete cover crop failure. This effect is not the same for every herbicide and is confounded by many other factors, which include but are not limited to growing season climate, rainfall, and soil type. The choice of cover crop species also may influence the outcome, as some cover crops may not be controlled by the herbicide. In addition, growers need to consider the rotational restrictions of the herbicides they're using, especially if the cover crop will be grazed. Herbicide labels will list the rotational restrictions under "rotational crop restrictions" or "rotational crop guidelines." If the cover crop is going to be used for grazing or forage, specified guidelines can often be found under "forage restrictions" on the herbicide label. Some labels list common cover crops and rotational intervals to better inform producers, however, this may not be included. The crop rotation interval is "the required time between application time and the time of next planting." It is used to ensure that the potential herbicide residual will not affect plant establishment and that no unsafe levels of herbicide are in plant tissues (SDSU Extension, 2018).

This study examined several commonly used corn herbicides that are known to provide residual control (see Table 1). These are labeled for application in a silage corn crop. The use of cover crops after silage corn harvest would be an ideal time to plant cover crops, as early fall rains and temperatures would provide good growing conditions for the cool season covers. However, herbicide residuals may be too high to allow for good establishment or growth.

Herbicides have been placed into groups that have similar mechanisms of action by Weed Science Society of America to help producers rotate chemicals to limit the occurrence of herbicide resistant weeds. The group numbers are found on the herbicide label. In the following paragraphs, herbicides with the same group number as discussed, as these have similar mechanisms of action, similar weed control spectrums, symptomology, and other common characteristics. The specifics (weeds controlled, soil half-life, expected injury symptoms, etc.) when the information differs for each herbicide used are provided as well.

The group 15 herbicides used in this study include metolachlor, acetochlor, and S-metolachlor. These herbicides all inhibit very long chain fatty acid synthesis and are applied pre-emergent to the weed. Parallel is a pre-emergent herbicide containing the chemical metolachlor. It is used to control most annual grasses and certain broadleaves. Metolachlor has a half-life of 91-152 days, and Parallel has a suggested cover crop planting date of 135 days for rye (Adama Essentials, 2012). Warrant is the trade name for a pre-emergent herbicide containing acetochlor that can control annual grasses and broadleaves. It has a suggested cover crop planting date of 120 days for rye and a half-life of 56-84 days (Monsanto, 2014). Acuron is a pre-emergent herbicide used to control grasses and broadleaves, containing S-metolachlor, which has a half-life 91-152 days and a suggested cover crop planting date of 120 days for rye (Syngenta, 2018). These group 15 herbicides are seedling shoot growth inhibitors that acts as long-chain fatty acid inhibitors in the plant. Seedling growth inhibitors interfere with new growth during germination or early emergence, which results in inability to emerge or abnormal development. Grasses will often produce malformed or twisted seedlings with leaves that are unable to unfurl, known as buggy-whipping (Fig. 1a). Broadleaf symptomology from this mode of action may result in cupped or crinkled leaf tissues (Fig. 1e), or a shortened main leaf vein, causing “drawstring” appearance (Fig. 1b) (Shumway and Scott, 2016).

The study also used some group 5 herbicides, including metribuzin and atrazine. Group 5 herbicides inhibit photosynthesis and can be applied pre or post-emergent but need to be translocated to the leaves to be active. They are translocated in the water stream (xylem) and show the symptoms in the oldest leaves. Glory is a trade name for metribuzin, which is used to control annual grasses and annual broadleaves. The suggested cover crop planting date is 120 days for rye and 540 days for radish, with a half-life of 14-28 days (Adama Essentials, 2011). Acuron also contains atrazine, which has a half-life of 30 days (Syngenta, 2018). These herbicides are photosynthesis inhibitors, so root development and seed germination are not affected. Signs of photosynthesis inhibitors are observed in the leaves with interveinal and leaf margin chlorosis (yellowing) of the leaf tissue (Fig. 1c), followed by necrosis (dead, browning tissues) (Fig. 1d). This herbicide moves in the xylem (apoplastic translocation) and injury symptoms are first observed in older leaf tissue, as these have the greatest transpiration rates (Shumway and Scott, 2016).

