COVER CROP AND HERBICIDE INTERACTIONS

by

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Chapter 1. Cover Crop Background

Introduction

Cover crops have become a growing interest to farmers with a goal to farm more sustainably and protect valuable soil resources. Cover crops are described as a way to prevent degradation of soil through wind and water erosion (Reicosky & Forcella, 1998). The United States Department of Agriculture and Natural Resources Conservation Service define a cover crop as "crops including grasses, legumes and forbs for seasonal cover and other conservation purposes. A cover crop managed and terminated according to these guidelines is not considered a "crop"" (USDA/NRCS 2013a). Soil Science Society of American defines a cover crop as "close-growing crop that provides soil protection, seedling protection, and soil improvement between periods of normal crop production, or between trees in orchards and vines in vineyards. When plowed under and incorporated into the soil, cover crops may be referred to as green manure crops" (America 2008). Modern agriculture practices have turned to cover crops as a way to provide and scavenge nutrients, manage weeds, improve water infiltration, reduce soil erosion, and improve soil quality (Curran & Lingenfelter, 2013). There are many potential benefits and pitfalls to planting, maintaining, and terminating cover crops. For some producers, they have become a mainstay in their production system and use them for winter cover and crop rotation situations. Many other producers just use cover crops occasionally or for experimentation and curiosity purposes. In early 2015, the North Central Sustainable Agriculture Research and Education (SARE), Conservation Technology Information Center (CTIC), Midwest Cover Crop Council, and American Seed Trade Association conducted a survey of farmers on cover crop use

(2015). This survey has been conducted three times and started in 2012 (Midwest Cover Crop Council 2015; SARE and CITC 2013;). In 2015 there were 1,229 respondents whom completed the survey representing 47 states. Of respondents, 47% were commodity crop farmers. Projected cover crop usage was estimated to be 151,248 hectares in 2015. These farmers in the study planted annual grasses and cereal grains (96%), brassicas (88%), and legumes (56%). The farmers see their cover crops with a primary benefit of overall increased soil health (22%), increased soil organic matter (21%), and weed control (11%). Of the farmers surveyed, 38% utilized direct seeding with a grain drill for establishment. The survey also questioned farmers about their termination methods and 59% utilized herbicides as their primary method of termination. Other farmers indicated other methods included: preferring to plant cover crop that winter kill (23%), utilizing cover crops that always winterkill (20%), tillage (10%), mowing (4%), other methods (4%), and roller-crimping (1%). Farmers were asked to indicate cover crop challenges and 21% indicated that establishing cover crops was their biggest challenge closely followed by cover crop seed cost at 19%.

History of Cover Crops in Cropping Systems

For centuries cover crops have been used in crop rotations. Cover crops have been a part of farming in North America since the Native Americans used plant species modern agriculture refers to as weeds as a cover crop. They did this through long periods of fallow, to keep the soil covered and help the soil recover from the previous year's crops. Once the Native Americans were ready to plant the vacant field they would burn off the weeds which would release potassium, lime and kill weed seeds in the process (Kroeck and Langer 2011). European colonies required farmers to utilize crop rotations of forage crops, pastures and grain crops. After the American Revolutionary War, crop rotation practices continued, but it wasn't until the late 1800's farmers began to move away from diverse crop rotations. Better crop transportation and industrialized practices paved the way for less biodiversity. The Green Revolution provided resources, like commercially produced nitrogen and other fertilizers, to go completely away from rotation (Kroeck and Langer 2011). Research on the ability of cover crops to improve soil qualities can be found dating back to the early 1980's (Kemper and Derpsch 1981). This research by Kemper found that cover crops increased water infiltration and created a much more friable soil which means finer texture resulting in a more desirable soil (Kemper and Derpsch 1981).

Farmers in other countries have strong interests in cover crops as well. In Honduras, cover crops have become a resource to prevent land clearing through slash and burn techniques which allows for soil erosion and severe pollution (Neill and Lee 2001). This practice often results in poor soil quality and leads to more deforestation. In Honduras slash and burning was a common practice that reduced the previous crops residue levels and prepped the soil for planting next year leaving the soil bare after the growing season. However the rainy season in Honduras occurs prior to crop planting resulting in the loss of nutrients and major soil erosion. A cover crop, usually a legume, is planted following the biomass harvest and grows enough prior to the rainy season to prevent soil erosion and nutrient losses. The biomass from the cover crop protects the soil during the rainy season and allows the farmer to plant into the cover crop following slashing the cover crop. Cover crops help Honduras farmers protect valuable soil and water resources.

A recent push for more crop diversity and protecting soil and water quality has given rise to a new interest in cover crops. This new push may be accredited to more education on agriculture's impacts on the environment, and a growing curiosity from consumers to know more information on where and how their food is grown. Both are recent developments in the long history of cover crops.

Cover Crop Advantages

Cover crops are typically established following either a summer or winter cash crop (Snapp et al. 2003) for a wide range of purposes. Modern agriculture practices have turned scientifically to use cover crops as a way to provide and scavenge for nutrients, suppress weeds, weed germination, potential yield increases, fixation of nitrogen, improve water infiltration, help reduce erosion, and improve overall soil quality (Bernstein et al. 2014; Clark, 2007; Curran and Lingenfelter 2013; Dabney et al. 2001; DeVore et al. 2013; Didon et al. 2014; Lotter et al. 2003; Lu et al. 2000; Midwest Cover Crop Council 2014; Perez-jones et al. 2005; Reicosky and Forcella 1998; Wells et al. 2014). In a recent publication by Norsworthy et al., cover crops have been recommended as one of many best management practices for preventing herbicide resistance (2012).

Cover crop advantages are also specific to cover crop species and growth (Clark 2007; Midwest Cover Crop Council 2014). For farmers this translates to reduction in fertilizer cost, less need for pesticides, improved soil health and yield, and protecting water quality (SARE 2012). In 2015 SARE and CITC reported that farmers perceive the benefits of cover crops to include increases in overall soil health, organic matter, yield in following crop, economic return, reduces soil erosion, provides a nitrogen source and scavenging, fibrous root system, control weeds, and deep tap roots (Midwest Cover Crop Council 2015).

Cover Crop Challenges

Cover crop challenges include increased production cost, weed potential, harboring crop diseases and insects, and termination (Clark 2007; Snapp et al. 2003;). Cover crops becoming weeds is a common concern because they have potential to overwinter such as annual ryegrass. Annual ryegrass (also known as Italian ryegrass) has been shown to become resistant to herbicides (Bosak and Davis 2014; Matzrafi et al. 2014; Perez-jones et al. 2005; Plumer et al. 2013). The 2015 Cover Crop Report from the Midwest Cover Crop Council indicated that among the 2814 respondents of the survey 5% worry that the cover crop will become a weed the following year and the cover crops will reduce yield, immobilize nitrogen, reduce crop yield, increase risk, disease, and insect potential (2015).

Cover crops may also be challenging to establish following residual herbicides used in conventional crop production. Residual herbicides can persist in the soil longer than initially desired at the time of application (Colquhoun 2006; Devlin et al. 1992; Horowitz 1969;). Since the use of residual herbicides and the use of cover crops are both increasing in upper Midwest corn and soybean systems, the potential concern for negative interactions must be investigated. As stated by Curran and Lingenfelter (2013), herbicide carryover that affects cover crop establishment is an important consideration for cover crop success. There have been several studies published (Barnes and Lavy 1991; Burnside and Wicks 1965; Carter 2000; Horowitz 1969; Krausz et al. 2010; Miller et al. 1978; Walsh et al. 1993) detailing carryover issues following many herbicides and in several crops; however, none have been specific to species commonly used as a cover crop. Moreover, herbicide labels typically do not include rotation restrictions for cover crops and only include limited instructions on crop rotation creating frustration for farmers and agronomists wanting to plant and utilize cover crops (Hartzler 2015). Some publications can help identify potential herbicide persistence and carryover concerns without cover crop data (Davis et al. 2015; Knezevic et al. 2015; Shaner 2014); however, there is no clear indication if a problem establishing cover crops following residual herbicides will occur.

