**Herbicide carryover evaluation following commonly applied silage corn and soybean herbicides** **ABSTRACT**

Cover crop establishment following herbicide use can be a challenge due to the residual properties of some herbicides. The objective of this study in 2013 and 2014 was to determine the effects of 28 commonly utilized corn and soybean herbicides on cover crop percent green cover (PGC), normalized vegetative difference index (NDVI), dry biomass weight (DW), and stand count (SC). Cover crops included winter rye (*Secale cereal*), crimson clover (*Trifolium incarnatum*), radish (*Raphanus* sp;), 70% oat (*Avena sativa*) plus 30% peas (*Pisum sativum)* mixture, and ‘King’ and ‘Bruiser’ annual ryegrasses (*Lolium multifloram*). NDVI and PC data were significantly correlated for all cover crops except crimson clover. In 2013, all cover crops except winter rye had herbicide injury shown through a significant reduction in PGC, NDVI, SC, or DW. In 2014 only ‘Bruiser’ annual ryegrass had significant herbicide injury with a reduction in DW. Annual ryegrass species winterkilled in 2013-2014 winter. Weather in May and June of the 2013 growing season after herbicide application received 74 mm more precipitation and was on average was 2.5 C° cooler than 2014. The precipitation event frequency was greater in May and June 2013 than 2014 which may have led to greater pesticide leaching and degradation. Cover crop herbicide carryover injury from commonly applied corn and soybean herbicides may reduce cover crop NDVI, PGC, DW, and SD, and injury is dependent upon year and cover crop species by cover crop combination.

**Introduction**

The application of soil residual herbicides is part of the best weed management strategies to help prevent herbicide resistance weeds (Norsworthy et al., 2012). The use of soil residual herbicides has proven to significantly reduce weed populations, including herbicide-resistant waterhemp (*Amaranthus tuberculatus)* and palmer amaranth (*Amaranthus palmeri*) (Meyer et al., 2015). However, depending on herbicide properties and weather conditions, residual herbicides could persist long enough to cause negative effects on subsequent sensitive crops (carryover). When herbicide carryover occurs, it is likely to affect subsequent crop in the form of stand reduction, visual observation of poor plant health and color, and/or a reduction of plant productivity usually noticed in reduction of vigor and biomass accumulation (Marchesan et al., 2010).

Several studies documented the impact of herbicide carryover and persistence issues in several commodity crops following herbicide application in corn and soybean (Ahrens and Fuerst, 1990; Curran et al., 1991; Alister and Kogan, 2005; Barnes and Lavy, 1991; Horowitz, 1969; Loux and Reese, 1993; Renner et al., 1988; Walsh et al., 1992a; 1992b). In the last decades, with interest on conservation agricultural practices, there have been an increase of growers’ adoption of cover crops in their operation. Cover crops are used as a conservation management practice to reduce erosion, scavenge or provide nutrients, suppress weeds, and improve overall soil quality (Hartwig and Ammon, 2002; Snapp et al., 2005). However, implementing cover crops in the upper Midwest United States is a challenging, especially with cover crop establishment after crop harvest.

For cover crops to accomplish their intended goals, they must establish well; establishment of cover crops can be compromised by use of residual herbicides for a period of time after application, applied to the preceding cash crop. The persistence of residual herbicides might affect the cover crop establishment later in the growing season. In addition, persistence of soil residual herbicides can be affected by a wide range of management (tillage, application rate, and herbicide application method) and soil properties (moisture, temperature, soil colloid properties, chemical reactions, pH, microbial population, soil texture and organic matter) (Krausz et al., 1998). For example, it was showed that residual herbicides applied on corn and soybean can persist in the soil longer than initially desired at the time of application and injure the following fall seeded cover crop (Cornelius and Bradley, 2017; Kending et al., 1991; Yu et al., 2015). Therefore, it is likely the use of soil applied herbicides with residual activity might negatively impact the establishment of cover crops seeded in the fall.

There is evidence that herbicide carryover potential on cover crops is greatly influenced by precipitation following herbicide application (Cornelius and Bradley, 2017), and higher soil clay content (Kendig, et al. 1991). Also, Cornelius and Bradley (2017) documented that herbicide carryover injury was not consistent from several growing seasons. In addition, the application of different soil residual herbicides is possible to cause different responses on cover crop species. Yu et al. (2015a) found that fall seeded cover crops had different responses to soil applied herbicides, including saflufenacil + dimethenamid-P, *S*-metolachlor + atrazine + mesotrione, and imazethapyr. Thus, there is evidence of increase on complexity of cover crop establishment when growers use soil-applied herbicide.

In Wisconsin, growers commonly plant silage corn for their livestock operation. With the possibility of using cover crops for gazing or forage, Wisconsin growers increase their interest on cover crops. However, there is no information available on the carryover effects of commonly applied herbicide on regularly used cover crops following silage corn and soybeans. We hypothesize that residual herbicide use might negatively affect fall seeded cover crops, including annual ryegrass (*Lolium multiflorum*), crimson clover (*Trifolium incarnatum*), radish (*Raphanus* spp), oat (*Avena fatua*), and oat/pea (*Pisum sativum*) mixture. The objective of this research was to determine if herbicides that are commonly applied to silage corn or soybean adversely affect cover crop dry biomass weight. We also evaluate how related the normalized difference vegetative index (NDVI) is in predicting outcomes of another variable, including herbicide injury, cover, and dry matter biomass weight.

**Materials and Methods**

**Site Description.** Field experiments were conducted at the University of Wisconsin Arlington Agricultural Research Station near Arlington, WI (43.30 °N, 89.33°W) during 2013 and 2014. Each year corn and soybean trial was located side by side in a Plano silt loam (fine silty, mixed, mesic Typic Argiudoll) soil with a pH of 6.3 and 3.4 % organic matter in 2013, and pH 6.85 with 3.35 % organic matter in 2014. Monthly (May-October) precipitation and temperatures for 2013 and 2014 were recorded (Table 1).

