COVER CROPS FOR HORSEWEED [*CONYZA CANADENSIS (*L.)] CONTROL BEFORE AND DURING A SOYBEAN CROP

by

ANDI MARIE CHRISTENSON

B.A., Kansas State University, 2012

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2015

Approved by:

Major Professor
Kraig Roozeboom

Approved by:

Major Professor
J. Anita Dille

Copyright

Abstract

Increasing numbers of herbicide-resistant weed species require alternative methods of weed suppression to be examined. This study quantified the interaction between various cover crop or herbicide systems and horseweed [*Conyza canadensis* (L.)] growth. Fall cover crops of winter wheat [*Triticum aestivum* (L.)], winter rye [*Secale cereal* (L.)], barley [*Hordeum vulgare* (L.)] and annual ryegrass [*Lolium multiflorum* (L.)] were seeded in November 2012 and 2013. Spring cover crop of oat [*Avena sativa* (L.)] was seeded in April 2013 or rye was seeded in March 2014. All cover crops were no-till seeded into grain sorghum stubble [*Sorghum bicolor* (L.) Moench]. Four herbicide treatments were fall or spring applied, with and without residual. The spring non-residual treatment was also applied to plots of winter rye. Cover crop plots were split and terminated with a roller crimper or glyphosate application prior to soybean [*Glycine max* (L.) Merr.] planting to determine the effect of termination method on treatment performance. Soybean was planted in June 2013 and May 2014 and mechanically harvested in October of both years. Horseweed density, biomass accumulation, and soybean yield data were quantified. Horseweed height, whole plant seed production, and seed subsamples were recorded in the untreated fallow control, winter wheat, and winter rye plots in 2014. Horseweed suppression by winter rye approached 90%, levels similar to suppression by herbicide systems. In both years, herbicide plots had less than half the horseweed biomass than any of the cover crop systems. In 2013, soybean yields in herbicide plots were at least 1,500 kg ha^{-1}, nearly more than double yields in cover crop plots. Soybean yields in 2014 were more consistent across treatments; barley and spring rye plots achieved yields equal to or greater than 2,000 kg ha^{-1}. Winter rye and winter wheat reduced horseweed seed production by 60% compared to the untreated fallow control, with no effect on individual seed weight. Seed production varied across

plants, with the untreated control producing the greatest number of seeds. Cover crops were successful at reducing horseweed biomass, suppressing horseweed pressure, preserving soybean biomass, and protecting soybean yields when compared to a fallow untreated control.

Table of Contents

List of Figures

List of Tables

Acknowledgements

Thank you to my major professors, Kraig and Anita, for your guidance the last two and a half years. Thank you to Dallas for serving on my committee, as well. I had a lot of catching up to do when I started, but you were always patient with me and let me learn from my mistakes. I've come a long way from where I started and I couldn't have done it without you.

Thank you to my lab mates and the student workers in both the Crop Production and Weed Ecology projects. We've shared a lot of experiences, and grad school wouldn't have been near as fun (or bearable) without such an awesome group.

Thank you to my husband, Brent, for believing in me when I didn't believe in myself and for pushing me to achieve this goal. Grad school would have been rough without your SAS help and without you turning me into something of a morning person.

Thank you to my family for their support and understanding throughout my education. I know that my excitement about weeds was probably a little strange to my farming family. I wouldn't have picked this major or career path if it wasn't for the passion for farming that I saw growing up.

Thank you to the Department of Agronomy, especially the Crop Production and Weed Science groups for funding for my project and assistantship. I'm very appreciative of the opportunities to attend conferences, workshops, and contests that have helped to enrich my grad school experience.

Chapter 1 - Literature Review

With the United States leading the world in soybean [*Glycine max* (L.) Merr.] production at a time of rising food demand, it is imperative that producers protect their yields however possible (USDA 2015). Glyphosate-resistant soybean varieties made up 83% of the acres planted in the United States in 2012 (USDA 2014). Producers in 2012 also estimated that glyphosate efficacy had been reduced on an estimated 44% of their planted acres, and reported that weeds were responsible for 39% of yield losses during the same year (USDA 2014). Herbicide-resistant weeds are especially threatening to soybean yields as losses of up to 27% were estimated when early season weed species were allowed to compete with the crop (Fickett et al. 2013). With this in mind, it is important to examine various strategies to control and reduce the densities of weeds found in producers' fields.

Horseweed

Horseweed [*Conyza canadensis* (L.)] is a weed native to North America and commonly found in reduced tillage or no-till cropping systems. Horseweed has a wide window of germination, and can be considered both a winter and summer annual (Weaver 2001). The plant overwinters or emerges as a basal rosette, bolts in the spring, and is capable of quickly reaching heights in excess of 1.8 m (Weaver 2001). Regeher and Bazzaz (1979) found that winter survival of horseweed increased as rosette size increased. It is capable of producing more than 200,000 seeds per plant (Bhowmik and Bekech 1993), with a dispersal range in excess of 500 km from the point of origin (Shields et al. 2006). Horseweed is particularly troublesome in soybean crops as it germinates and emerges over an extended period of time, from fall until spring, and is generally present before soybean planting (Weaver 2001). In addition, herbicide-resistant biotypes have been found in 16 countries, and glyphosate-resistant biotypes were confirmed in Kansas in 2005 (Heap 2015).