There has been limited research regarding the potentially negative effects of residual herbicide use prior to cover crop establishment. A study in 1991 screened fall seeded crimson clover, hairy vetch, wheat and rye and used cotton and soybean herbicides (Kending et. al) and found that higher soil clay content increases carryover potential. This study found crimson clover was the most susceptible to carryover injury and rye was the least susceptible to injury from the herbicides applied (Kending et. al 1991). A 2015 study found that fall seeded cover crops had different responses to saflufenacil + dimethenamid-p, s-metholachlor + atrazine + mesotrione, and imazethapyr (Yu et al.). The study concluded the residues from imazethapyr caused visible injury, affected oilseed radish's ability to attenuate light and scavenge for nitrate-nitrogen (Yu et al. 2015). This study also concluded none of the herbicide treatments negatively affected oats, hairy vetch, or winter rye (Yu et al. 2015). However, limited data is available on the effects of many commonly applied corn and soybean herbicides on commonly used cover crops following silage corn and soybeans.

As cover crop popularity increases, Wisconsin growers are increasingly interested in utilizing fall established cover crops. In Wisconsin many common cover crops need to be established much earlier than corn and soybean harvest allow. Interseeding with a modified grain drill may allow earlier establishment. There are several options to establish the cover crop earlier. These options include aerial seeding, over seeding with a modified sprayer, broadcasting inter-crop (Uchino et al. 2009), and interseeding with special built implements to deliver the cover crop inter-row such as one recently built by Penn State (Houser, n.d.). These methods usually result in utilizing methods of seeding that rely on special machines with potentially high seeding cost and/or methods that lacks insurance of good seed to soil contact. Interseeding with a modified grain drill may solve these potential problems.

Conclusion

Cover crop utilization has been increasing the past five years. Farmers and researchers see cover crops as a tool to provide many agronomic and environmental benefits. Cover crops do have disadvantages and challenges but the steady increase in production land planted to cover crops shows farmers are willing to accept these. More research is needed to address the challenges that farmers face when considering using cover crops. These challenges include establishing cover crops following residual herbicide applications, termination of cover crops, and establishing cover crops using interseeding early in the growing season to receive the cover crop benefits.

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Chapter 2. Herbicide carryover evaluation following commonly applied silage corn and soybean herbicides

Introduction

Cover crop utilization by farmers in the United States has been increasing the past five years (Midwest Cover Crop Council 2015). Cover crops are an agronomic practice that provide and scavenge for nutrients, suppress weed emergence and competition, improve water infiltration, reduce erosion, and improve overall soil quality (Bernstein et al. 2014; Clark 2011; Curran and Lingenfelter 2013; Dabney et al. 2001; DeVore et al. 2013; Didon et al. 2014; Lu et al. 2000; Midwest Cover Crop Council 2014; Reicosky and Forcella 1998; Wells et al. 2014). Cover crops are desired by farmers for the above benefits, however, herbicides are a weed control method often used by farmers that may negatively affect cover crop establishment.

Some herbicides have activity in the soil for a period of time after application and are often classified as 'residual herbicides' (Colquhoun 2006). The persistence, i.e. length of time at which these herbicides have residual activity, can be affected by tillage, soil moisture, application rate, microbial decomposition, photodegradation, chemical properties of the herbicides, soil pH, soil texture, organic matter, plant residue, temperature, and rainfall (Colquhoun 2006; Devlin et al. 1992; Horowitz 1969; Krausz et al. 2010; Shahgholi and Ahangar 2014; Walsh et al. 1993;).

Residual herbicides are often recommended as part of diversified herbicide programs to help prevent herbicide resistance (Norsworthy et al. 2012; Vencill et al.

2012). This strategy has proven to significantly reduce the populations of common herbicide-resistant weeds like common waterhemp (*Amaranthus tuberculatus)* and palmer amaranth (*Amaranthus palmeri*) (Meyer et al. 2015). Herbicides have long been a staple of weed control programs in United States corn production with 97% of corn acres treated by an herbicide in 2014 (USDA 2014). In 2012, 98% of United States soybean acres were treated with a herbicide and contemporary soybean production systems have a higher need for residual herbicides than before (USDA 2012). This is because soybean yield potential is positively correlated with earlier planting dates (Bastidas et al. 2008; De Bruin and Pedersen 2008; De Bruin and Pedersen 2009). Subsequently, earlier planted soybeans are more susceptible to negative early-season weed competition, and the use of a preemergence (PRE) residual herbicide can reduce negative effects from weed interference (DeWerff et al. 2015).

While there are the aforementioned benefits of residual herbicides, one downfall to residual herbicides is sometimes they persist in the soil longer than initially desired at the time of application (Colquhoun 2006; Devlin et al. 1992; Horowitz 1969). The presence of a herbicide in the soil longer than desired is defined as herbicide carryover (Devlin et al. 1992). Herbicide carryover is noticed when negative effects can be assessed on a 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).

Since the use of residual herbicides and the use of cover crops are both increasing in upper Midwest corn and soybean systems, the potential concern for negative interactions must be investigated. As stated by Curran and Lingenfelter, herbicide carryover that affects cover crop establishment is an important consideration for cover crop success (Curran and Lingenfelter 2013). There have been several studies published (Barnes and Lavy 1991; Burnside and Wicks 1965; Carter 2000; Horowitz 1969; Krausz et al. 2010; Miller et al. 1978; Walsh et al. 1993) detailing carryover issues following many herbicides and in several crops; however, none have been specific to species commonly used as a cover crop. Moreover, herbicide labels typically do not include rotation restrictions for cover crops and only include limited instructions on crop rotation creating frustration for farmers and agronomists wanting to plant and utilize cover crops (Hartzler 2015). Some publications can help identify potential herbicide persistence and carryover concerns without cover crop data (Davis et al. 2015; Knezevic et al. 2015; Shaner 2014); however, there is no clear indication if a problem establishing cover crops following residual herbicides will occur.

There has been limited research regarding the potentially negative effects of residual herbicide use prior to cover crop establishment. A study in 1991 screened cotton and soybean herbicides on fall seeded crimson clover, hairy vetch, wheat, and rye (Kending et. al 1991) and found that higher soil clay content increases carryover potential. This study found crimson clover was the most susceptible to carryover injury and rye was the least susceptible to injury from the herbicides applied (Kending et. al 1991). A 2015 study found that fall seeded cover crops had different responses to saflufenacil + dimethenamid-p, s-metholachlor + atrazine + mesotrione, and imazethapyr (Yu et al. 2015). The study concluded the residues from imazethapyr caused visible injury, affected oilseed radish's ability to attenuate light and scavenge for nitrate-nitrogen (Yu et al. 2015). This study also concluded none of the herbicide treatments negatively affected oats, hairy vetch, or winter rye (Yu et al. 2015). However, limited data is available on the effects of many commonly applied corn and soybean herbicides on commonly used cover crops following silage corn and soybeans.

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, stand, percent green cover, and normalized difference vegetative index (NDVI) and to access whether any of these data are correlated. The hypothesis was that residual herbicide use will significantly negatively affect the dry biomass weight, stand, percent green cover, and NDVI of fall seeded cover crops.

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 one corn and one 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 are shown in 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. In addition to the herbicide treatments, weeds were uniformly managed by applying postemergence (POST) glyphosate over the entire experiment. This application was to prevent weed competition on the corn and soybean development, or allow weed escapes to leave differing residues which could affect the cover crop planting and establishment confounding herbicide impacts. 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, Monsanto Company, 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 John Deere (John Deere, Moline, IL) 1750 Max Emerge vacuum planter. 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 recommended labeled rates commonly used by growers (Davis et al. 2015; Knezevic et al. 2015; Loux et al. 2015). All treatments were applied with a CO_2-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 meter boom delivering 140.2 L ha^{-1} of spray solution at 276 kPa pressure, using Air Induction Extended Range nozzles with 110 degree spray pattern (AIXR11002) 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 manufactured by Tye (AGCO, Duluth, GA) with three rows closed off to allow for six cover crops to be spaced evenly in the 15 meter corn and soybean herbicide plots. To consistently plant the cover crops within the plots John Deere Auto Trac™ real time kinetics (RTK) guidance was used. The cover crop plots were 1.95 meters wide with row spacing of 19 cm. Cover crops planted were radish (*Raphanus* sp;) at 12.3 kg ha^{-1}, crimson clover (*Trifolium incarnatum*) at 11.2 kg ha^{-1}, winter rye (*Secale cereal*) at 134.4 kg ha^{-1}, 70% oat (*Avena sativa*) plus 30% peas (*Pisum sativum)* mixture at 100.8 and 33.6 kg ha^{-1}, and two annual ryegrass (*Lolium multifloram*) 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 crops were evaluated for herbicide injury once a week for three weeks after emergence. Injury evaluation data included digital images for digital imagery analysis and normalized difference vegetative index readings. 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 degree 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 (Fastone.org 2015). Once resized the pictures were analyzed to determine the percentage of cover using Sigma Scan Pro Version 5® (Systat Software, Inc., San Jose, CA) utilizing macro Turf Analysis 1-2 for automation (University of Arkansas, Fayetteville, AR) using methods adopted from 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, Inc. Lincoln, NE). The sensor was held 91 cm above each subplot.