Fifteen herbicide treatments within each corn (Table 2) and soybean (Table 3) trial were arranged as a randomized complete block with four replications. Six cover crop species were planted perpendicular in strips across herbicide treatments within blocks, but the order of the cover crops species strips (plus non-planted strip) were randomized across herbicide blocks to make randomized subplots for each herbicide x cover crop combination. Previous to trial establishment, fields were in a corn-soybean crop rotation and were minimum tilled by a chisel plow the previous fall followed by spring field cultivation prior to planting.

Hybrid corn planted in 2013 was DKC53-45 RIB (DEKALB brand, Bayer Crop Science, St Louis, MO) and in 2014 FS36RV4 RIB (FS InVision brand, FS Seeds, Bloomington, IL). Soybean varieties used were AG 2031 (Asgrow brand, Monsanto Company, St. Louis, MO) in 2013 and S22-S1 (Syngenta Seeds Inc., Greensboro, NC) in 2014. Both corn and soybean trials were planted 3 June 2013 and 22 May 2014 using a 3 m wide vacuum planter (Model 1750, John Deere, Moline, IL). Herbicide plots were 3 m wide x 15 m long and included four 76-cm wide rows in both crops. Corn seeds were planted 3.8 cm deep at 81,000 seed ha-1, and soybean seeds were planted 2.5 cm deep at 385,000 plants ha-1.

Pre-emergence (PRE) herbicide treatments were applied for both corn and soybean trials on 9 May 2013 and 22 May 2014. Early-postemergence (EPOST) herbicides were applied to V2 corn development stage on 18 June 2013 and 9 June 2014. POST soybean applications at V3 soybean development stage and late postemergence (LPOST) applications were applied to V4 corn development stage on 2 July 2013 and 23 June 2014. All treatments were applied at full-labeled rates and the herbicides are commonly recommended to growers (Jensen et al. 2018). All treatments were applied with a CO2-pressurized back-pack sprayer at 4.8 km h-1 delivering 140.2 L ha-1 of spray solution at 172 kPa pressure using XR11002 flat-fan nozzles (Spraying Systems Co. Wheaton, IL). Corn and soybean plots were also sprayed POST twice each year to minimize weed competition with glyphosate (Touchdown Total, Syngenta Crop Protection, Greensboro, NC) at 1.17 kg acid equivalent per ha-1 and ammonium sulfate at 7.7 kg per 387.5 L of water. These POST maintenance applications were applied with a tractor mounted three-point sprayer with a 6 m boom delivering 140.2 L ha-1 of spray solution at 276 kPa pressure, using Air Induction Extended Range (AIXR11002, Spraying Systems Co., Wheaton, IL) flat-fan nozzles.

Both corn and soybean trials were harvested as forage with a self-propelled forage chopper on 8 September 2013 and 15 September 2014. Six different cover crop species and/or varieties were no-till seeded uniformly perpendicular across all herbicide treatments on 9 September 2013 and 17 September 2014. Cover crops were seeded using a 2.5 m wide no-till drill (Tye, AGCO, Duluth, GA) with three rows closed off to allow for six cover crops to be spaced evenly in the 15 m corn and soybean herbicide plots. To consistently plant the cover crops within the plots, real time kinetics (RTK) guidance (Auto Trac™, John Deere, Moline, IL) was used. The cover crop plots were 1.95 meters wide with row spacing of 19 cm. Cover crops planted were radish at 12.3 kg ha-1, crimson clover at 11.2 kg ha-1, winter rye at 134.4 kg ha-1, 70% oat (*Avena sativa*) plus 30% peas mixture at 100.8 and 33.6 kg ha-1, and two annual ryegrass varieties at 37 kg ha-1. The annual ryegrass varieties included ‘Bruiser’ and ‘King’. Winter rye and the 70% oats 30% pea mixture were planted 2.5 cm deep. Crimson clover, radish, and annual ryegrass varieties were planted 0.6 cm deep.

**Data Collection.** Cover crop biomass collection occurred before, but as close to, the first killing frost as best as could be predicted from weather forecasts in 2013 and 2014. Biomass was collected from 25 cm linear row in each subplot from an arbitrarily selected corner. The biomass was sampled in a corner of each subplot to avoid interfering with the digital imagery analysis or NDVI readings. Biomass samples collected were dried for two weeks at 60°C and weighed to the hundredth of a gram. Winter rye was the only cover crop to survive winter 2013 and 2014. Spring data collection occurred 29 May 2014 and 28 May 2015. This was one day prior to desired termination timing.

Cover crops were also evaluated for herbicide injury beginning one week after cover crop emergence and evaluated for three weeks total. Injury evaluation data included digital imagery analysis and NDVI. The methods for digital imagery analysis data collection were adapted from Purcell (2000). Digital images were taken at 91 cm above each subplot. A standard digital camera was mounted at a 70° angle on a 2.54 by 114 cm board. This board creates a stand for the camera to capture consistent photos of the plots. The camera was set to auto mode with zoom set to 0. These pictures were resized and renamed using FastStone Image Viewer (FastStone Soft, 2015). Once resized the pictures were analyzed to determine the percentage of cover using Sigma Scan Pro (v. 5.0; SPSS Science, 1998) utilizing the macro Turf Analysis 1-2 following methods described by Richardson and Karcher (2005). The software allows for color threshold values of hue and saturation to be adjusted for light intensity and to define the area to be read (Purcell, 2000). Saturation values used ranged from 13-26 with the maximum always set at 100. Hue values used ranged from 47-60 with the maximum always set to 120. Adjustments were made between each data collection date, but not from within each data collection timing.

Normalized difference vegetative index (NDVI) readings were taken once a week for three weeks following cover crop emergence in each subplot. NDVI data was collected using a model ACS-430 Crop Circle (Holland Scientific). The sensor was held 91 cm above each subplot.