Group 2 herbicides used in this cover crop study include flumetsulam, primisulfuron-methyl and prosulfuron. These group 2 herbicides are amino acid synthesis inhibitors that act within the plant as acetolactate synthesis (ALS) inhibitors, which stops the synthesis of branched chain amino acids, and subsequently stops protein synthesis. Flumetsulam, another pre-emergent herbicide, is labeled under the trade name Python. It is used primarily to control broadleaves and has a reported half-life of 60 days. The recommended cover crop planting date after application is 120 days for rye and 270 days for radish (Dow AgroSciences, 2017). The post-emergence herbicide Spirit, containing the chemicals Primisulfuron-methyl and Prosulfuron, is used to control broadleaves. The suggested cover crop planting date after a Spirit application is 90 days for rye and 540 days for radish. Primisulfuron-methyl has a half-life of 30 days, while Prosulfuron has a half-life of 19 days (Syngenta, 2013). These herbicides often have foliar and soil activity and may be labeled for both pre- and post- emergence applications. Depending on the herbicide, soil residuals may be prolonged, causing potential carryover problems. Common symptoms include inhibition of new growth within the meristematic region, resulting in stunting, chlorosis in new growth within 1-3 days, which later becomes necrotic, with older tissue becoming chlorotic and necrotic later in development, and loss of growing point, resulting in lack of new growth. Monocots may produce reddish to purple pigmentation on older leaf tissue (Fig. 1g), while dicots may develop purple pigmentation within the main veins of leaf tissue (Fig. 1h). Although less defined, there can sometimes be a root pruning effect. There may be stacking of nodes (no elongation of stem), resulting in short, less competitive plants, and cessation of growth shortly after emergence in some seedling plants. These symptoms may be confused with non-herbicidal symptoms such as nutrient deficiencies (especially phosphorus due to purpling of leaf tissue) or plants grown in saturated soils (Shumway and Scott, 2016).

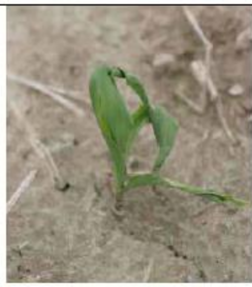
Acuron also contains mesotrione and bicyclopyrone, the two group 27 herbicides used in the study. Group 27 herbicides are pigment inhibitors that act as 4-hydroxyhenyl-pyruvatedioxygenase (HPPD) inhibitors, which stops the production of plastoquinones. Although these herbicides are in the same group, they have different half-lives, 5-15 days (mesotrione) and 213 days (bicyclopyrone). The herbicide label has a suggested cover crop planting date of 120 days for rye, but due to the long half-life of the bicyclopyrone component, a limited field test in areas suspected to have the greatest carryover potential is recommended (Syngenta, 2018). As pigment inhibitors, mesotrione and bicyclopyrone lead to bleached (white) appearance (Fig. 1f) when plastoquinone production is stopped. Seedlings that emerge are bleached white (Fig. 1i), and later become necrotic. Under certain growth stages and environmental conditions, there may be reddish-purple pigmentation (Shumway and Scott, 2016).

Table 1. Herbicides, rates, suggested cover crop planting dates, and target species.
*(Shaner, 2014)

Herbicide Trade Name	Chemical Name(s)	Mode of Action*	Site of Action*	Half-Life*	Rate Applied/Ac	Suggested Cover Crop Planting Date	Herbicide Target Weeds
Parallel	Metolachlor (Group 15)	Seedling Shoot Growth Inhibitor	Long-chain Fatty Acid Inhibitor	91-152 d	2 pt.	135 d (rye)	Most annual grasses and certain broadleaves
Glory	Metribuzin (Group 5)	Photosynthesis Inhibitor	Photosystem II Inhibitor	14-28 d	8 oz	120 d (rye) 540 d (radish)	Annual grasses and annual broadleaves
Python	Flumetsulam (Group 2)	Amino Acid Synthesis Inhibitor	ALS Inhibitor	60 d	1.33 oz	120 d (rye) 270 d (radish)	Broadleaves
Warrant	Acetochlor (capsulated form) (Group 15)	Seedling Shoot Growth Inhibitor	Long-chain Fatty Acid Inhibitor	56-84 d	3 qt	120 d (rye)	Annual grasses and broadleaves
Acuron	S-metolachlor, Atrazine, Mesotrione, Bicyclopyrone (Group 15, 5, 27, 27)	Seedling Shoot Growth Inhibitor, Photosynthesis Inhibitor, Pigment Inhibitor, Pigment Inhibitor	Long-chain Fatty Acid Inhibitor, Photosystem II Inhibitor, HPPD Inhibitor, HPPD Inhibitor	91-152 d, 30 d, 5-15 d, 213 d	3 qt	120 d (rye) Field test recommended	Grasses and broadleaves
Spirit	Primisulfuron-methyl, Prosulfuron (Group 2, 2)	Amino Acid Synthesis Inhibitor	ALS Inhibitor	30 d, 19 d	1 oz	90 d (rye) 540 d (radish)	Grass and Broadleaves