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. Stand counts were collected only in 2013, due to an early snow event in 2014. Stand counts occurred at the same time as biomass collection. Cover crop stand was counted from a 25 cm linear row in each subplot from an arbitrarily selected corner.

Winter rye was the only cover crop to survive winter 2013 and 2014. Spring data collection consisted of digital images for digital imagery analysis, biomass collection, and NDVI measurements on winter rye using the same methods previously described for fall data collection.

Statistical Analyses. All data were subjected to analysis of variance (ANOVA) using PROC MIXED in SAS (SAS v9.3, SAS Institute Inc., Cary, NC) to examine the effects of herbicide treatment, cover crop dry biomass weight, percent green cover, stand, and NDVI. All data were separated by year to assess different treatment effects that may have occurred in the two years. Herbicide treatments were considered fixed effects, and replication was considered a random effect. Boxplots and residual plots were evaluated to confirm variance assumptions and homogenous data utilizing the Proc Univariate and Proc Plot functions in SAS, and if needed data were natural log transformed (Oehlert 2000). For clarity, all data are presented untransformed. Means were separated using Tukey-Kramer adjustment method at 10% level of significance. The CORR procedure in SAS was utilized to examine the correlation of cover crop dry biomass weight, percent green cover, stand, and NDVI to one another and the Pearson correlation coefficients were compared to examine the strength of correlation.

Results

Weather

The Arlington Agriculture Research Station, near Arlington, Wisconsin had variable weather conditions during 2013 and 2014 which may explain the lack of consistent carryover in 2013 and 2014. 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 previous research (Carter 2000; Colquhoun 2006; Devlin et al. 1992;

Horowitz 1969; 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 with 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 Baker et al. 1991 and Leep et al. 2001 provide data to support that less snow cover in 2014-2015 would make winter survival difficult (1991; 2001).

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, 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 cover were significantly correlated in 2014 for the corn and soybean treatments.

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, 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).

Radish. In 2013 and 2014 no corn herbicide treatments significantly reduced dry biomass weight, stand, 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).

Crimson Clover. In 2013 and 2014 no corn herbicide treatments significantly reduced dry biomass weight, stand (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, percent green cover, or NDVI (Table 6).

'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).

'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).

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).

Discussion

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. whom found that rye was not negatively impacted by saflufenacil + dimethenamid-p, S-metolachlor + atrazine + mesotrione, and imazethapyr (Yu. Et al. 2015). 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.

In the spring, percent green cover data for the winter rye indicated nicosulfuron injury. Nicosulfuron is known for annual and some perennial grass control with a half-life of 4.5 hours so injury 300 days after application is not expected (Shaner 2014). The mechanism responsible for injury in 2013 is unclear and no injury occurred in 2014.

Radish, 'King' annual ryegrass, and oats plus peas mixture 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). The radish injury data is similar to results found by Yu et al. which found imazethapyr caused injury to radish three months after herbicide application (Yu et al. 2015).

Radish had herbicide carryover injury from fomesafen, an herbicide known for control of many annual broadleaf weeds (Shaner 2014). Fomesafen has a half-life of 100 days and can injure susceptible crops up to one year after application, so the radish established in this study 170 days after application would have the potential to be injured from fomesafen (Shaner 2014).

Crimson clover, ‘King’ and ‘Bruiser’ annual ryegrass, and oats peas mixture were all injured by flumioxazin plus pyroxasulfone. ‘King’ and ‘Bruiser’ annual ryegrass and oats and peas mixture were 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.

Crimson clover and 'King' and 'Bruiser' annual ryegrasses were injured by S-metolachlor + mesotrione. Injury to 'King' and '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-metolachor only treatment likely S-metolachlor alone caused the injury to the cover crops in this treatment. Radish was not injured by S-metolachlor plus mesotrione and this data is supported by Yu et al. which found three months after herbicide application no injury to radish (Yu et al. 2015).

‘Bruiser’ annual ryegrass dry biomass weight was reduced by flumioxazin in 2013. Flumioxazin, a broadleaf herbicide, breaks down by microbial degradation and has a half-life of up to 17.5 days (Shaner 2014). Since flumioxazin is a broadleaf herbicide carryover injury would not be expected in ‘Busier’ annual ryegrass and the mechanism responsible for injury is unclear.

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). This study confirms previous research on dimethenamid-p in which a study by Yu et al. found no herbicide injury to winter rye and radish three months after herbicide application (Yu et al. 2015). The difference in these results may be due to different soil and environmental characteristics.

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 †.

Month	Total Precipitation				Mean Air Temperature			
	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 + fumetsulam + 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.

	STC†		PC‡		DM§		NDVI¶	
Data	Corn	Soybean	Corn	Soybean	Corn	Soybean	Corn	Soybean
				Oat				
STC	.	.	0.41	0.22	NS	NS	0.26	NS
DM	NS	NS	0.37	0.70	.	.	0.32	0.60
NDVI	0.26	NS	0.71	0.77	0.32	0.60	.	.
				Rye				
STC	.	.	NS	-0.37	NS	NS	0.27	-0.31
DM	NS	NS	0.52	0.38	.	.	0.40	0.38
NDVI	0.27	-0.31	0.71	0.84	0.40	0.38	.	.
				Radish				
STC	.	.	NS	0.51	NS	0.51	NS	0.39
DM	NS	0.51	0.35	0.79	.	.	0.41	0.77
NDVI	NS	0.39	0.77	0.89	0.41	0.77	.	.
				Crimson				
STC	.	.	NS	0.43	0.27	NS	NS	0.29
DM	0.27	NS	NS	NS	.	.	NS	NS
NDVI		0.29	0.73	0.69	NS		.	.
				'King' Annual Ryegrass				
STC	.	.	0.41	0.53	NS	0.28	0.30	0.45
DM		0.28	0.70	0.62	.	.	0.64	0.54
NDVI	0.30	0.45	0.89	0.83	0.64	0.54	.	.
				'Bruiser'				
STC	.	.	0.41	0.06	0.25	0.29	0.52	0.44
DM	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	.	.

† STC, stand count per 25 cm linear row.

‡ PC, percent green cover collected using digital imagery analysis.

§ DM, dry biomass weight (grams) per 25 cm linear row.

¶ NDVI, normalized difference vegetative index.

Table 5. 2014 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.

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

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

Table 6. Dry biomass weight, normalized difference vegetative index, and percent green cove 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.

	Rye		Radish		Crimson		'King' Annual Ryegrass		'Bruiser' Annual Ryegrass		70% Oat 30% Pea		Rye Spring Data	
Data	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
							Corn Treatments							
DM†							<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	
STC¶	0.064						0.002		<0.001		0.04			
							Soybean Treatments							
DM			<0.001				0.018		0.002		0.001			
NDVI		0.096	<0.001	0.04			0.002		<0.001	0.087	0.044			
PCM			<0.001				<0.001	0.075			<0.001			
STC	0.055						0.001		0.023					

†DM, dry biomass weight (grams) per 25 cm linear row.

‡NDVI, normalized difference vegetative index.

§PC, percent green cover collected using digital imagery analysis.

¶STC, stand count per 25 cm linear row.

Table 7. Dry biomass weight, normalized difference vegetative index, and percent green cover nontreated mean data

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

	Rye		Radish		Crimson		'King' Annual Ryegrass		'Bruiser' Annual Ryegrass		70% Oat 30% Pea		Rye Spring Data	
Data	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
							Corn Treatments							
DM†	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
STC¶	16	-	6.5	-	13	-	26	-	21	-	11 oat#	-	-	-
							Soybean Treatments							
DM	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
PCM	54	31	56	19	38	4	66	21	58	24	65	9	91	62
STC	15	-	5	-	15	-	27	-	30	-	9 oat 2 pea	-	-	-

†DM, dry biomass weight (grams) per 25 cm linear row.