**Statistical Analyses.** There was interaction between years. Therefore, cover crop dry biomass data were presented separated in each year. Data was subjected to analysis of variance (ANOVA) using generalized linear mixed-effects models in R (R software, 2019) Analysis of dry biomass was conducted separately for each cover crop species. Herbicide treatments were considered fixed effects, and replication was considered a random effect. Residual variance was evaluated to confirm variance assumptions and homogenous data utilizing Shapiro-Wilk test of normality function *shapiro.test* in R software. For clarity, all data are presented untransformed. Means were separated using Tukey-Kramer adjustment method at 10% level of significance. Pearson correlation at P=0.05 was performed with *cor.test* in R software to examine the correlation among cover crop dry biomass weight, percent green cover, and NDVI.

**Results and Discussion**

## **Weather**

May and June of the 2013 growing season after herbicide application received 74 mm more rain and was on average was 2.5 C° cooler than 2014. The precipitation event frequency was greater in May and June 2013 than 2014 which may have led to greater pesticide leaching and degradation which is supported by Shahgholi and Ahangar (2014). At cover crop establishment in 2013 temperature was on average 4 C° warmer and a precipitation event occurred the day after planting; combined, these may have led to more biomass and cover accumulation compared to 2014. Weather data is shown in table 1. In 2013-2014 winter rye, ‘King’ and ‘Bruiser’ annual ryegrasses survived winter and the Arlington Research Station received 30 mm precipitation from 1 December through 1 March, which was lower than the 30 year normal. Winter rye was the only cover crop the survive the 2014-2015 winter and while precipitation was 40 mm between 1 December through 1 March temperatures were warmer and lead to less snow cover than 2013. Research by Leep et al. provide data to support that less snow cover in 2014-2015 would make winter survival difficult (2001).

**Herbicide Effects on Cover Crops**

**Winter Rye.** In 2013 and 2014 none of the corn or soybean herbicide treatments significantly reduced the rye dry biomass weight, stand count, percent green cover, or NDVI at alpha 0.1 (Table 6). In spring of 2014 the 2013 applied corn herbicide treatment nicosulfuron significantly reduced percent green cover by seven percent. In spring 2014 no corn herbicide treatments significantly reduced spring rye NDVI or dry biomass weight. In spring 2015 no corn herbicide treatments significantly reduced spring rye dry biomass weight, percent green cover, or NDVI. In spring 2014 and 2015 at rye termination no herbicide treatments in soybean significantly reduced the rye dry biomass weight, percent green cover, or NDVI (Table 6).

Winter rye was not affected by any of the herbicides in this study and these results are similar to results found by Yu et al. (2015) whom found that rye was not negatively impacted by saflufenacil + dimethenamid-p, S-metolachlor + atrazine + mesotrione, and imazethapyr. Winter rye results are also similar to Kendig et al. (1991) which also found that winter rye was not consistently impacted by metribuzin and chlorimuron. Research by Cornelius and Bradley (2017) found 27 corn and soybean herbicides did not injure winter rye.

In the spring, percent green cover data for the winter rye indicated nicosulfuron injury. Nicosulfuron is a postemergence grass weed control herbicide with a rotational interval of 4 months for winter rye (Anonymous 2009). The mechanism responsible for injury in 2013 is unclear and no injury occurred in 2014.

**Radish.** In 2013 and 2014 no corn herbicide treatments significantly reduced dry biomass weight, stand count, or NDVI at alpha 0.1 (Table 6). In 2013 the corn herbicide treatment flumetsulam significantly reduced percent green cover by 21%. In 2013 the following soybean herbicide treatments significantly reduced percent green cover: fomesafen (61%) reduction, imazethapyr (67%), and imazethapyr + glyphosate (82%). In 2013 imazethapyr and imazethapyr + glyphosate reduced NDVI by 38 and 72%. These same treatments reduced dry biomass weight by 92 and 88%. 2013 radish stand was not significantly reduced by any of the soybean herbicide treatments (Table 6). In 2014 no soybean herbicide treatments significantly reduced the radish dry biomass weight, percent green cover, or NDVI (Table 6). Cornelius and Bradley (2017) found no soybean herbicide carryover injure to radish in 2014 and no corn herbicide injure in 2013 and 2015.

Imazethapyr is a soybean herbicide with residual properties that controls broadleaf and grass weeds (Anonymous 2018). The radish injury data is similar to results found by Yu et al. (2015) which found imazethapyr caused injury to radish three months after herbicide application. Cornelius and Bradley (2017) found that imazethapyr in 2013 reduced stand by 41% and biomass weight by 76% 104 days following herbicide application. In 2015 imazethapyr reduced stand by 32% and biomass weight by 39% 102 days following herbicide application (Cornelius and Bradley 2017).

Radish had herbicide carryover injury from fomesafen, a soybean herbicide known for control of many annual broadleaf and grass weeds (Anonymous 2016). Cornelius and Bradley (2017) found fomesafen reduced stand by 28% and biomass reduction 51% in 2013 and in 2014 stand reduction of 41% and biomass reduction of 33%. Similarly, 2014 no injure was found by Cornelius and Bradly (2017) to radish from fomesafen.

Radish was not injured by S-metolachlor plus mesotrione and this data is supported by Yu et al (2015). The study found three months after herbicide application no injury to radish (Yu et al. 2015).

**Crimson Clover.** In 2013 and 2014 no corn herbicide treatments significantly reduced dry biomass weight, stand count (2013 only), or percent green cover and in 2014 no corn herbicide treatments significantly reduced NDVI (Table 6). In 2013 the following corn herbicide treatments significantly reduced percent green cover by 37%: a PRE treatment of S-metolachlor plus mesotrione plus a POST treatment of S-metolachlor plus glyphosate plus mesotrione; and flumioxazin plus pyroxasulfone. In 2013 the corn herbicide treatment flumioxazin plus pyroxasulfone reduced NDVI by 27%. In 2013 and 2014 no soybean herbicide treatment significantly reduced the crimson clover dry biomass weight, stand count, percent green cover, or NDVI (Table 6).