Using the label and symptomology information, the carryover potential of these herbicides in two soils using two different cover crop species was examined under greenhouse conditions. Initial herbicide damage seen included cupping, interveinal bleaching (Figure 2), and some necrosis in radish, and buggy whipping and purple pigmentation in rye. Although there were initially herbicide damage symptoms, as the crops continued to grow, they mostly outgrew the visible damage symptoms.

Figure 1. Herbicide damage symptomology



a. Buggy Whipping (Group 15) https://ipm.missouri.edu/IPCM/2009/4/Cool-Wet-Soils-Can-result-in-More-Corn-Injury-from-Preemergence-Residual-Herbicides/

b. Drawstring Leaves (Group 15) http://www.wiscweeds.info/img/2018%20Herbicide%20SOA%20injury%20chart/2018_HerbicideInjury_EN.pdf

c. Interveinal Chlorosis (Group 5 + 2) http://www.reflector.com/Look/2017/07/01/Herbicide-damage-in-landscapes.html

d. Interveinal Necrosis (Group 5 + 2) https://www.btny.purdue.edu/Extension/Weeds/HerbInj2/InjuryHerb1.html

e. Cupped Leaves (Group 15) https://www.dtnpf.com/agriculture/web/ag/news/crops/article/2017/06/02/suspect-dicamba-damage-3

f. Interveinal Bleaching (Group 27) https://plants.uaex.edu/herbicide/docs/HERBICIDE_SYMPTOMOLOGY_MANUAL_2016_V1.0.pdf

g. Purple Pigmentation (Group 27)

h. Purple Leaf Veins (Group 2)

i. Bleached Seedlings (Group 27) http://fieldcropnews.com/2012/07/herbicide-injury-

https://plants.uaex.edu/herbicide/docs/HERBICIDE_SYMPTOMOLOGY_MANUAL_2016_V1.0.pdf	https://plants.uaex.edu/herbicide/docs/HERBICIDE_SYMPTOMOLOGY_MANUAL_2016_V1.0.pdf	scenarios-in-corn-diagnostic-day-plots/

Materials and Methods

At Groton, SD and Beresford, SD research sites (Table 2), five different pre-plant herbicides were sprayed in strips in early to mid-May (Table 2). Soil type was a Beotia Silt Loam at Groton, and an Egan-Trent Silty Clay Loam Beresford (Table 2). The herbicides Parallel, Glory, Python, Warrant, and Acuron were applied at labeled rates (Table 1). Treatments were applied in a randomized complete block design with four replications. Corn was planted May 17th at Beresford and May 5th at Groton. After the crop was planted, Spirit, a post-plant herbicide, was applied at the Groton location on May 7th. The corn grew without other herbicide treatments and was harvested for silage in mid to late August.

After harvest, soil samples were taken with a soil probe from 0-10 cm depth at Beresford on September 16th and at Groton on September 18th (Table 2). The samples were put in plastic bags, thoroughly mixed, and sealed. The plastic bags were then put into paper bags that had been labeled with the sample locations number, the field location, and the date of sampling. Samples were placed in a 5°C cooler until the greenhouse test was established, about 6 weeks after sampling.

Table 2. Herbicide application date, weather (GDD day, rainfall from application to soil sampling) and soil type at study locations

Location/ Herbicide	Date Applied	Date Soil Sampled	Number of Days	Rainfall (mm)	GDD (Base 10°C)	Soil Type
Beresford						
Pre-emerge	5/16/2018	9/16/2018	122	443	1469	Egan-Trent Silty Clay Loam[a]
Groton						
Pre-emerge	5/4/2018	9/18/2018	136	266	1393	Beotia Silt Loam[b]
Spirit	6/7/2018	9/18/2018	102	236	1096	Beotia Silt Loam[b]

a. Average of 25-35% clay and 3-15% sand
b. Average of 18-27% clay

In the greenhouse, conetainers (4 mm in diameter and 21 mm in height) were filled with about 5 cm of sand and then 8 cm of sample soil was applied over the top. The sand was used to help with water movement and to have enough sample soil for other experiments. Four radish or four rye seeds were planted into each soil. Soil samples for each cover crop species by herbicide were done in duplicate, and with the four field replicates, each herbicide by soil treatment had eight replicates. Conetainers were watered from the top when necessary.