Winter wheat [*Triticum aestivum* (L.)] used as a cover crop reduced densities of horseweed for up to one month after cover crop planting (Davis et al. 2007), which may be long enough to allow for adequate growth of fall-planted cash crops to outcompete the weed. However, spring-emerging cohorts in Indiana constituted up to 90% of a total horseweed population at the time of soybean planting (Davis et al. 2008). Horseweed germination was reduced when placed in conditions receiving less than 13 hours of light and in temperatures less than 12/6 C (day/night) (Nandula et al. 2006); conditions that likely can be obtained by shading when using competitive cover crops or in cover crop residue.

Cover Crops

Given the competitiveness of horseweed, the complication of herbicide-resistant biotypes, and the related crop yield losses, producers have begun searching for alternative methods of weed suppression. Producers have planted over 400 million ha of cover crops in the United States for a number of reasons, including to examine and utilize alternative methods to suppress weeds while maintaining or increasing their cash crop yields without relying solely on herbicides (USDA 2012). Cover crops have been a tool widely adopted by many for weed suppression, as they offer an alternative or complement to herbicide applications and, in many circumstances, outcompete weeds. Although a cover crop species may be planted for a specific purpose, benefits can be beyond the initial intention of the grower. Cover crops can improve fertility, soil and water quality while also reducing erosion and insect pressure (Clark 2008). Tall and fast growing cover crops (typically cereal grasses) are competitive with weeds for sunlight. They may also shade the soil surface, lowering or maintaining the soil temperature and therefore extending the date of germination for some weed species. Legumes, such as crimson clover [*Trifolium incarnatum* (L.)], hairy vetch [*Vicia villosa* (Roth)] and field peas [*Pisum sativum* (L.)] are often planted to fix nitrogen, and the subsequent biomass breakdown can add nitrogen back into the soil to improve fertility. Cereal grains, including winter wheat, winter rye [*Secale cereal* (L.)], and winter barley [*Hordeum vulgare* (L.)] help to minimize soil and water erosion while offering the possibility of a flex crop that could be harvested as a cash crop when conditions allow or the possibility of being utilized as a grazing option for cattle. Many producers are utilizing mixtures of cover crops for a more well-rounded cover cropping system. Mixtures could include two species with the same life cycle to fill a fallow period or they may be part of a longer crop rotation and include up to a dozen species of warm- and cool-season grasses, broadleaves, and legumes. Cover crops can alter the environment of a site to make it less susceptible to weed pressure and can impact the overall cropping system through physical suppression, the secretion of allelochemicals, tillage operations, cover crop termination methods, mulching, and the rotation of herbicides.

Cover crops physically alter the microclimate of a location by shading the soil surface and decreasing the amount of solar radiation available to weeds, affecting weed seed germination, emergence, and growth (Moore et al. 1994). Physical weed suppression starts during the growing season of the cover crop and can last for as long as living or dead crop residue remains on the soil surface. The more cover crop biomass left on the soil surface, the greater the level of weed suppression that can be achieved and the longer the duration of suppression due to the reduction of sunlight reaching the soil surface (Nord et al. 2011). The presence of winter rye cover crop biomass has been shown to decrease the emergence of redroot pigweed [*Amaranthus retroflexus* (L.)] seedlings by up to 87% (Moore et al. 1994). In the same study, soybeans that were planted into the winter rye mulch produced more seeds per plant with greater seed weights than soybeans planted in plots without cover crop mulch. In one study, yields of soybeans in the cover crop plots were up to 91% greater than in plots with no cover crop and no other method of weed control (Moore et al. 1994).

Competition is another key feature provided by cover crops that can be planted as a "smother crop" with the intention of rapid growth. Cover crop species may be selected with their growth habit and growth rate in mind. Species that grow quickly, either upward or outward, will capture sunlight that would be intercepted by weeds otherwise (Perry and Galatowitsch 2006). Severino and Christoffoleti (2004) found that sunn hemp [*Crotalaria juneca* (L.)] was competitive enough to effectively suppress all weeds found in control plots. Hairy vetch suppressed grassy weeds by 27% in one study (Teasdale et al. 1991). Persian clover [*Trifolium resupinatum* (L.)] and white clover [*Trifolium repens* (L.)] were able to more effectively suppress shepherd's purse [*Capsella bursa-pastoris* (L.) Medick] than subterranean clover [*Trifolium subterraneum* (L.)] (Den Hollander et al. 2007).