Crimson clover was injured by flumioxazin plus pyroxasulfone. Flumioxazin is broadleaf weed control herbicide with a typical half-life of up to 17.5 days (Shaner 2014) so carryover from flumioxazin alone is unlikely since the cover crops were analyzed for injure 170 days after application. Since flumioxazin is a broadleaf herbicide carryover potential to grasses is unlikely however in 2013 injury occurred. In 2013, the mechanism that cause the herbicide carryover injury is unclear and injury was not seen in 2014. Pyroxasulfone is known for control of broadleaf and grass weeds and has a half-life of 26 days (Shaner 2014). Microbial degradation is the main source of breakdown for pyroxasulfone (Shaner 2014). Weather conditions were favorable for microbial degradation and the cover crop were planted 170 days after herbicide application so the mechanism that resulted in herbicide injury is unclear. In 2014, no injury from pyroxasulfone occurred.

Crimson clover was injured by S-metolachlor + mesotrione. S-metolachlor is a grass and broadleaf weed herbicide with a half-life of 70 days and is known to persist for 10 – 12 weeks (Shaner 2014). S-metolachlor is broken down by photodegradation and microbial degradation (Shaner 2014). Mesotrione is a broadleaf herbicide, has a half-life of 15-21 days, and is primary degraded through microorganisms (Shaner 2014). Since the half-life on mesotrione is fairly short and not known to cause persistence, herbicide carryover injury also occurred in the S-metolachlor only treatment likely S-metolachlor alone caused the injury to the cover crops in this treatment.

There was no reduction in stand on crimson clover for soybean herbicides metribuzin and chlorimuron in this study and the data contradict previous research by Kendig et al. which found carryover injury from metribuzin and chlorimuron affected crimson clover stand (1991).

**‘King’ Annual Ryegrass.** In 2013 the corn herbicide treatment consisting of a PRE application of S-metolachlor plus mesotrione plus a POST treatment of S-metolachlor plus glyphosate plus mesotrione significantly reduced dry biomass weight by 2230 kg ha‑1, 73% less percent green cover, 44% less NDVI, and 75% less stand from the nontreated plot. In 2013 the corn herbicide treatment flumioxazin plus pyroxasulfone significantly less percent green cover from the nontreated plot by 42%. In 2014 no corn herbicide treatments significantly reduced ‘King’ annual ryegrass dry biomass weight, percent green cover, or NDVI.

In 2013 the soybean herbicide treatment S-metolachlor significantly reduced percent green cover by 52% and stand by 47%. In 2013 the soybean herbicide treatment pyroxasulfone significantly reduced percent cover by 47% and NDVI by 29%. In 2013 the soybean herbicide treatment imazethapyr significantly reduced percent green cover by 33%. In 2014 no soybean herbicide treatments significantly reduced the ‘King’ annual ryegrass dry biomass weight, percent green cover, or NDVI (Table 6).

‘King’ annual ryegrass had herbicide carryover injury from imazethapyr. According to the Herbicide Handbook (Shaner 2014) imazethapyr controls annual broadleaf weeds and several annual grasses so imazethapyr has the ability inhibit growth of radish, annual ryegrass, and oats and peas. Imazethapyr has a half-life of 60-90 days, however there was approximately 170 days between herbicide application and data collection in this study and significant injury occurred (Shaner 2014). A study by Walsh et al. found that when imazethapyr was applied in the spring annual ryegrass could be planted safely the following spring 309 days after herbicide application without a reduction in biomass (1993). Absorption of imazethapyr increases as herbicide increases as soil moisture decreases so dry conditions in the summer of 2013 may have increased carryover potential (Shaner 2014). Imazethapyr persistence is dependent on microbial degradation and photolysis and in this study conditions for photolysis and microbial activity would have been different between 2013-2014 and 2014-2015 growing seasons resulting in no imazethapyr carryover in 2014-2015 (Alister and Kogan 2005; Madani et al. 2003; Marchesan 2010).

‘King’ annual ryegrass was injured by flumioxazin plus pyroxasulfone. ‘King’ annual ryegrass was also injured from pyroxasulfone alone. Flumioxazin is broadleaf weed control herbicide with a typical half-life of up to 17.5 days so carryover from flumioxazin alone is unlikely since the cover crops were analyzed for injure 170 days after application. Since flumioxazin is a broadleaf herbicide carryover potential to grasses is unlikely however in 2013 injury occurred. In 2013, the mechanism that cause the herbicide carryover injury is unclear and injury was not seen in 2014. Pyroxasulfone is known for control of broadleaf and grass weeds and has a half-life of 26 days (Shaner 2014). Microbial degradation is the main source of breakdown for pyroxasulfone (Shaner 2014). Weather conditions were favorable for microbial degradation and the cover crop were planted 170 days after herbicide application so the mechanism that resulted in herbicide injury is unclear. In 2014, no injury from pyroxasulfone occurred.

‘King’ annual ryegrasses was injured by S-metolachlor + mesotrione. Injury to ‘King’ annual ryegrasses was also found in the S-metolachlor treatment alone. S-metolachlor is a grass and broadleaf weed herbicide with a half-life of 70 days and is known to persist for 10 – 12 weeks (Shaner 2014). S-metolachlor is broken down by photodegradation and microbial degradation (Shaner 2014). Mesotrione is a broadleaf herbicide, has a half-life of 15-21 days, and is primary degraded through microorganisms (Shaner 2014). Since the half-life on mesotrione is fairly short and not known to cause persistence, herbicide carryover injury also occurred in the S-metolachlor only treatment likely S-metolachlor alone caused the injury to the cover crops in this treatment.

**‘Bruiser’ Annual Ryegrass.** In 2013 the corn herbicide treatment consisting of a PRE application of S-metolachlor plus mesotrione plus a POST treatment of S-metolachlor plus glyphosate plus mesotrione significantly reduced dry biomass weight by 2700 kg ha-1, 54% less percent green cover, 68% less stand, and 45% less NDVI. In 2013 the corn herbicide treatment flumioxazin plus pyroxasulfone significantly reduced NDVI by 20% and percent green cover 68%. In 2014 no corn herbicide treatments significantly reduced ‘Bruiser’ annual ryegrass dry biomass weight, percent green cover, or NDVI (Table 6).