‡NDVI, normalized difference vegetative index.

§PC, percent green cover collected using digital imagery analysis.

¶STC, stand count per 25 cm linear row.

#No peas in nontreated corn

following corn and soybean herbicides in 2013 and 2014 nine weeks after cover crop establishment at Arlington Agriculture Research Station, Arlington WI.

		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		DM, NDVI, PC, STC		DM, NDVI, PC, STC					
12	flumioxazin + pyroxasulfone					PC, NDVI		PC		NDVI, PC					
	Soybean Herbicide Treatments														
3	flumioxazin										DM				
8	pyroxasulfone							PC, NDVI		NDVI, DM		PC			
10	S-metolachlor							PC, STC		DM, STC					
12	fomesafen			PC											
13	imazethapyr			PC, NDVI, DM				PC				PC, DM			
14	imazethapyr + glyphosate			PC, NDVI, DM								PC			

[†]Dry biomass weight (grams) per 25 cm linear row.

[‡]Normalized difference vegetative index.

[§]Percent green cover collected using digital imagery analysis.

[¶]Stand count per 25 cm linear row.

[#]TRT, treatment.

[††]AI, active ingredient.

Chapter 3. Termination of winter rye (Secale cereal) and annual ryegrass (Lolium multiflorum) utilized as a spring forage crop

Introduction

Wisconsin dairies commonly utilize fall established winter rye and annual ryegrass as both a cover crop and a forage crop prior to planting more traditional spring annual crops (Hardin 2012; Stute et. al. 2009). While forage quantity and quality is important for winter rye and annual ryegrass, effective suppression following harvest is critical to prevent competition in the next crop. Failure to terminate the cover crop/forage species could result in these species becoming weeds in the subsequent crops. If unsuccessful termination occurs, yield-loss from competition in the subsequent crop can occur. A yield reduction of 24% has been demonstrated in organically managed no-till soybeans soybean following winter rye (Bernstein et. al. 2014) and timely winter rye termination has been demonstrated as an important factor to optimize corn yield (Clark et. al. 1997). While no data exists with respect to annual ryegrass, this species has been implicated as a weed, providing extensive early season competition (Curran and Lingenfelter 2013; Legleiter et. al. 2012) and has developed herbicide resistance to six herbicide mode of actions in multiple countries (Heap 2015; Legleiter et. al. 2012; Perez-Jones et. al. 2005).

Termination of cover crops is accomplished by a range of methods. A survey conducted across the United States indicated that most farmers (59%) utilized herbicides as their primary termination method, but also utilize tillage (10%), mowing (4%), or planting species that cannot survive the winter conditions therefore does not need termination (20%) (Midwest Cover Crop Council 2015). As organic agriculture has widely adopted cover crops, they have developed alternative termination techniques such as crimping that have proven to be effective for winter rye (Clark 2007; Mohler et. al. 2009).

While non-herbicidal techniques are effective, many possess limitations. Tillage techniques such as using a rotary tiller, while effective, can reduce soil surface residue and can increase soil nutrient loss, erosion, and decreased water quality (Dickey et. al. 1984; Sharpley and Smith 1994). Utilizing a roller-crimper is common in organically managed cropland for winter rye, however, this is a specialized piece of equipment that conventional growers would not normally own (Ashford and Reeves 2003; Bernstein et. al. 2011; Price et. al. 2009; Silva 2014). Selection of crops that do not survive the winter is an effective option in colder climates but is dependent of the plant's physiological mechanism for winter hardiness, ice sheeting, snow cover, and air and soil temperature (Baker et. al. 1991; Clark 1997; Leep et. al. 2001). Response can also vary based on establishment timing or varieties thus it is common to see variable winter survival from year to year (Bosak and Davis 2014). Termination by mowing can be a useful cover crop suppression tool if timed to coincide with head emergence to lesson regrowth however, this fails to provide termination (Wilkins and Bellinder 1996). Research has not evaluated if harvesting could impact effectiveness as mowing leaves the residue behind which acts as a mulch preventing regrowth in potentially providing weed suppression and reducing soil erosion (Carrera et. al. 2004; Creamer and Dabney 2002; Creamer et. al. 1995; Kemper and Derpsch 1981;).

While popular, cover crop termination techniques utilizing herbicides have not been rigorously studied. Herbicides are commonly used for weed control and cover crop termination in conventional and conservation farming systems. Glyphosate is used in these systems because it controls wide range of perennial and annual weeds, particularly annual grasses and has short crop rotation restrictions (Anonymous 2014). Thus, cover crop termination utilizing glyphosate is commonly recommended (Clark 2007; Bosak and Davis 2014; Legleiter et. al. 2012; Midwest Cover Crop Council 2014) as well as a burndown herbicide prior to crop planting/emergence (Davis et. al. 2015; Knezevic et. al. 2015).

Cover crop size and growth stage should be considered for proper termination utilizing herbicides. When utilizing glyphosate for rye termination the crop should be at boot to head stage for best results according to the Roundup PowerMAXX® herbicide label (Anonymous 2012). Annual ryegrass is not specifically mentioned on the Roundup PowerMAXX® herbicide label but glyphosate is commonly recommended for annual ryegrass control (Anonymous 2012; Bosak and Davis 2014; Legleiter et. al. 2012; Plumer et. al. 2013). While most herbicides do not allow for termination applications prior to harvesting, Roundup PowerMAXX® label allows harvesting of alfalfa 36 hours prior to grazing (Anonymous 2012). Producers have applied glyphosate just prior to harvesting annual ryegrass and winter rye although it is not a labeled treatment (personal observation).

As common termination methods for annual ryegrass and winter rye being utilized in Wisconsin as a forage are not registered for use (glyphosate prior to harvest), we designed experiments to test the efficacy of legal applications of herbicides following harvest. The objective was to evaluate methods and timings applicable in a conventional dairy system for annual ryegrass and winter rye termination when used as forage. To accomplish this we conducted field trials over two years that evaluated the effectiveness of harvesting alone or in combination with glyphosate applications after harvest to the stubble at two stages of development of these crops. As observations suggest that glyphosate performance is poor, two additional studies evaluated the effect of labeled glyphosate rates at controlling annual ryegrass and winter rye.

Materials and Methods

Sites. Field experiments were conducted at Arlington Agricultural Research Station near Arlington, WI (43.30 °N, 89.33°W) during 2013 and 2014. At Arlington soil type is Plano silt loam (fine silty, mixed, mesic Typic Argiudoll) with a pH of 6.5 with 3.6 % organic matter in 2013 trial site and pH 6.9 with 3.1 % organic matter in 2014 trial site. Monthly precipitation and temperatures for 2013, 2014, and January through June 2015 are shown in Table 1.

Experimental Design. Experiments were arranged as randomized complete block trials with four replications for each forage/cover crop and studies and were conducted over two years. Study one examined termination efficacy at two timings where four different termination treatments were applied. Study two examined termination efficacy of labeled rates of glyphosate for termination applied at three timings to three annual ryegrass species and winter rye.

Establishment. Experiments were planted into fields of corn harvested for forage in fall prior to seeding forage crops 2013 and 2014. Once harvested the forage crops were no-till seeded perpendicular to the harvested crop rows in the second week of September. Annual ryegrass varieties were seeded at 37 kg ha^{-1} and 0.6 cm deep. Winter rye was seeded at 134.4 kg ha^{-1} and 2.5 cm deep. Each plot was 2.29 meters wide by 12.95 meters long with row spacing of 19 cm. Study one cover crops included winter rye and 'King' annual ryegrass while study two included 'Gulf,' 'Bruiser,' and 'King' annual ryegrass varieties and winter rye.

Study one treatments were applied in mid-May at Feekes 9 during vegetative growth, and at full flowering Feekes 10.5.2 growth stage in early June (13 and 8 d apart in 2014 and 2015 respectively). Treatments included glyphosate, harvesting, and harvesting plus glyphosate. Harvest treatments were applied using a sickle bar mower and the plants were cut to approximately 9 cm height and the biomass was raked off the plots to simulate forage harvest. Glyphosate was applied at a rate of 1.26 kg ae $ha^{-1}$and if applied after harvest applications were made the same day as harvest. Untreated control plots were also present within the experimental design but were excluded from analysis.