Allelopathy

Crops and weeds also interact by way of chemical secretions, known as allelochemicals. Allelopathy can be defined as "any direct or indirect harmful or beneficial effect by one plant (including microorganisms) on another through the production of chemical compounds that escape into the environment" (Rice 1984). The effects of allelochemicals on nearby weeds and future crops depend on the amount of allelochemical produced, soil type, rainfall, the cover crop and cultivar, amount of biomass accumulated, and field conditions for the following crop (Weston 2005). Grass species tend to be the most widely researched in terms of allelopathy. Rice [*Oryza sativa* (L.)], sorghum [*Sorghum bicolor* (L.) Moench], winter wheat, triticale [x

Triticosecale Wittm. (ex A Camus.)], winter rye, and barley all contain allelochemicals (Boz 2003, Dhima et al. 2006, Olofsdotter 2001). Brassica species, such as brown mustard [*Brassica juncea* (L.) Czern.], black mustard [*Brassica nigra* (L.)], white mustard [*Sinapis alba* (L.)], and canola [*Brassica napus* (L.)] contain glucosinolates (Bialy et al. 1990, Turk and Tawaha 2003), which act as an allelochemical and have been shown to effectively suppress weeds. Aqueous extracts from sunflowers [*Helianthus annuus* (L.)] contain other allelochemicals that negatively impact weed growth (Jabran and Farooq 2013). Allelopathic compounds have been observed in the straw and roots of winter rye and winter wheat, the roots of rice, and the leaves of alfalfa [*Medicago sativa* (L.)] (Boz 2003, Chung et al. 2001, Chon and Kim 2002).

Allelochemcials seem to suppress the germination of small-seeded weeds most effectively, however, more research is necessary to understand allelopathic compounds and their effects. In greenhouse studies, the extract of several winter cereals (rye, triticale and barley) affected germination, seedling fresh weights and root length of barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] and bristly foxtail [*Setaria verticillata* (L.) Beauv.] (Dhima et al. 2006). Extracts from the barley cultivar “Athinaida” inhibited germination of barnyardgrass by 39% and bristly foxtail by 64%. This cultivar reduced barnyardgrass seedling fresh weight by 69% and reduced root length by 70%. In a similar outdoor experiment, incorporating the biomass of “Athinaida” into soil reduced barnyardgrass stem number by 61% and bristly foxtail stems by 56% at four weeks post incorporation. Conversely, corn [*Zea mays* (L.)] was not affected by “Athinaida” or any other winter cereal extracts or residues (Dhima et al. 2006).

Cover crop mixtures are sometimes used in cropping systems. A mixture of species can provide excellent weed control because allelopathic chemicals can be specific to certain weed species (Creamer et al. 1992). Having multiple allelochemicals present in a system can have an additive effect on inhibiting weed seed germination; greater concentrations of allelochemicals present at once means a larger impact on the seeds of a larger number of weed species (Creamer et al. 1992). A mixture of species could provide well-rounded allelopathic weed control under certain cropping systems (Creamer et al. 1996, Purvis et al. 1985).

Tillage

In cropping systems that utilize conventional tillage and herbicides, producers have more flexibility in their options for weed control. Producers can use a mixture of herbicides, tillage methods, and cover crops to achieve satisfactory weed control. The interaction between cover crops and tillage methodology may seem trivial, but tillage has a great impact on the species of weeds present in a subsequent cash crop. Reduced and no-till systems are being increasingly adopted by producers, with over 40% of soybean producers utilizing no-till practices in 2012 (USDA 2013). Soybeans planted in a no-till system have a longer critical period of weed control than soybeans in conventional tillage systems (Halford et al. 2001). The critical period of weed control describes the length of time that it is necessary for a crop to be free of competition from weeds in order to prevent a reduction in grain yield. Soil in no till systems remains cooler for a longer period of time, prolonging the period of weed germination (Knezevic et al. 2002). Depending on the frequency and timing of tillage, small seeds may be buried or large seeds brought to the surface and exposed for a duration that renders the seed unviable (Ball 1992). Small-seeded weeds generally germinate and emerge from the surface of the soil and do not germinate and emerge when buried deeply, but large-seeded weeds have difficulty germinating in shallow soil, are less dependent on light for germination, and have higher germination and emergence rates when buried more deeply (Milberg et al. 2000). Small-seeded weeds, like annual grasses and horseweed, are known to be more prevalent in no-till systems than in conventional tillage systems, but large-seeded weeds have been observed to decrease with the adaptation of a no-till system (Teasdale et al. 1991). There is no correct answer in the matter of whether or not a producer should till; the producer simply needs to be aware of the type of weeds to expect is his tillage system. Regardless of the cropping type and tillage system, cover crops have been shown to suppress both small and large-seeded weeds by competing for resources and shading the soil surface (Moore et al. 1994, Nord et al. 2011, Teasdale et al. 1991).