In 2013 the soybean herbicide treatment pyroxasulfone significantly reduced dry biomass weight by 1670 kg ha-1 and NDVI by 38%. In 2013 the soybean herbicide treatment S-metolachlor significantly reduced dry biomass weight by 1680 kg ha-1 and 39% less stand. In 2014 the soybean herbicide treatment flumioxazin significantly reduced dry biomass weight by 71%. In 2014 no soybean herbicide treatment significantly reduced the ‘Bruiser’ annual ryegrass percent green cover, or NDVI (Table 6).

‘Bruiser’ annual ryegrass was injured by flumioxazin plus pyroxasulfone. ‘Bruiser’ annual ryegrass was also injured from pyroxasulfone alone. Flumioxazin is broadleaf weed control herbicide with a typical half-life of up to 17.5 days so carryover from flumioxazin alone is unlikely since the cover crops were analyzed for injure 170 days after application. Since flumioxazin is a broadleaf herbicide carryover potential to grasses is unlikely however in 2013 injury occurred. In 2013, the mechanism that cause the herbicide carryover injury is unclear and injury was not seen in 2014. Pyroxasulfone is known for control of broadleaf and grass weeds and has a half-life of 26 days (Shaner 2014). Microbial degradation is the main source of breakdown for pyroxasulfone (Shaner 2014). Weather conditions were favorable for microbial degradation and the cover crop were planted 170 days after herbicide application so the mechanism that resulted in herbicide injury is unclear. In 2014, no injury from pyroxasulfone occurred.

‘Bruiser’ annual ryegrasses was injured by S-metolachlor + mesotrione. Injury to ‘Bruiser’ annual ryegrasses was also found in the S-metolachlor treatment alone. S-metolachlor is a grass and broadleaf weed herbicide with a half-life of 70 days and is known to persist for 10 – 12 weeks (Shaner 2014). S-metolachlor is broken down by photodegradation and microbial degradation (Shaner 2014). Mesotrione is a broadleaf herbicide, has a half-life of 15-21 days, and is primary degraded through microorganisms (Shaner 2014). Since the half-life on mesotrione is fairly short and not known to cause persistence, herbicide carryover injury also occurred in the S-metolachlor only treatment likely S-metolachlor alone caused the injury to the cover crops in this treatment.

**Oats and Peas Mixture.** In 2013 and 2014 no corn herbicide treatments significantly reduced the oat peas mixture dry biomass weight, percent green cover, stand count (2013 only), or NDVI (Table 6). In 2013 the soybean herbicide treatment imazethapyr significantly reduced dry biomass weight by 1880 kg ha-1, 34% less percent green cover. In 2013 the soybean herbicide treatment imazethapyr plus glyphosate significantly reduced percent cover by 40%. In 2013 the soybean herbicide treatment pyroxasulfone reduced percent green cover by 34%. In 2014 no herbicide treatments in soybean significantly reduced the oats and peas mixture dry biomass weight, percent green cover, or NDVI (Table 6).

Oats peas mixture was injured by flumioxazin plus pyroxasulfone. ‘Flumioxazin is broadleaf weed control herbicide with a typical half-life of up to 17.5 days so carryover from flumioxazin alone is unlikely since the cover crops were analyzed for injure 170 days after application. Since flumioxazin is a broadleaf herbicide carryover potential to grasses is unlikely however in 2013 injury occurred. In 2013, the mechanism that cause the herbicide carryover injury is unclear and injury was not seen in 2014. Pyroxasulfone is known for control of broadleaf and grass weeds and has a half-life of 26 days (Shaner 2014). Microbial degradation is the main source of breakdown for pyroxasulfone (Shaner 2014). Weather conditions were favorable for microbial degradation and the cover crop were planted 170 days after herbicide application so the mechanism that resulted in herbicide injury is unclear. In 2014, no injury from pyroxasulfone occurred.

**Correlation Analysis**

In 2013 and 2014 for corn and soybean herbicide treatments NDVI and percent green cover were significantly correlated at alpha 0.1 for all cover crops except crimson clover (Tables 4 and 5). In 2013 significant correlation occurred for stand count, percent green cover, NDVI, and dry biomass weight in the corn and soybean herbicide treatments for ‘King’ annual ryegrass and ‘Bruiser’ annual ryegrass. In 2014 percent green cover, dry biomass weight, and NDVI were all significantly correlated in all cover crops except crimson clover. In 2014 corn and soybean treatments crimson clover dry biomass weight was not significantly correlated to percent green cover and NDVI. Crimson Cover NDVI and percent green cover were significantly correlated in 2014 for the corn and soybean treatments.

**Conclusion**

Cover crop biomass accumulation, percent green cover, and NDVI were all greater in 2013 and were contributed in part to more timely precipitation and warmer fall temperatures (table 7 shows nontreated data). Radish and annual ryegrass varieties were proven to be most prone to herbicide carryover injury. The results of this experiment supports the hypothesis because cover crops established following commonly applied corn and soybean herbicides were adversely impacted by the herbicide treatments (summary table 8). NDVI and percent green cover was significantly correlated for almost all comparisons. This research demonstrates winter rye biomass, percent green cover, and NDVI have little negative response from the herbicides in this trial and will may not be significantly impacted by commonly used corn and soybean herbicides. The lack of significant herbicide injury and ability to survive winter gives winter rye an advantage over the other cover crops in this study. This study shows that weather variability is a key component to herbicide carryover affecting fall established cover crops. Results from this experiment, especially in 2013, indicate cover crop carryover potential is dependent on year and cover crop species by herbicide combination. None of the cover crops were consistently affected in 2013 and 2014 by any of the herbicide combinations. Farmers need to be mindful of these potential herbicide carryover effects while trying to achieve maximum cover crop growth.