Study two treatments were applied at three timings in mid-May late-May, and early-June based on annual ryegrass height ranges of 23, 31, and 55 cm and there was 8 days between timing one and two and six days between two and three in 2014 and 2015. Winter rye was at Feekes 9, 10, and 10.5.2 growth stage. Treatments used included nontreated control and glyphosate at rates of 0.63, and 1.26 kg ae ha^{-1}. These rates were chosen because 0.63 kg is the lowest labeled glyphosate rate and 1.26 kg ae ha^{-1} is the current burndown rate.

Glyphosate used for both trials was Roundup POWERMAX® (0.54 kg ae L^{-1}) and was applied with a CO_2-pressurized back-pack sprayer at 4.8 km h^{-1} , 51 cm above crop canopy, delivering 140.2 L ha^{-1} of spray solution at 172 kPa pressure using XR11002 flat-fan nozzles (Spraying Systems Co., Wheaton, Illinois). All glyphosate applications included the use of ammonium sulfate at 7.7 kg per 378.5 L of spray solution. All applications occurred under dry, active growing conditions in the mid to late afternoon, with mid to full sun, 22-30°C air temperatures, and 2-12 km^{-1} wind speeds.

Measurements. Cover estimates were collected two weeks after treatments in both studies. Cover of forage crops was determined using digital imagery analysis data collection adapted from Purcell (2000). Digital images for digital imagery analysis were taken at 91 cm above each sub-subplot. A standard digital camera was mounted at a 70 degree 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

(Fastone.org 2015). Once resized the pictures were analyzed to determine the percentage of cover using Sigma Scan Pro Version 5®(Systat Software, Inc., San Jose, CA) utilizing macro Turf Analysis 1-2 for automation (University of Arkansas, Fayetteville, AR) using methods adopted from Richardson and Karcher (2001 and 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 18-250 with the maximum always set at 100. Hue values used ranged from 37-55 with the maximum always set to 120. Adjustments were made between each data collection date, but not from within each data collection timing.

In study one single time biomass collection occurred two weeks after herbicide applications. Plant biomass was collected in each sub-subplot from a 25 cm linear row. The samples were dried for two weeks at 60°C and weighed to the tenth of a gram.

Statistics. All data were subjected to analysis of variance (ANOVA) using PROC MIXED in SAS (SAS v 9.3, SAS Institute Inc., Cary, NC) to examine the effects of termination treatment and timing. Boxplots and residual plots were evaluated to confirm variance assumptions and homogenous data utilizing the Proc Univariate and Proc Plot functions in SAS and if needed data were natural log transformed (Oehlert 2000). Percent green cover for study two was converted to a percent green cover reduction from the nontreated control plot mean data and square root transformation was done. For clarity, all data are presented untransformed. For study one factors included treatment, application timing, and application timing x treatment with year and block as random effects for winter rye. Factors were similar for annual ryegrass except for year which was excluded as populations did not survive winter of 2014-2015. Study two factors included for annual ryegrass: annual ryegrass population, application timing, glyphosate rate, and all interactions between population, timing, and rate. Winter rye factors for year include application timing, glyphosate rate, and timing by rate. Year and block were treated as random factors for the winter rye data, but only block for annual ryegrass as populations did not survive winter of 2014-15. All means were separated using Tukey-Kramer adjustment method at 5% level of significance with the PDMIX package in SAS (Oehlert 2000).

Results and Discussion

Study 1-Ryelage Harvest.

Annual ryegrass: Biomass and cover was significantly affected by an interaction between timing and treatment with annual ryegrass two weeks after treatment (Table 2). All treatments except harvesting at the late timing resulted in cover $\leq$ 7% except the late harvest only treatment which had 43% cover (Table 3). In contrast, biomass varied considerably with the late harvest and glyphosate treatment having the least cover although not different from glyphosate early and harvest and glyphosate early. Variability in this response was high due to the area sampled was small and biomass included the treated, senesced tissue in the glyphosate treatments. Annual ryegrass quickly regrew from the harvest only treatment in timing B, suggesting that glyphosate should be utilized if waiting to harvest until this stage, but may not be necessary at timing A (Table 3). No similar studies have been done on annual ryegrass; however glyphosate is a common recommendation for the control of many grass species (Anonymous 2012).

Winter rye: Only biomass was significantly affected by treatments, where an interaction between timing and treatment was observed two weeks after treatment (Table 2). While cover of winter rye was 1% when utilizing harvesting and glyphosate at either timing, it was not different from glyphosate alone or harvest alone treatments which ranged between 2 and 18 % cover (Table 3). Biomass was higher when glyphosate was used early without harvesting or late with or without harvesting, but data included senesced biomass so it is difficult to determine successful termination from these data. Winter rye termination effectiveness by harvest at Feekes 10 growth stage are supported by a study by Wilkins and Bellinder that found rye mowed after Feekes growth stage 10 had limited regrowth (Wilkins and Bellinder 1996). Others found successful winter rye termination (>95%) utilizing a flail mower, undercutter, and sickle bar mower (Creamer et. al. 1995). Glyphosate has been documented to be an effective tool for Winter rye termination as researchers found a rate of 1.68 kg ae ha^{-1} provided 95% control of winter rye at a similar timing to our B and more effective that utilizing at roller-crimper for termination (Ashford and Reeves 2003).

Study 2- Glyphosate Rate.

Annual ryegrass: Varieties established in 2014 to be treated in 2015 winter-killed, therefore the analysis was only done on the study established in 2013 and treated in

2014. Winter precipitation and snow cover was much lower in the 2014-2015 winter which likely resulted in the winter-kill (Baker et. al. 1991; Leep et. al. 2001). In the 2013-14 study, variety of annual ryegrass and rate of glyphosate affected the reduction in green cover two weeks after treatment ($P<0.05$) (Table 4). While different, all varieties had > 92% reduction thus while differences were detected they were all considered successfully terminated (data not shown). Rate of glyphosate applied did affect the reduction of green cover, but both rates (0.63 and 1.26 kg ae ha^{-1}) had >95% reductions indicating successful termination two weeks after treatment (Table 6). Visual assessment three weeks after applications confirmed successful termination of all annual ryegrass populations (data not shown). This result is supported by results found by Perez-Jones et.al (2005) when a dose response on ryegrass was conducted and the results indicated that the susceptible population, based on shoot biomass, was terminated at a 0.1 kg ae ha^{-1} glyphosate rate. Using a glyphosate rate of 1.26 kg ha^{-1} also is recommended for consistent termination (Legleiter et. al. 2012). Farmers and agronomists have commented on difficulties terminating annual ryegrass with a variety of glyphosate rates, including those exceeding label recommendations, however the data from study two demonstrates that annual ryegrass can be controlled utilizing the lowest labeled rate of glyphosate of 0.62 kg ae ha^{-1} (Anonymous 2012; personal conversation; and Plumer et al. 2013). This suggests that weather may be affecting results, as applications were conducted under optimal conditions in this study.

Winter rye: Winter rye termination was only impacted by timing ($P<0.0001$) (Table 4). Results over two years found that timing A had 33 and 42 % less reduction in green cover compared to timings B and C respectively (Table 5). This suggests that termination failure can occur when applications are made at Feekes 9, however, visual assessment three weeks after application confirms 100% termination for timings A, B, and C (data not shown). Winter rye termination efficacy data shown in this study is supported by Price et al. (2009) that demonstrated that glyphosate at rates of 0.21-0.84 kg ae ha^{-1} provided ≥97% termination of winter rye applied at Feekes 10.1 growth stage (2009).

While winter rye and annual ryegrass behaved differently, results suggest that utilizing glyphosate immediately following harvest can provide successful termination of both species. Harvesting alone was effective but timing may reduce effectiveness if harvested after Feekes 9. Burndown rates recommended for glyphosate (0.63 and 1.26 kg ae ha^{-1}) were effective in terminating both species. Future work should focus on glyphosate application on annual ryegrass and winter rye under less than ideal weather conditions.

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

Month	Total Precipitation				Mean Air Temperature			
	30 yr. Normal[b]	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	59	125	13	14	14	15
June	119	189	238	81	19	24	26	19
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	32	-	1	0.38	-3	-
December	37	11	33	-	-6	-9	-3	-

[a] Automated weather station located at the Arlington Agriculture Research Station, Arlington, Wisconsin. Global positioning system coordinates: 43.31, -89.38(Extension 2015).