Herbicides

When used correctly, herbicides can be applied in a cover cropping system to minimize overall weed pressure and subsequently reduce the amount of herbicide used in future crops. Cover crops often are used to suppress germination, emergence, and growth of weeds in systems that face issues with herbicide resistance (Teasdale et al. 1991). For example, by integrating a broadleaf cover crop (such as forage soybeans) into a grass cropping system (such as continuous corn), a producer can use a herbicide to control grass weeds during the cover crop phase and reduce the amount of weed seed entering the seedbank. As a result, fewer grass weeds appear in the next corn crop (Ball 1992). This rotation of crops and herbicides can reduce selection pressure on the weed species that could potentially lead to the prevalence of herbicide-resistant biotypes. Some weeds in a population may be naturally resistant to a particular herbicide, and when tank mixes are not used, those plants are able to survive the herbicide application, and reproduce- furthering the population of herbicide resistant weeds. Rotations also can help to reduce weeds that are crop mimics, such as downy brome [*Bromus tectorum* (L.)] in a wheat crop or johnsongrass [*Sorghum halepense* (L.) Pers.] in a sorghum crop. These species are difficult to distinguish from cash crops, making control nearly impossible in some instances. A rotation allows for more variation within the cropping system and helps to slow or prevent the convergence of the crop species and the weed species (Liebman and Dyck 1993).

Cover Crop Termination

Not all cover crops winterkill, so it often is necessary to terminate cover crops by alternative methods. Chemical termination of cover crops with herbicides is common and can serve as a pre-plant herbicide application. Roller-crimpers and mowers are other options for producers who may be looking to reduce or eliminate herbicide applications while still terminating cover crops. A rolled winter rye cover crop may reduce the number of weeds early in the season, but hasn't been shown to decrease weed density later in the growing season (Mischle et al. 2010). An issue that frequently arises when using a roller-crimper is incomplete kill of a cover crop due to incorrect termination timing or variation in cover crop maturity throughout a field. The cover crop can then become a weed in a cash crop. Despite this, roller-crimpers are still often used by producers concerned by herbicide resistant weeds. However, research has indicated that the use of a roller-crimper paired with glyphosate can have 91% efficacy in cover crop termination (Ashford et al. 2000).

Mowing is used occasionally as a method of cover crop termination and weed suppression, but this method can have issues with cover crop regrowth and variability in the distribution of residue (Davis 2010).Sickle bar mowers are more desirable for cover crop termination over other mowers because residue left behind tends to be more uniform in distribution and does not form a mat that could potentially interfere with emergence of subsequent crops (Clark 2008). Cover crops that are terminated too late may not aid in the suppression of weeds, as the weeds have already had the opportunity to establish within the cover crops (Mischle et al. 2010). For this reason, it is imperative to select cover crops that will be established prior to the germination of problem weeds. For example, with horseweed having a wide window of germination starting in the fall, cover crops must be planted in the fall prior to a soybean crop in order to effectively suppress these fall-emerging horseweed plants.

Enhancing the Use of Cover Crops

Recent research has shed light on more tactics that cover crops use for weed suppression. Research has found cover crop mixtures that work best in specific locations and for specific purposes while proving to be economical; studies were conducted in Mead, Nebraska to examine the efficacy of various mixtures of cover crop species versus weeds in conjunction with termination by field disk or sweep plow undercutter. Cover crops terminated with the sweep plow undercutter were seen to increase yield in subsequent crops (Wortman et al. 2012). Recent and ongoing studies have been examining how cover crops interact with soil microorganisms. Fungi and bacteria can affect cash crop and weed growth, as found by Njeru et al. (2014) with colonization of mycorrhizal fungi being greater in corn following hairy vetch. Preliminary research is being conducted to examine the impacts cover crop seeding rates, planting and termination dates, and amounts of cover crop residues and the impact of these factors on weed control in an organic cropping system and the ways in which the residues interact with the cash crops (Carr et al. 2013). Allelopathy continues to be a topic of interest, as researchers continue to discover new allelochemicals and examine the manner in which they work to suppress weeds and their subsequent impact on cash crops (Khanh et al. 2013, Schulz et al. 2013). The effects of various combinations of cover crops paired with specific herbicide regimens and the resulting weed seed bank is another point of study (Mobli and Hassannejad 2013). Many of these studies are finding that cover crops and their benefits tend to be highly variable in their effect from location to location, and even year to year. There is no correct or universal cover crop that fits into every system in every location.

Conclusion

Cover crops can be a versatile tool to alter a no-till soybean cropping system to make it less susceptible to horseweed pressure and to reduce existing weed populations by fitting into an otherwise fallow period during a cropping system. A producer may plant cover crops with the intention of reducing erosion or aerating the soil but has added the benefit of suppressing herbicide-resistant weeds. Reducing the overall density of horseweed plants with cover crops potentially can reduce weed competition with a subsequent cash crop, protecting and maintaining yields.