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Table 1. Monthly precipitation and mean air temperatures during 2013, 2014 and January through May 2015 compared to 30 year average at the Arlington Agriculture Research Station, Arlington, Wisconsin †.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Total Precipitation | | | | Mean Air Temperature | | | |
| Month | 30 yr.  Normal.‡ | 2013 | 2014 | 2015 | 30 yr.  Normal. | 2013 | 2014 | 2015 |
|  | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_mm\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_C°\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | |
| January | 29 | 49 | 4 | 5 | -9 | -7 | -13 | -8 |
| February | 33 | 33 | 15 | 2 | -6.5 | -7 | -13 | -11 |
| March | 48 | 51 | 23 | 13 | -0.3 | -4 | -4 | 0.4 |
| April | 89 | 154 | 172 | 168 | 7 | 5 | 6 | 8 |
| May | 94 | 158 (139)§ | 59 (16) | 125 | 13 | 14 (15) | 14 (18) | 15 |
| June | 119 | 189 | 238 | - | 19 | 24 | 26 | - |
| July | 106 | 69 | 38 | - | 21 | 25 | 24 | - |
| August | 99 | 42 | 65 | - | 20 | 26 | 26 | - |
| September | 90 | 0.25 | 31 | - | 15 | 25 | 21 | - |
| October | 65 | 50 | 65 | - | 9 | 9 | 8 | - |
| November | 61 | 57(0.77) | 32(4) | - | 1 | 0.35(4) | -3(5) | - |
| December | 37 | 11 | 33 | - | -6 | -9 | -3 | - |

† Automated weather station located at the Arlington Agriculture Research Station, Arlington, Wisconsin. Global positioning system coordinates: 43.31, -89.38(Extension 2015).  
‡30 year normal precipitation and temperature obtained from the Wisconsin State Climatology office (Madison, WI).  
§2013 and 2014 temperature and precipitation data in parenthesis partial month to show weather during established trial.

Table 2. Corn herbicide treatments applied spring 2013 and 2014 to evaluate herbicide carry over in cover crops following corn harvest at Arlington Agriculture Research Station.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Treatment | Herbicide Active Ingredient | Trade Name | Treatment Timing† | Rate | Manufacturer |
| 1 | nontreated |  |  |  |  |
| 2 | simazine | Princep | EPOST | 907.18 | Syngenta Crop Protection, Greensboro, NC |
| 3 | mesotrione‡¶ | Callisto | EPOST | 85.04 | Syngenta Crop Protection |
| 4 | tembotrione# | Laudis | EPOST | 37.2 | Bayer Crop Science, Research Triangle Park, NC |
| 5 | topramezone# | Impact | EPOST | 7.44 | AMVAC Corp. Guelph, Ontario |
| 6 | clopyralid | Stinger | EPOST | 85.04 | Dow AgroSciences LLC  Indianapolis, IN |
| 7 | flumetsulam§ | Python | PRE | 22.68 | Dow AgroSciences |
| 8 | rimsulfuron‡§ | Resolve | EPOST | 7.09 | DuPont,  Wilmington, DE |
| 9 | nicosulfuron‡§ | Accent Q | EPOST | 13.91 | DuPont |
| 10 | acetochlor + flumetsulam + clopyralid | SureStart | EPOST | 318.93 + 10.20 + 32.32 | Dow AgroSciences |
| 11 | S-metolachlor + mesotrione | Zemax | PRE | 757.50 + 74.84 | Syngenta Crop Protection |
| 12 | flumioxazin + pyroxasulfone | Fierce | PRE | 21.65 + 27.47 | Valent U.S.A. Corp, Walnut Creek, CA |
| 13 | rimsulfuron + thifensulfuron-methyl‡¶ | Basis Blend | EPOST | 1.87 + 0.94 | DuPont |
| 14 | saflufenacil + dimethenamid-p# | Verdict | PRE | 30.30 + 265.78 | BASF |
| 15 | S-metolachlor + glyphosate + mesotrione‡§ | Halex GT | LPOST | 426.60 + 426.60 + 42.66 | Syngenta Crop Protection |

† PRE, applied prior to planting; EPOST, early post emergence herbicide application applied at V2 corn; LPOST, late post emergence herbicide application applied V4 corn.  
‡ Ammonium sulfate (AMS) at 7.93 kg per 378.5 L was included.  
§ Nonionic surfactant (NIS) at 0.25% (v/v) was included.  
¶ Crop oil concentrate (COC) at 0.25% (v/v) was included.  
# Methylated seed oil (MSO) at 1% (v/v) was included.

Table 3. Soybean herbicide treatments applied spring 2013 and 2014 to evaluate herbicide carry over in cover crops following soybean harvest at Arlington Agriculture Research Station.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Treatment | Treatment | Treatment  Timing† | Trade Name | Rate | Manufacturer |
|  |  |  |  | g ai or ae ha-1 |  |
| 1 | nontreated |  |  |  |  |
| 2 | sulfentrazone | PRE | Sharpen | 113.40 | BASF |
| 3 | flumioxazin | PRE | Valor | 36.15 | Valent |
| 4 | metribuzin | PRE | Sencor | 170.10 | Bayer |
| 5 | chlorimuron-ethyl | PRE | Classic | 7.09 | DuPont |
| 6 | sulfentrazone + metribuzin | PRE | Authority MTZ | 61.23 + 91.85 | FMC, Philadelphia, PA |
| 7 | Flumioxazin | PRE | Gangster | 52.05 | Valent |
| 8 | pyroxasulfone | PRE | Zidua | 72.29 | BASF |
| 9 | cloransulam-methyl‡¶ | EPOST | Firstrate | 7.14 | Dow AgroSciences |
| 10 | S-metolachlor | EPOST | Dual II Magnum | 576.13 | Syngenta |
| 11 | acetochlor | EPOST | Warrant | 510.29 | Monsanto Company, St. Louis, MO |
| 12 | fomesafen‡§ | EPOST | Flexstar | 106.59 | Syngenta |
| 13 | imazethapyr‡§ | EPOST | Pursuit | 28.35 | BASF |
| 14 | imazethapyr + glyphosate‡¶ | EPOST | Extreme | 6.64 + 20.98 | BASF |
| 15 | lactofen | EPOST | Cobra | 88.59 | Valent |

† PRE, applied prior to planting; POST, post emergence herbicide application applied at V3 soybean.  
‡ Ammonium sulfate (AMS) at 7.93 kg per 378.5 L was included.  
§ Nonionic surfactant (NIS) at 0.25% (v/v) was included.  
¶ Crop oil concentrate (COC) at 0.25% (v/v) was included.