[b] 30 year normal precipitation and temperature obtained from the Wisconsin State Climatology office (Madison, WI).

Table 2. 2014 and 2015 Ryelage harvest trial winter rye and annual ryegrass[1] ANOVA table for dry biomass and percent green cover effect on timing, treatment, and timing by treatment two weeks after termination application at Arlington Agricultural Research Station, Arlington, WI.

	Winter Rye		Annual Ryegrass[a]	
	Dry Biomass	Percent Cover	Dry Biomass	Percent Cover
Effect	Pr>F			
Timing	<0.0001	NS	0.0018	<0.0001
Treatment	NS	NS	NS	<0.0001
Timing X Treatment	0.02	NS	0.0037	<0.0001

[a] Annual ryegrass data for 2014 only.

Table 3. 2014 and 2015 Ryelage harvest trial dry biomass and percent green cover of winter rye two weeks after termination treatment at Arlington Agricultural Research Station, Arlington, WI.[a]

			Winter Rye		Annual Rye	
Timing	Treatment		Dry biomass	Percent green Cover	Dry biomass	Percent green Cover
	Harvest	Glyphosate[b]	kg ha^{-1}	%	kg ha^{-1}	%
A	No	Yes	7041 A	18 A	692 BC	1 B
	Yes	No	2250 B	11 A	1776 AB	1 B
	Yes	Yes	5608 AB	1 A	976 ABC	1 B
B	No	Yes	9433 A	2 A	1902 B	2 B
	Yes	No	230 B	10 A	1603 AB	43 A
	Yes	Yes	1214 B	1 A	288 C	7 B
p-value			0.02	NS	0.0037	<0.0001

[a] Means within a column followed by the same letter are not different according to the Tukey-Kramer method at P≤0.05.

[b] Glyphosate applied at 1.26 kg ae ha^{-1}.

Table 4. 2014 and 2015 Glyphosate rate trial ANOVA table for annual ryegrasses and winter rye percent green cover reduction two weeks after termination application at Arlington Agricultural Research Station, Arlington, WI.

	Winter Rye[1]	Annual Ryegrass
Effect	Pr>F	
Variety	NA	0.0686
Timing	<0.0001	NS
Rate	NS	0.0031
Variety X Timing	NA[2]	NS
Variety X Rate	NA	NS
Timing X Rate	NS	NS
Variety x Timing X Rate	NA	NS

[1]Only winter rye in 2015 due to annual ryegrass winterkill.

[2]As only one variety of winter rye was utilized in this study any factor involving population was excluded from the analysis with winter rye.

Table 5. 2014 and 2015 Glyphosate rate trial reduction in percent cover means for winter rye and annual ryegrass species by timing for two weeks after termination application at Arlington Agricultural Research Station, Arlington, WI. [a]

	Winter Rye	Annual Rye
Timing	Mean Reduction in Percent Cover	
A	54 B	98
B	87 A	98
C	96 A	99
p-values	<0.0001	NS

[a] Means within a column followed by the same letter are not different according to the Tuckey-Kramer method at P≤0.05.

Table 6. 2014 and 2015 Glyphosate rate trial reduction in percent cover means for winter rye and annual ryegrasss species by rate two weeks after termination application at Arlington Agricultural Research Station, Arlington, WI. [a]

	Winter Rye	Annual Rye
Rate (kg ae ha^{-1})	Mean Reduction in Percent Cover	
0.63	78	97 B
1.26	80	99 A
p-values	NS	0.0031

[a] Means within a column followed by the same letter are not different according to the Tukey-Kramer method at P≤0.05.

Appendix: Additional Contributions to Wisconsin Weed Science

Weed Suppression in Cover Crops

Weed counts were performed in the nontreated winter rye plots of the corn and soybean herbicide carryover trial. Count data were taken from m^2 quadrants in the center of each winter rye nontreated plot prior to termination in late May 2014 and 2015. Weed counts were also taken one month after cover crop termination. Data are shown in tables 1 and 2.

Early-season weed density was lower for the winter rye plots than the late-season winter rye plots in both spring 2014 and 2015. Winter rye consistently decreased weed density in both the corn and soybean herbicide programs in both 2014 and 2015 when compared to the nontreated plots. These results support similar studies that examined the effects of winter rye on weed suppression (Bernstein et al. 2011; Bernstein et al. 2014; DeVore et al. 2013; Korres and Norsworthy 2015)

Cover Crop Herbicide Carryover Evaluation following Wheat Herbicides

The objective of this research was to determine if herbicides that are commonly applied to what adversely affect cover crop dry biomass weight, stand, percent green cover and normalized difference vegetative index (NDVI) and to access whether any of these data are correlated.

Wheat trials were established near Sauk City, WI in fall 2013 and Arlington Agricultural Research Station, Arlington, WI in fall 2014. Wheat trials had fourteen commonly recommended herbicide treatments applied at common labeled rates and timings. Treatments are shown in table 3. Treatments were replicated four times and a control treatment which had no residual herbicide applied. The wheat was harvested for grain and straw value at the end of July, and seven different cover crop species and/or varieties were seeded uniformly across all herbicide treatments. The cover crops included radish (*Raphanus* sp;), crimson clover (*Trifolium incarnatum*), 'Guardian' winter rye (*Secale winter*), a mixture of 70% oat (*Avena sativa*) plus 30% peas (*Pisum sativum)*, red clover (*Trifolium pretense*), hairy vetch (*Vicia villosa* Roth), and berseem clover (*Trifolium alexandrinum*) were seeded at recommended rates and depths. Nearly two months after seeding, the cover crops were evaluated for herbicide injury with digital image analysis for percent green cover, plant height and stand counts, and by weighing total dried biomass collected from a $0.10m^2$ quadrat. All cover crops did not have reduced stand, dry biomass weight, or percent green cover following any of the residual herbicide treatments. From these results, we suggest commonly used wheat herbicides evaluated in this study had little potential to adversely affect the establishment of many different cover crops, although this could be different under drastically different weather, cover crop species, or specific herbicide combinations not examined in this trial.

Cover Crop Interseeding in Wisconsin using a modified grain drill

Introduction

Wisconsin growers are increasingly interested in utilizing cover crops. While cover crop establishment is relatively easy following corn silage, small grains, and processing vegetables, establishing cover crops successfully following corn or soybean has been more difficult. Aerial seeding or over-the canopy seeding late in the growing season can be done with moderate success. An alternative approach is to interseed cover crops into a standing corn crop early in the growing season. This management practice requires special or at least modified equipment, but can improve cover crop establishment by drilling seed rather than broadcasting. Ideally, the cover crop will establish prior to canopy closure, but then survive to the end of the growing season without creating too much competition for resources (nutrients and water) for the corn crop. Little experimentation has occurred in Wisconsin to evaluate cover crop growth when interseeded into standing corn and the impact of interseeding cover crops on corn grain yield. The objective of this study was to evaluate interseeding cover crops into V5 corn using a modified grain drill and to access cover crop biomass and corn grain yield.

Materials and Methods

Field experiments were conducted at the Arlington Agricultural Research Station. The field was fall chisel plowed and then field cultivated in the spring prior to corn establishment. Corn was planted in early June in 2014 and in mid-May 2015. Five cover crops treatments were planted into corn: (1) radish, (2) red clover, (3) winter rye, (4) oat/pea mixture (70% oats, 30% pea), and (5) no cover crop. Table 4 shows seeding depth and rates. Cover crops were drill seeded when corn was at the V5 growth stage (14 July, 2014 and 6 June, 2015) using a modified no-till grain drill. The drill had four row units removed, leaving 6 row units to allow the drill to go through the crop rows and plant three rows of cover crops between each corn row. The no-till disks and supporting hardware were also removed to prevent damage to the corn. Corn was harvested for grain, and following harvest cover crops were evaluated by weighing the total dried biomass collected from a 0.25 by 0.25 m quadrat in each plot.