Cover crops increase options for herbicide rotations, which can reduce crop-mimic weeds and weed selection pressure. The decision of producers to till or not to till remains an important factor in the types of weeds they must attempt to control. Tillage practices play a role in horseweed control, and no-till systems affect the weeds present in a cropping system, increasing the number of small seeded weeds such as horseweed. Tillage also aids in mixing cover crop residue into the soil profile. This helps to incorporate allelopathic chemicals into the zone of weed seed germination and can reduce the need for additional herbicide applications, also aiding in decreasing selection pressure toward herbicide-resistant weeds. Physical barriers and competition also play a major role in reducing the growth and density of weed species, a fact that is particularly integral in cropping systems at risk of herbicide-resistant weed infestations.

It is apparent that there is a need to determine the effects of cover crop and herbicide systems on soybean production, the level of horseweed suppression obtained by cover crop systems, herbicide systems, and a combination of cover crop with herbicide system, and to determine if horseweed growth and seed production were affected by cover crops.

References

Anonymous (2015) Table 11: Soybean Area, Yield and Production. www.fas.usda.gov. Accessed: March 24, 2015

Anonymous (2014) Agricultural Resource Management Survey: U.S. Soybean Industry. www.nass.usda.gov. Accessed April 6, 2015

Anonymous (2013) 2012 ARMS-Soybean Industry Highlights. www.nass.usda.gov. Accessed: April 5, 2015

Anonymous (2012) Summary by Farm Typology Measured by Gross Cash Farm Income, Primary Occupation of Small Family Farm Operators, and Non-Family Farms- United States: 2012. www.agcensus.usda.gov. Accessed: April 6, 2015

Ashford DL, Reeves DW, Patterson MG, Wehtje GR, Miller-Goodman MS (2000) Roller vs. herbicides: an alternative kill method for cover crops. Annual Southern Conservation Tillage Conference: Sustainable Agriculture-Agricultural Water Quality and Quantity 21:64-69

Ball DA (1992) Weed seedbank response to tillage, herbicides, and crop rotation sequence. Weed Sci 40:654-659

Bhowmik PC, Bekech MM (1993) Horseweed (*Conyza canadensis*) seed production, emergence, and distribution in no-tillage and conventional-tillage corn (*Zea mays*). Agron J 1:67-71

Bialy Z, Olezek W, Lewis J, Fenwick GR (1990) Allelopathic potential of glucosinolates (mustard oil glycosides) and their degradation products against wheat. Plant Soil 129:277-281

Boz O (2003) Allelopathic effects of wheat and rye straw on some weeds and crops. Asian J Plant Sci 2:772-778

Carr PM, Horsley RD, Gunderson JJ, Winch TJ, Martin GB (2013) Weed growth and crop performance following hairy vetch, rye, and wheat cover crops in a cool semiarid region. Organic Agriculture 3:149-161

Chon SU, Kim JD (2002) Biological activity and quantification of suspected allelochemicals from alfalfa plant parts. J Agron Crop Sci 188: 281-285

Chung IM, Ahn JK, Yun SJ (2001) Identification of allelopathic compounds from rice (*Oryza sativa L*.) straw and their biological activity. Can J Plant Sci 81: 815-819

Clark A, ed. (2008) Managing cover crops profitably. DIANE Publishing

Creamer NG, Bennett MA, Stinner BR (1992) Cover crop mixtures for vegetable production. Hort Science 27:664-664

Creamer NG, Bennett MA, Stinner BR, Cardina J, Regnier EE (1996) Mechanisms of weed suppression in cover crop-based production systems. HortScience 31:410-413.

Davis AS (2010) Cover-crop roller-crimper contributes to weed management in no-till soybean. Weed Sci 58:300-309

Davis VM, Gibson KD, Bauman TT, Weller SC, Johnson WG (2007) Influence of weed management practices and crop rotation on glyphosate-resistant horseweed population dynamics and crop yield. Weed Sci 55:508-516

Davis VM, Johnson WG (2008) Glyphosate-resistant horseweed (*Conyza canadensis*) emergence, survival, and fecundity in no-till soybean. Weed Sci 56:231-236

Den Hollander NG, Bastiaans L, Kropff MJ (2007) Clover as a cover crop for weed suppression in an intercropping design: II. Competitive ability of several clover species. Eur J Agron 26:104-112

Dhima KV, Vasilakoglou IB, Eleftherohorinos IG, Lithourgidis AS (2006) Allelopathic potential of winter cereals and their cover crop mulch effect on grass weed suppression and corn development. Crop Sci 46:345-352

Fickett ND, Boerboom CM, Stoltenberg DE (2013) Soybean yield loss potential associated with early-season weed competition across 64 site-years. Weed Sci 61:500-507

Halford C, Hamill AS, Zhang J, Doucet C (2001) Critical period of weed control in no-till soybean (*Glycine max*) and corn (*Zea mays*). Weed Technol 15:737-744

Heap I (2015) The International Survey of Herbicide Resistant Weeds. www.weedscience.org. Accessed: March 16, 2015

Jabran K, Farooq M (2013) Implications of potential allelopathic crops in agricultural systems. Pages 349-385 *in* Cheema ZA, Farooq M, Wahid A, eds. Allelopathy: Current Trends and Future Applications. Berlin: Springer