The plants were harvested after 6 weeks and measurements for shoot length, shoot weight, root length, and root weight were taken. In order to measure shoot height, plant shoots were clipped off at the soil line. The roots and soil were then taken out of the conetainers and rinsed to separate most of the soil from the roots, allowing the measurement of root length. The shoots were then placed in an envelope with the treatment number for reference when weighing. The roots were placed in a mesh bag and rinsed with a sink sprayer, enabling the remove of the rest of the soil. After rinsing, the roots were patted dry and measured on a scale for weight. The same scale was used to measure the shoot weight. The data were analyzed separately by locations using a one-way paired t-test to compare parameters of plants grown in herbicide to non-treated soil.

Results

Rainfall and warm temperatures influence herbicide dissipation (Curran, 2001). After herbicide application, the number of days to sampling was 122 days at Beresford, 136 for the pre-emerge herbicides and 102 for Spirit at Groton (Table 2). At the Beresford site, rainfall from application to harvest was 443 mm and GDD (base 10°C) were 1469. At Groton the rainfall from application to harvest was 266 mm for the pre-emerge herbicides and 236 for Spirit and GDD was 1393 for the pre-emerge herbicides and 1096 for Spirit (Table 2). Based on this it would be expected that there would be greater herbicide dissipation at Beresford, as increased temperatures and soil moisture increases chemical decomposition rates. In addition, soil type can influence herbicide sorption, with more sorbed to clay particles compared with sand. The higher clay content at Beresford may result in higher herbicide residues at the end of the season (Curran, 2001). Additionally, the specific active ingredient of the herbicide influences the herbicide half-life (time to ó concentration). All the herbicides tested have been reported to have ó lives longer than 30 d, which could lead to susceptible plant injury after a short-season crop. Cover crop planting dates based on labelled recommendations range from 90 to 540 days (Table 1). However, some recommend field testing in addition to the suggested days. Since climate and soil type also influence the herbicidal activity, this study can be used to get a better understanding of which herbicide/cover crop species may be more successful than others at different South Dakota locations.

Figure 2. Herbicide damage on radish

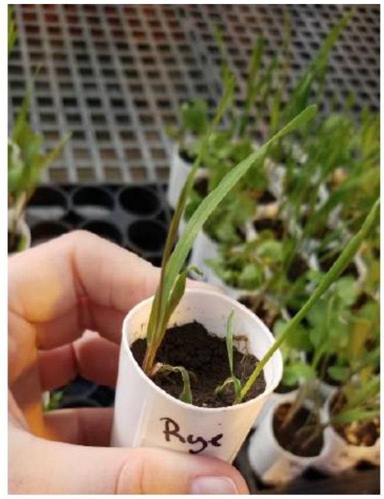


Figure 3. Herbicide damage on rye

While symptoms were observed early in the radish, the radish data showed no injury from any of the herbicides at the end of the experiment. When compared with growth from the non-treated soil, several herbicides reduced rye shoot fresh weight, height, and root weight with some locational differences (Table 3). Rye shoot weights were reduced by 59% with Warrant in Beresford soil and 31% (Python), 23% (Warrant), and 27% (Spirit) in Groton soil. Rye shoot heights in Beresford were reduced by 23% (Parallel), 19% (Glory), 15% (Python), 22% (Warrant), and 15% (Acuron) (Figure 3). Rye root weights were reduced by 35% (Parallel), 38% (Glory), 49% (Python), 54% (Warrant), and 35% (Acuron) in Beresford soil and 44% (Warrant) in Groton soil.