Results and Discussion

All cover crops were successfully established in 2014 and 2015. Within four weeks of seeding radish, red clover, and winter rye had germinated, had consistent growth during the growing season, and had good vigor up until two weeks of grain harvest. In 2015 the oat/pea did not have good vigor and had very poor biomass accumulation. Table 5 shows cover crop biomass accumulation. The corn never showed any visible symptoms of stress and the cover crops did not significantly reduce corn yields (<0.0001). Corn yields are shown in Figure 1 and 2. In 2014, radish and oat/pea winterkilled and rye was the only cover crop that needed terminated in spring. In 2014, the red clover looked very poor at the time of corn harvest; the late corn harvest stressed the red clover too much for it to survive the winter. Both years all cover crops were completely buried by the corn residue after harvest and resulted in variable biomass data. Future research will focus on evaluating the soil conservation, soil carbon building, and potential N credits obtained with interseeding these cover crops.

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Table 1. Soybean herbicide trial mean weed density data for 2014 and 2015 spring major weed species prior to winter rye cover crop termination early timing† and four weeks following termination late timing‡ at the Arlington Agriculture Research Station, Arlington, WI.

		2014				2015			
		Early		Late		Early		Late	
Common name	Latin name	Winter Rye	Nontreated	Winter Rye	Nontreated	Winter Rye	Nontreated	Winter Rye	Nontreated
		plants m^{-2}							
Common lambsquarters	*Chenopodium album*	6.3	20.8	1	1	0.3	12	4.3	5.8
Eastern black nightshade	*Solanum ptycanthum*	0	0	0	0	0	4.3	0	0
Velvetleaf	*Abutioln theophrasti*	0	11.3	0.3	0.5	0	13	0	0
Horseweed	*Conyza canadensis*	0	0	0	0	0	0	0	0
Common ragweed	*Ambrosia artemisiifolia*	0	0			3	25.5	0	0
Common dandelion	*Taraxacum officinale*	0	0.3	8.3	5.8	1.3	3.8	80.3	39.3
Woolly cupgrass	*Eriochloa villosa*	0	27.3	0.3	1	0	4.3	0	1
Giant foxtail	*Setaria* faber	0	0	0.3	1	0.8	59.3	0..3	0.3
Lady’s thumb	*Persicaria maculosa*	0	0	0	0	0	2.8	0	0
Wild buckwheat	*Polygonum convolvulus*	0	0	0	0	0	3.8	0	0
Redroot pigweed	*Amaranthus retroflexus*	0	0	0.3	0.3	0	0.3	0.3	1.3
Yellow foxtail	*Setaria pumila*	0	0	0	0	0.5	0.5	0	0
Barnyardgrass	*Echinochloa crus-galli*	0	0	0	0	0	0	0.3	1.8
Large crabgrass	*Digitaria sanguinalis*	0	0	0	0.3	0	0	0	0

†Early data collected on June 4th 2014 and May 28 2015 within five days of winter rye termination.

‡Late data collected on July 9th 2014 and July 8th 2015 approximately four weeks following winter rye termination.

Table 2. Corn herbicide trial mean weed density data for 2014 and 2015 spring major weed species prior to winter rye cover crop termination early timing† and four weeks following termination late timing‡ at the Arlington Agriculture Research Station, Arlington, WI.

		2014				2015			
		Early		Late		Early		Late	
Common name	Latin name	Winter Rye	Nontreated	Winter Rye	Nontreated	Winter Rye	Nontreated	Winter Rye	Nontreated
		plants m^{-2}							
Common lambsquarters	*Chenopodium album*	0	9.8	0.5	1	0.8	9	3.5	2
Shepherd's purse	*Capsella bursa-pastorius*	0	0.3	0	0	0	0	0	0
Velvetleaf	*Abutioln theophrasti*	0	3	0	0	0.5	0.3	0	0
Horseweed	*Conyza canadensis*	0	0	0	0	0	1.5	0	0
Common ragweed	*Ambrosia artemisiifolia*	0	1.3		0	10.8	74.5	2	1.3
Common dandelion	*Taraxacum officinale*	0	0	0	8	2	11	56.3	117
Woolly cupgrass	*Eriochloa villosa*	0	4.5	8.3	0.5	5.8	18.5	9.3§	2.3§
Giant foxtail	*Setaria* faber	0	1.5	0.8	4	0	0		
Spotted knapweed	*Centaurea stoebe*	0	0	0	0	0	1		
Redroot pigweed	*Amaranthus retroflexus*	0	0	0	0	0	0	0.3	0.5
Yellow foxtail	*Setaria pumila*	0	0	0	0	0	0	0	0
Large crabgrass	*Digitaria sanguinalis*	0	0	0	0.3	0	0	0	0

†Early data collected on 4 June 2014 and 28 May 2015 within five days of winter rye termination.

‡Late data collected on 9 July 2014 and 8 July 2015 approximately four weeks following winter rye termination.

§2015 POST grass species data were combined.

Table 3. Wheat herbicide treatments applied in spring of 2014 and 2015 prior to cover crop establishment near Sauk City and Arlington Agricultural Research Station, Arlington, WI.

Treatment	Active Ingredient	Rate	Timing*
		(g ai/ae ha^{-1})	
1	Nontreated		
2	thifensulfuron-methyl[1]	18	A
	tribenuron-methyl	18	
3	thifensulfuron-methyl[1]	18	B
	tribenuron-methyl	18	
4	dicamba	140	A
5	bromoxynil	560	A
6	bromoxynil	560	B
7	thifensulfuron-methyl[1]	18	A
	tribenuron-methyl	9	
8	thifensulfuron-methyl[1]	18	B
	tribenuron-methyl	9	
9	prosulfuron	23	A
10	pyrasulfotole[2]	41	A
	bromoxynil	230	
11	pyrasulfotole	41	B
	bromoxynil	230	
12	pendimethalin	1330	A
13	clopyralid	140	A
14	MCPA[1]	389	A
15	florasulam[1]	2	A
	MCPA	348	

* Timing A applied at Feekes 4 and timing B applied at Feekes 7 growth stage.

[1] Adjuvant: NIS 0.25% v/v.

[2] Adjuvant: Ammonium Sulfate 7.9 kg / 378.5 L.

Table 4. Cover crop interseeding seeding rate and seed depth placement.

Cover Crop	Seeding Rate (lb ac^{-1})	Depth (in)
Winter Rye	120	1
Red Clover	12	0.25
Radish	12	0.25
Oat/Pea Mix	90 / 10	1

Table 5. 2014 and 2015 Interseeded cover crop biomass following grain harvest at Arlington Agriculture Research Station.

Cover Crop	2014 Biomass (lb ac^{-1})[1]	2015 Biomass (lb ac^{-1})
Red Clover	229 (137-311)	511 (200-899
Winter Rye	209 (51-334)	485 (214-971)
Radish	900 (303-1944)	635 (57-1014)
Oat/Pea	201 (59-504)	21 (14-29)

[1]Biomass weight (data range in lb ac^{-1})

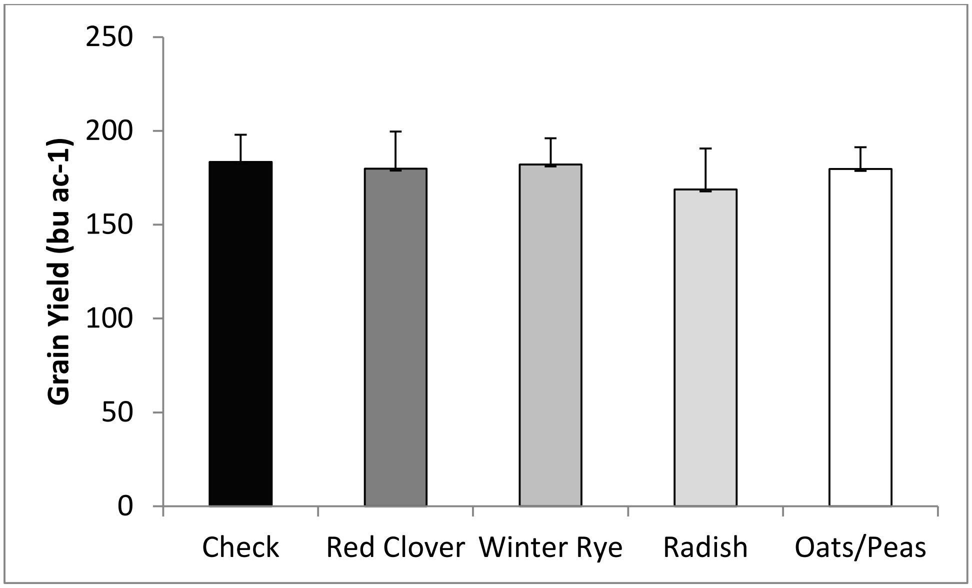

Figure 1. 2014 Cover crop interseeding corn grain yield at Arlington Agriculture Research Station.