Khanh TD, Linh LH, Linh TH, Quan NT, Cuong DM, Hien VTT, Ham LH, Xuan TD (2013) Integration of allelopathy to control weeds in rice. Ann Appl Biol 151:325-339

Knezevic SZ, Evans SP, Blankenship EE, Van Acker RC, Lindquist JL (2002) Critical period for weed control: the concept and data analysis. Weed Sci 50:773-786

Liebman M, Dyck E (1993) Crop rotation and intercropping strategies for weed management. Ecol Appl 92-122

Milberg P, Andersson L, Thompson K (2000) Large-seeded species are less dependent on light for germination than small-seeded ones. Seed Sci Res 10:99-104

Mischle RA, Curran WS, Duiker SW, Hyde JA (2010) Use of a rolled-rye cover crop for weed suppression in no-till soybeans. Weed Technol 24:253-261

Mobli AR, Hassannejad A. (2013) The effects of some cover crops on weed species seed bank. Tech J Eng Appl Sci 3:3085-3089

Moore MJ, Gillespie TJ, Swanton CJ (1994) Effect of cover crop mulches on weed emergence, weed biomass, and soybean (*Glycine max*) development. Weed Technol 8:512-518

Nandula VK, Eubank TW, Poston DH, Koger CH, Reddy KN (2006) Factors affecting germination of horseweed (*Conyza canadensis*) Weed Sci 898-902

Njeru EM, Avio L, Sbrana C, Turrini A, Bocci G, Barberi P, Giovannetti, M (2014) First evidence for a major cover crop effect on arbuscular mycorrhizal fungi and organic maize growth. Agron Sustain Dev 34:841-848

Nord EA, Curran WS, Mortenson DA, Mirsku SB, Jones BP (2011) Integrating multiple tactics for managing weeds in high residue no-till soybean. Agron J 103:1542-1551

Olofsdotter M (2001) Rice- a step toward use of allelopathy. Agron J 93:3-8

Perry LG, Galatowitsch SM (2006) Light competition for invasive species control: A model of cover crop–weed competition and implications for *Phalaris arundinacea* control in sedge meadow wetlands. Euphytica 148:121-134

Purvis CE, Jessop RS, Lovett JV (1985) Selective regulation of germination and growth of annual weeds by crop residues. Weed Res 25:415-421

Regeher DL, Bazzaz FA (1979) The population dynamics of *Erigeron canadensis*, a successional winter annual. J of Ecol 67:923-933

Rice EL (1984) Allelopathy. 2nd edn. Access Online via Elsevier. Pp 1-21

Schulz M, Marocco A, Tabaglio V, Macias FA, Molinillo JMG (2013) Benzoxazinoids in rye allelopathy-from discovery to application in sustainable weed control and organic farming. J Chem Ecol 39:154-174

Severino FJ, Christoffoleti PJ (2004) Weed suppression by smother crops and selective herbicides. Scientia Agricola 61:21-26

Sheilds EJ, Dauer JT, VanGessel MJ, Neumann G (2006) Horseweed (*Conyza canadensis*) seed collected in planetary boundary layer. Weed Sci 54:1063-1067

Teasdale JR, Beste CE, Potts WE (1991) Response of weeds to tillage and cover crop residue. Weed Sci 39:195-199

Turk MA, Tawaha AM (2003) Allelopathic effect of black mustard (*Brassica nigra* L.) on germination and growth of wild oat (*Avena fatua* L.). Crop Prot 22:673-677

Weaver SE (2001) The biology of Canadian weeds. 115. *Conyza canadensis*. Can J Plant Sci, 81:867-875

Weston LA (2005) History and current trends in the use of allelopathy for weed management. HortTechnology 15:529-534

Wortman SE, Francis CA, Bernards ML, Drijber RA, Lindquist JL (2012) Optimizing cover crop benefits with diverse mixtures and an alternative termination method. Agron J 104:1425-1435