Table 3. Measured shoot weight, shoot height, root weight, and P-values compared to respective control

	Shoot						Root	
	Weight (g)	P-value		Height (cm)	P-value		Weight (g)	P-value
Beresford								
Control	0.56			17.33			0.30	
Parallel	0.52	ns		13.35	0.002		0.19	0.017
Glory	0.46	ns		14.07	0.005		0.18	0.011
Python	0.38	ns		14.69	0.008		0.15	0.004
Warrant	0.23	0.001		13.54	0.002		0.14	0.000
Acuron	0.42	ns		14.65	0.008		0.19	0.007
Groton								
Control	1.03			19.69			0.63	
Parallel	1.03	ns		18.17	ns		0.60	ns
Glory	1.13	ns		19.96	ns		0.43	ns
Python	0.72	0.034		18.99	ns		2.14	ns
Warrant	0.79	0.034		19.23	ns		0.35	0.019
Acuron	1.00	ns		19.72	ns		0.47	ns
Spirit	0.75	0.037		19.59	ns		0.69	ns

Discussion and Conclusion

Other studies have reported cover crop injury in field studies using the same or related herbicides. For example, Palhano et al. (2018) conducted studies in Arkansas to determine the sensitivity of soil applied herbicides that were also included in our study (metolachlor, mesotrione, atrazine) and carryover potential of herbicides to fall-applied cover crops following corn harvest. These studies conclude that several cover crop species at this more southerly location after a longer season than SD conditions were sensitive to low rate residual herbicides commonly applied in corn, cotton, and soybean, with small-seeded broadleaf cover crops more likely to be affected. In the sensitivity study, atrazine reduced cover crop density of Austrian winterpea, crimson clover, and hairy vetch, emergence of berseem clover, and biomass of all cover crops evaluated. Mesotrione reduced density of Austrian winterpea, cereal rye, and oats, and emergence of berseem clover. S-metolachlor reduced density of crimson clover and emergence of barley, oats, and wheat. In the carryover study, the 2x rate application did not affect emergence or biomass production of cover crops, but it should be emphasized that persistence of these herbicides will vary based on soil and environmental factors, meaning these results cannot be generalized overall production environments (Palhano et al., 2018). This shows that other cover crop studies have also found that cover crops can be negatively impacted by soil residual herbicides.

In another study in Missouri, Cornelius and Bradley (2017) determined the residual effects of common corn and soybean herbicides used in the Midwest on fall cover crop establishment. Some of the herbicides observed were also included in our study, including atrazine, acetochlor, flumetsulam, metribuzin, mesotrione, and S-metolachlor. Atrazine was shown to reduce biomass in winter wheat, crimson clover, and Italian ryegrass in the corn herbicides. In the soybean herbicide study, acetochlor reduced biomass and stand density in crimson clover, which is consistent with the 8-month rotational restriction listed on the herbicide label. Biomass of winter oat, Austrian winterpea, and hairy vetch were also reduced by acetochlor. In the corn herbicides, flumetsulam reduced the biomass of winter wheat, oilseed radish, and hairy vetch and stand density of oilseed radish. Flumetsulam herbicide has a rotational restriction of 26-months for canola, which is likely to have similar herbicidal sensitivity in oilseed radish. In the soybean herbicide carryover, metribuzin reduced biomass of crimson clover, Austrian winterpea, and hairy vetch. As a corn herbicide, biomass was reduced in Austrian winterpea and hairy vetch by mesotrione. S-metolachlor in the soybean herbicides reduced biomass of crimson clover, Austrian winterpea, and hairy vetch (Cornelius and Bradley, 2017). This shows that in the Midwest, herbicide residuals after corn and soybean impact cover crop growth and must be considered when choosing a productive cover, although there were some differences due to climactic variances compared to South Dakota.

Herbicides with soil residual are used in the spring to lessen weed problems, especially during the critical weed-free period, which occurs during 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. The degree of injury from each residual was different between species and location. Several herbicides (flumetsulam, acetochlor, and primisulfuron-methyl + prosulfuron) in the Groton soil reduced rye shoot weight, whereas in the Beresford soil more herbicides (metolachlor, metribuzin, flumetsulam, acetochlor, and S-metolachlor + atrazine + mesotrione + bicyclopyrone) reduced rye shoot height and root weight. The Beresford site saw more reduction from more herbicides than the Groton location, even though GDD were greater and temperatures warmer.

The information provided here can be used by producers in order 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 radish growth, it could be planted as a cover crop following silage corn that had been sprayed with these herbicides. Rye could be planted following applications of all the herbicides used in the study, except Warrant, and would be more likely to see reduced biomass at the Beresford location. The study will be repeated in 2019 to better understand how different climatic conditions may impact cover crop growth and determine if results are similar between years.

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