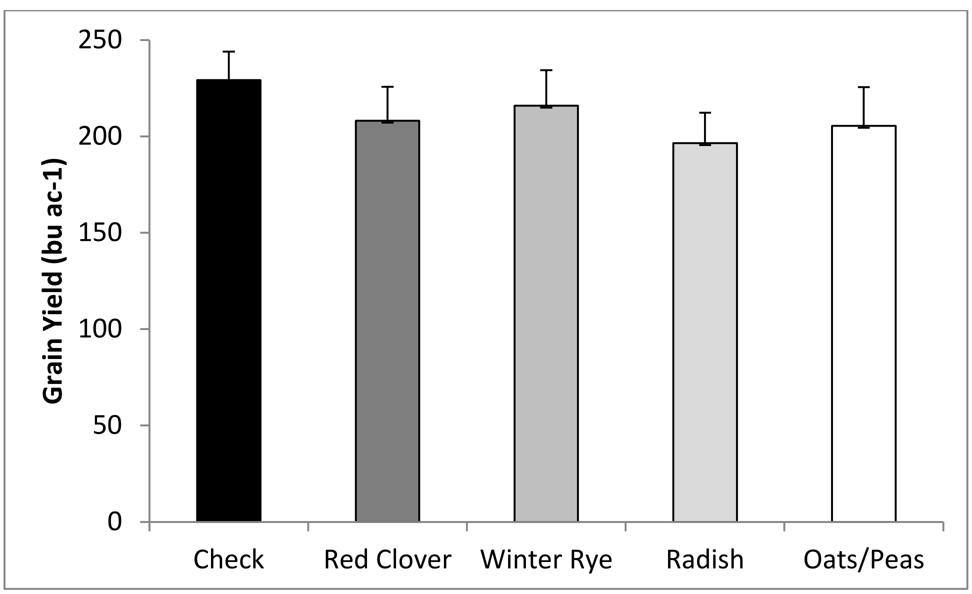

Figure 2. 2015 Cover crop interseeding corn grain yield at Arlington Agriculture Research Station.

Scientific Presentations

Smith, D.H., Bosak, E.J., Johnson, W.G., Legleiter, T. R., Davis, V.M. 2013. "Herbicide carryover evaluation in cover crops following corn and soybean herbicides" North Central Weed Science Society Annual Meeting, 9-13 Dec., Columbus, OH. Poster.

Smith, D.H., Davis, V.M. 2014. "Termination strategies for winter rye and overwintering annual ryegrass with glyphosate" North Central Weed Science Society Annual Meeting, 1-4 Dec., Minneapolis, MN. Poster.

Smith, D.H., Bosak, E.J., Johnson, W.G., Legleiter, T. R., Davis, V.M. 2014. "Herbicide carryover evaluation in cover crops following corn and soybean herbicides" North Central Weed Science Society Annual Meeting, 1-4 Dec., Minneapolis, MN. Oral Paper.

Hammer, D.J., Bailey, R.R., Butts, T.R., Smith, D.H., Bosak, E.J., Davis, V.M. 2014. "Sequential herbicide evaluation in glufosinate-resistant corn in Wisconsin" North Central Weed Science Society Annual Meeting, 1-4 Dec., Minneapolis, MN. Poster.

Smith, D.H., Bosak, E.J., Johnson, W.G., Legleiter, T. R., Davis, V.M. 2015. "Cover crop establishment issues following corn and soybean herbicides in Upper Midwest" Weed Science Society of America Annual Meeting, 9-12 Feb., Lexington, KY. Oral Paper.

Smith, D.H., Bosak, E.J., Johnson, W.G., Legleiter, T. R., Davis, V.M. 2016. "Herbicide carryover in cover crops following corn and soybean herbicides" University of Wisconsin-Madison Plant Sciences Graduate Student Annual Symposium, 5 Nov., Madison, WI. Oral Paper.

Smith, D.H., Bosak, E.J., Johnson, W.G., Legleiter, T. R., Davis, V.M. 2015. "Cover crop establishment following commonly applied corn and soybean herbicides in Upper Midwest" ASA, CSSA, & SSSA International Annual Meeting, 15-18 Nov. Minneapolis, MN. Oral Paper.

Smith, D.H., Ruark, M.D., Arriaga, F.J, Davis, V.M. 2015. "Cover crop interseeding in grain corn using a modified drill" North Central Weed Science Society Annual Meeting, 7-10 Dec., Indianapolis, IN. Oral Paper.

Smith, D.H., Davis, V.M. 2015. "Herbicide carryover evaluation in cover crops following wheat herbicides" North Central Weed Science Society Annual Meeting, 7-10 Dec., Indianapolis, IN. Poster.

Extension and Other Presentations

Davis, V.M., Bosak, E.J., Butts, T.R., Smith, D.H. 2013. "National threat of glyphosate resistant pigweeds: UW efforts to research and extend relevant information in Wisconsin" Pest Management Field Day- 11 Jun., Arlington, WI. Oral Paper.

Davis, V.M., Bosak, E.J., Trower, T.L., DeWerff, R.P., Recker, R.A., Bailey, R., Butts, T.R., Smith, D.H. 2013. "Wisconsin Crop Weed Science Research Report 2013" Department of Agronomy College of Agriculture and Life Science University of Wisconsin- Madison

Smith, D.H., Davis, V.M. 2014. “Cereal rye and annual ryegrass termination” University of Wisconsin-Madison Cover Crop Field Day, 8 Oct., Arlington, WI. Oral Paper.

Bosak, E.J., Davis, V.M., Smith, D.H. 2014. “Herbicide considerations for cover crops” University of Wisconsin-Madison Cover Crop Field Day, 8 Oct., Arlington, WI. Oral Paper.

Davis, V.M., Bosak, E.J., Bailey, R., Butts, T.R., Smith, D.H. 2014. “Wisconsin Crop Weed Science Research Report 2014” Department of Agronomy College of Agriculture and Life Science University of Wisconsin- Madison

Smith, D.H., Davis, V.M. 2015. “Cover crop establishment following commonly applied corn and soybean herbicides in Wisconsin” Wisconsin Crop Management Conference, 13-15 Jan., Madison, WI. Oral Paper.

Smith, D.H., Davis, V.M., Bosak, E.J. 2015. “Cover Crop Termination” Wisconsin Association of Professional Agricultural Consultants Annual Meeting 12-13 Mar. Wisconsin Dells, WI. Oral Paper.

Smith, D.H., Ruark, M.D., Arriaga, F.J. 2015. “Interseeding cover crop into V5 corn” Wisconsin Crop Manager Newsletter, 27 Aug. Vol. 22 Number 25. Article.

Smith, D.H., Ruark, M.D., Arriaga, F.J. 2015. “Interseeding cover crop into corn in Wisconsin: Can it work?” Wisconsin Crop Manager Newsletter-Youtube Video. https://www.youtube.com/watch?v=ipw2lsyYZ0E

Smith, D.H. 2015. “Establishing cover crops following residual herbicides in corn and soybeans and terminating winter rye and annual ryegrass” Thesis Defense, 24 Nov.

Smith, D.H., Ruark, M.D., Arriaga, F.J, Davis, V.M. 2016. Interseeding Cover crops into corn in Wisconsin” Wisconsin Crop Management Conference, 12-14 Jan., Madison, WI. Oral Paper.

Crops and Weeds Team

2013 North Central Weed Science Society Weeds Contest, Monmouth, IL 6 undergrads, 7 grad students

2014 North Central Weed Science Society Weeds Contest, Des Moines, IA Co-Leader 9 undergrads, 5 grad students

2015 Weed Olympics Weeds Contest, Columbus, OH- Co-Coach/Precipitant (David Marburger, Devin Hammer) North Central Division- 1st and 3rd place undergraduate team, numerus North Central placings, overall top undergraduate; 6 undergrads, 3- grad students

2015 Regional Crops Contest, Platteville, WI- Co-Coach (David Marburger) – 3 undergrads

2015 Collegiate Crops Contest, Chicago, IL- Co-Coach (David Marburger) - 3 undergrads