Chapter 2 - Cover Crops to Suppress Horseweed Before and During a Soybean Crop

Abstract

Increasing numbers of herbicide-resistant weed species require alternative methods of weed suppression to be examined. This study quantified the interaction between various cover crop or herbicide systems and horseweed [*Conyza canadensis* (L.)] growth. Fall cover crops of winter wheat [*Triticum aestivum* (L.)], winter rye [*Secale cereal* (L.)], barley [*Hordeum vulgare* (L.)] and annual ryegrass [*Lolium multiflorum* (L.)] were seeded in November 2012 and 2013. Spring cover crop of oat [*Avena sativa* (L.)] was seeded in April 2013 or rye was seeded in March 2014. All cover crops were no-till seeded into grain sorghum stubble [*Sorghum bicolor* (L.) Moench]. Four herbicide treatments were fall or spring applied, with and without residual. The spring non-residual treatment was also applied to plots of winter rye. Cover crop plots were split and terminated with a roller crimper or glyphosate application prior to soybean [*Glycine max* (L.) Merr.] planting to determine the effect of termination method on treatment performance. Soybean was planted in June 2013 and May 2014 and mechanically harvested in October of both years. Horseweed density, biomass accumulation, and soybean yield data were quantified. Horseweed height, whole plant seed production, and seed subsamples were recorded in the untreated fallow control, winter wheat, and winter rye plots in 2014. Horseweed suppression by winter rye approached 90%, levels similar to suppression by herbicide systems. In both years, herbicide plots had less than half the horseweed biomass than any of the cover crop systems. In 2013, soybean yields in herbicide plots were at least 1,500 kg ha^{-1}, nearly more than double yields in cover crop plots. Soybean yields in 2014 were more consistent across treatments; barley and spring rye plots achieved yields equal to or greater than 2,000 kg ha^{-1}.

Winter rye and winter wheat reduced horseweed seed production by 60% compared to the untreated fallow control, with no effect on individual seed weight. Seed production varied across plants, with the untreated control producing the greatest number of seeds. Cover crops were successful at reducing horseweed biomass, suppressing horseweed pressure, preserving soybean biomass, and protecting soybean yields when compared to a fallow untreated control.

Introduction

The United States leads the world in soybean production, producing 32% of the world's crop or 91.39 million metric tons in 2014 (USDA 2015). KS produced a total of 2.28 million metric tons of soybeans on 1.5 million ha in 2012. Soybeans were thus the third most economically productive cash crop grown in KS (USDA 2013). However, soybean production is being severely impacted by herbicide-resistant weeds. Within KS there are 15 weed species resistant to one or more of six different sites of action (Heap 2015). Horseweed is one of Kansas' resistant weeds; the weed exhibits resistance to glyphosate and ALS inhibitors. Populations of horseweed in KS were confirmed to be resistant to glyphosate (EPSP synthase inhibitor) in 2005, and resistance to ALS inhibitors was confirmed in 2011 (Heap 2015). Horseweed has been shown to grow into highly competitive plants and to produce a large number of seed that disperse long distances (Bhowmik and Bekech 1993, Shrestha et al. 2010). The weed is particularly troublesome in soybeans due to its long period of germination, presence in the field before soybean planting, and its fast growing nature combined with lack of control with glyphosate; this early season competition can reduce soybean yields (Shrestha et al. 2010).

Research has indicated that the ideal herbicide application timing to reduce horseweed plant and seedbank densities is a spring pre-plant application containing a residual herbicide (Davis et al. 2009). These applications also decreased the ratio of glyphosate-resistant to glyphosate-susceptible horseweed seeds found in the seed bank after four years, which eventually lead to a decrease in the number of glyphosate-resistant plants in the field. Glyphosate-only herbicide control programs (both pre-plant and post-emergence) had 17 times the amount of glyphosate-resistant horseweed seed when compared to the program with spring residual pre-plant herbicide application (Davis et al. 2009).

Cover crops are of interest for many producers looking to reduce herbicide use while reducing weed densities. Cover crops have been shown to effectively control weed pressure for up to 60 days after cover crop termination (Weston 1990). High biomass producing forage grasses, such as Italian ryegrass [*Lolium multiflorum* Lam.] and perennial ryegrass [*Lolium perenne* (L.)] showed greater suppression than lower biomass producing cereal grains, such as oats (Weston 1990). The termination method of cover crops can also include an herbicide application. Terminating fall-planted cover crops in the spring with a residual herbicide could prove to be an excellent combination for horseweed suppression.

The number of ha of cover crops grown in the United States has increased five-fold from 2008 to 2013 (CTIC 2013). Producers have taken an interest in these alternative crops and cropping systems as a method to suppress weeds in a following cash crop; 28% of producers that planted cover crops in 2013 cited weed control as their primary reasoning for doing so (SARE 2014). Cover crops were planted preceding summer row crops of soybean and corn [*Zea mays* (L.)] on 39% of the ha surveyed. Cover crops suppress weeds by competing with weeds for sunlight, nutrients, space, and water (Teasdale et al. 2007). Fast-growing cover crops can shade the soil surface to create a cooler microclimate that delays the germination of certain weed species. Cereal grains can fill this niche and are also attractive to producers because they can be grazed by cattle or can be a potential flex crop to be harvested for additional income (Teasdale et al. 2007).

The objectives of this study were to 1) determine the level of horseweed suppression obtained by cover crop systems, herbicide systems, and a combination system of cover crop with herbicide, 2) evaluate the effects of cover crop and herbicide systems on soybean production, and 3) determine if horseweed growth and seed production were affected by cover crops.