Table 4. 2013 Cover crop stand count, percent green cover, dry biomass weight, and normalized vegetative difference index significant (P<0.1) correlation comparisons between all variables nine weeks after cover crop establishment following corn and soybean herbicide treatments at Arlington Agriculture Research Station, Arlington WI.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | SC† | | | PGC‡ | | | DW§ | | | NDVI¶ | | |
| Data | Corn | | Soybean | Corn | | Soybean | Corn | | Soybean | Corn | | Soybean |
| Oat | | | | | | | | | | | | |
| SC | . | . | | 0.41 | 0.22 | | NS | NS | | 0.26 | NS | |
| DW | NS | NS | | 0.37 | 0.70 | | . | . | | 0.32 | 0.60 | |
| NDVI | 0.26 | NS | | 0.71 | 0.77 | | 0.32 | 0.60 | | . | . | |
| Rye | | | | | | | | | | | | |
| SC | . | . | | NS | -0.37 | | NS | NS | | 0.27 | -0.31 | |
| DW | NS | NS | | 0.52 | 0.38 | | . | . | | 0.40 | 0.38 | |
| NDVI | 0.27 | -0.31 | | 0.71 | 0.84 | | 0.40 | 0.38 | | . | . | |
| Radish | | | | | | | | | | | | |
| SC | . | . | | NS | 0.51 | | NS | 0.51 | | NS | 0.39 | |
| DW | NS | 0.51 | | 0.35 | 0.79 | | . | . | | 0.41 | 0.77 | |
| NDVI | NS | 0.39 | | 0.77 | 0.89 | | 0.41 | 0.77 | | . | . | |
| Crimson | | | | | | | | | | | | |
| SC | . | . | | NS | 0.43 | | 0.27 | NS | | NS | 0.29 | |
| DW | 0.27 | NS | | NS | NS | | . | . | | NS | NS | |
| NDVI |  | 0.29 | | 0.73 | 0.69 | | NS |  | | . | . | |
| ‘King’ Annual Ryegrass | | | | | | | | | | | | |
| SC | . | . | | 0.41 | 0.53 | | NS | 0.28 | | 0.30 | 0.45 | |
| DW |  | 0.28 | | 0.70 | 0.62 | | . | . | | 0.64 | 0.54 | |
| NDVI | 0.30 | 0.45 | | 0.89 | 0.83 | | 0.64 | 0.54 | | . | . | |
| ‘Bruiser’ | | | | | | | | | | | | |
| SC | . | . | | 0.41 | 0.06 | | 0.25 | 0.29 | | 0.52 | 0.44 | |
| DW | 0.25 | 0.39 | | 0.61 | 0.29 | | . | . | | 0.71 | 0.67 | |
| NDVI | 0.52 | 0.49 | | 0.80 | 0.44 | | 0.71 | 0.67 | | . | . | |

† SC, stand count per 25 cm linear row.  
‡ PGC, percent green cover collected using digital imagery analysis. § DW, dry biomass weight (grams) per 25 cm linear row.  
¶ NDVI, normalized difference vegetative index.

Table 5. 2014 Cover crop percent green cover, dry biomass weight, and normalized vegetative difference index significant (P<0.1) correlation comparisons between all variables nine weeks after cover crop establishment following corn and soybean herbicide treatments at Arlington Agriculture Research Station, Arlington WI.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | PGC† | | | DW‡ | | | NDVI§ | | |
| Data | Corn | | Soybean | Corn | | Soybean | Corn | | Soybean |
| Oat | | | | | | | | | |
| DW | 0.47 | 0.35 | | . | . | | 0.29 | 0.60 | |
| NDVI | 0.61 | 0.68 | | 0.29 | 0.60 | | . | . | |
| Rye | | | | | | | | | |
| DW | 0.34 | 0.44 | | . | . | | 0.35 | 0.33 | |
| NDVI | 0.85 | 0.88 | | 0.35 | 0.33 | | . | . | |
| Radish | | | | | | | | | |
| DW | 0.81 | 0.81 | | . | . | | 0.73 | 0.74 | |
| NDVI | 0.78 | 0.85 | | 0.73 | 0.74 | | . | . | |
| Crimson | | | | | | | | | |
| DW | NS | NS | | . | . | | NS | NS | |
| NDVI | 0.42 | 0.66 | | NS | NS | | . | . | |
| ‘King’ Annual Ryegrass | | | | | | | | | |
| DW | 0.26 | NS | | . | . | | 0.36 | 0.46 | |
| NDVI | 0.88 | 0.82 | | 0.36 | 0.46 | | . | . | |
| ‘Bruiser’ | | | | | | | | | |
| DW | 0.35 | 0.57 | | . | . | | 0.25 | 0.64 | |
| NDVI | 0.90 | 0.86 | | 0.25 | 0.64 | | . | . | |

† PGC, percent green cover collected using digital imagery analysis.  
‡ DW, dry biomass weight (grams) per 25 cm linear row. § NDVI, normalized difference vegetative index.

Table 6. Dry biomass weight, normalized difference vegetative index, percent green cover, and stand count significant treatment p-values for corn and soybean herbicide treatments in 2013 and 2014 nine weeks after cover crop establishment at Arlington Agriculture Research Station, Arlington WI.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Winter Rye | | Radish | | Crimson | | ‘King’  Annual Ryegrass | | ‘Bruiser’  Annual Ryegrass | | 70% Oat 30% Pea | | Winter Rye Spring Data | | |
| Data | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 |
|  | Corn Treatments | | | | | | | | | | | | | | |
| DW† |  |  |  |  |  |  | <0.001 | 0.082 | 0.001 |  |  |  |  |  |
| NDVI‡ |  |  | 0.069 |  | 0.011 | 0.088 | 0.001 |  | <0.001 |  | 0.056 |  |  |  |
| PGC§ |  |  | 0.059 |  | 0.002 |  | <0.001 |  | 0.006 |  | 0.002 |  | 0.004 |  |
| SC¶ | 0.064 |  |  |  |  |  | 0.002 |  | <0.001 |  | 0.04 |  |  |  |
|  | Soybean Treatments | | | | | | | | | | | | | | |
| DW |  |  | <0.001 |  |  |  | 0.018 |  | 0.002 |  | 0.001 |  |  |  |
| NDVI |  | 0.096 | <0.001 | 0.04 |  |  | 0.002 |  | <0.001 | 0.087 | 0.044 |  |  |  |
| PGC |  |  | <0.001 |  |  |  | <0.001 | 0.075 |  |  | <0.001 |  |  |  |
| SC | 0.055 |  |  |  |  |  | 0.001 |  | 0.023 |  |  |  |  |  |

†DW, dry biomass weight (grams) per 25 cm linear row.  
‡NDVI, normalized difference vegetative index. §PGC, percent green cover collected using digital imagery analysis.  
¶SC, stand count per 25 cm linear row.

Table 7. Dry biomass weight, normalized difference vegetative index, percent green cover, and stand count nontreated mean data for corn and soybean herbicide treatments in 2013 and 2014 nine weeks after cover crop establishment at Arlington Agriculture Research Station, Arlington WI.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Winter Rye | | Radish | | Crimson | | ‘King’  Annual Ryegrass | | ‘Bruiser’  Annual Ryegrass | | 70% Oat 30% Pea | | Winter Rye Spring Data | | |
| Data | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 |
|  | Corn Treatments | | | | | | | | | | | | | | |
| DW† | 2.92 | 6.91 | 4.70 | 3.74 | 1.57 | 1.01 | 2.81 | 2.51 | 3.13 | 1.06 | 3.58 | 1.35 | 28.38 | 35.22 |
| NDVI‡ | 0.53 | 0.39 | 0.51 | 0.31 | 0.44 | 0.19 | 0.54 | 0.25 | 0.55 | 0.27 | 0.54 | 0.23 | 0.55 | 0.72 |
| PGC§ | 45 | 24 | 52 | 14 | 38 | 2 | 66 | 13 | 63 | 15 | 62 | 6 | 91 | 56 |
| SC¶ | 16 | - | 6.5 | - | 13 | - | 26 | - | 21 | - | 11 oat# | - | - | - |
|  | Soybean Treatments | | | | | | | | | | | | | | |
| DW | 2.82 | 6.35 | 4.24 | 2.78 | 1.98 | 0.43 | 2.69 | 1.88 | 2.88 | 3.99 | 3.37 | 2.40 | 33.20 | 61.96 |
| NDVI | 0.58 | 0.39 | 0.50 | 0.27 | 0.43 | 0.16 | 0.58 | 0.23 | 0.56 | 0.26 | 0.58 | 0.22 | 0.57 | 0.72 |
| PC | 54 | 31 | 56 | 19 | 38 | 4 | 66 | 21 | 58 | 24 | 65 | 9 | 91 | 62 |
| SC | 15 | - | 5 | - | 15 | - | 27 | - | 30 | - | 9 oat  2 pea | - | - | - |

†DW, dry biomass weight (grams) per 25 cm linear row.  
‡NDVI, normalized difference vegetative index. §PGC, percent green cover collected using digital imagery analysis.  
¶SC, stand count per 25 cm linear row. #No peas in nontreated corn

Table 8. Summary of significant reduction of dry biomass †, normalized vegetative difference index‡, percent green cover §, and stand count¶ following corn and soybean herbicides in 2013 and 2014 nine weeks after cover crop establishment at Arlington Agriculture Research Station, Arlington WI.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | | | Winter Rye | | | | Radish | | | Crimson | | | ‘King’  Annual Ryegrass | | | | ‘Bruiser’  Annual Ryegrass | | | | 70% Oat 30%Pea | | | | Rye Spring Data | | |
| TRT# | Herbicide AI†† | | | 2013 | | 2014 | | 2013 | | 2014 | 2013 | 2014 | | 2013 | | 2014 | | 2013 | | 2014 | | 2013 | | | 2014 | 2013 | 2014 |
| Corn Herbicide Treatments | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | flumetsulam | | |  | |  | | PC | |  |  |  | |  | |  | |  | |  | |  | | |  |  |  |
| 9 | nicosulfuron | | |  | |  | |  | |  |  |  | |  | |  | |  | |  | |  | | |  | PC |  |
| 11 | S-metolachlor + mesotrione + S-metolachlor + glyphosate + mesotrione | | |  | |  | |  | |  | PC |  | | DW, NDVI, PC, SC | |  | | DW, NDVI, PC, SC | |  | |  | | |  |  |  |
| 12 | flumioxazin + pyroxasulfone | | |  | |  | |  | |  | PC, NDVI |  | | PC | |  | | NDVI, PC | |  | |  | | |  |  |  |
| Soybean Herbicide Treatments | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | flumioxazin |  | |  | |  | |  | |  | |  | |  | |  | |  | | DW | |  |  | |  |  |
| 8 | | pyroxasulfone |  | |  | |  | |  | |  | |  | | PC, NDVI | |  | | NDVI, DW | |  | | PC |  | |  |  |
| 10 | | S-metolachlor |  | |  | |  | |  | |  | |  | | PC, SC | |  | | DW, SC | |  | |  |  | |  |  |
| 12 | | fomesafen |  | |  | | PC | |  | |  | |  | |  | |  | |  | |  | |  |  | |  |  |
| 13 | | imazethapyr |  | |  | | PC,  NDVI,DW | |  | |  | |  | | PC | |  | |  | |  | | PC,  DW |  | |  |  |
| 14 | | imazethapyr + glyphosate |  | |  | | PC, NDVI,DW | |  | |  | |  | |  | |  | |  | |  | | PC |  | |  |  |

†DW, dry biomass weight (grams) per 25 cm linear row.  
‡NDVI, normalized difference vegetative index. §PC percent green cover collected using digital imagery analysis.  
¶SC, stand count per 25 cm linear row.  
#TRT, treatment.  
††AI, active ingredient.