Materials and Methods

Experiments were conducted over two growing seasons in 2012/2013 and 2013/2014 at the Kansas State University Department of Agronomy Research Farm in Manhattan, KS. Soil in the study area was a Wymore silty clay loam (Fine, smectitic, mesic Aquertic Argiudolls) in year one and a Smolan silt loam (fine, smectitic, mesic Pachic Argiustoll) in year two. Cover crops were planted after grain sorghum and preceding soybean. The location in year one had been no-till for 10 years prior to the planting of the study, and the second location had been no-till for four years. Prior to initiating this study, grain sorghum had been no-till planted in 0.76-m rows at 64,640 seeds/ha using residue managers and double-disc openers to maintain correct planting depth. Grain sorghum was harvested on 15 October 2012, yielding 1,788 kg/ha and on 28 October 2013, yielding 5,900 kg/ha. The crop was mechanically harvested both years, using a combine with a chopper-spreader to ensure that residue was spread evenly across the field. Standing residue was approximately 30 cm tall.

The study was arranged in a randomized complete block design with four replications with a strip plot, split block treatment structure. Eleven cover crop/herbicide treatments were established in each replication: five cover crops, four herbicides, one combination cover crop/herbicide, and one untreated fallow control. Each treatment plot was 1.5 m by 18 m long and the cover crop termination method was stripped across the cover crop/herbicide treatments to create 22 combinations of cover/crop herbicide and termination method in experimental units that were 1.5 m wide by 9 m long.

Fall-planted cover crops were established on 5 November 2012 and 28 October 2013. Winter rye, barley, annual ryegrass, and winter wheat were planted in 19-cm rows using a no-till drill (Model 3P605NT, Great Plains Manufacturing, Inc., Salina, KS) with double-disc openers at a depth of 2.5 cm. Barley, winter rye, and winter wheat were seeded at 101 kg/ha, and annual ryegrass was seeded at 9 kg/ha. A tank mix of dicamba (285 g /ha) plus flumioxazin (85 g /ha) and chlorimuron (29 g /ha) with 1% v/v crop oil concentrate was applied as a fall residual treatment, and dicamba (71 g/ha) plus 2,4-D (1135 g ae ha) was applied as a fall non-residual treatment using a backpack sprayer at a volume of 140 l/ha at 275.8 kPa using TT110015 Turbo TeeJet wide angle flat fan nozzles (TeeJet Technologies, Wheaton, IL) on 16 November 2012 and 14 November 2013.

Spring oats were planted 5 April 2013 at 67 kg/ha, and spring rye was planted 20 March 2014 at 101 kg/ha. Spring herbicide treatments were the same as the fall treatments and were applied 4 April 2013 and 22 April 2014. One set of the previously established winter rye plots was sprayed with the non-residual herbicide to impose the cover crop/herbicide combination treatment. Fallow was used as an untreated control.

Cover crops were terminated 28 May 2013 and 20 May 2014, with timing selected so that the cover crops were at the early flowering stage of reproduction. Cover crop and horseweed biomass were collected from one random 0.5-m^2 quadrat in each plot the day before termination. Biomass was oven dried at 70 degrees C for 72 hours; biomass weights presented hereafter will be dry biomass. Cover crop heights, weed heights, and horseweed suppression notes were taken; suppression notes were on a scale of 0 to 100, with 0 being no suppression and 100 being complete suppression of horseweed. One half (9 m) of each plot was sprayed with glyphosate (1277 g/ha) and 2% w/v AMS using a tractor-mounted sprayer at a volume of 140 L/ha at 275.8 kPa, and the other half of each plot was rolled with a crimper perpendicular to the direction of cover crop planting.

Soybeans were seeded at a rate of 350,000 seeds ha^{-2} and planted in the direction of cover crop termination (perpendicular to cover crop plots) in 0.76-m rows. Glyphosate-resistant varieties were Phillips 385NRS planted on 3 June 2013 and Asgrow 3803 planted on 23 May 2014, with both varieties being treated with insecticide and fungicide. Soybean plant density was determined at VC-V2 (emergence – early vegetative stages). Due to very heavy horseweed and Palmer amaranth [*Amaranthus palmeri* S. Wats.] pressure and volunteer sorghum, all plots were sprayed with glyphosate (1277 g/ha) and cloransulam (18 g/ha) with 2% w/v AMS at a volume of 140 L/ha at 275.8 kPa on 26 June 2013 and 9 July 2014 using a tractor-mounted sprayer. Plots in 2013 were hand weeded periodically to control later emerging Palmer amaranth; plots in 2014 did not contain adequate Palmer amaranth pressure to require hand weeding.

At the start of soybean senescence, horseweed suppression notes were taken, and horseweed and soybean biomass samples were collected from 0.5-m^2 quadrats in each plot. Soybeans were mechanically harvested to determine seed yield on 24 October 2013 and 20 October 2014 using a plot combine with a 1.5-m platform head. Soybean seed moisture, oil, protein, and visual scores were collected from 0.5 L subsamples from each plot.

In 2014, horseweed height over time and seed production were quantified for a subset of the treatments. Up to three horseweed plants were identified in winter rye, winter wheat, and untreated control plots that were terminated with glyphosate. Starting 5 May 2014, these individually-marked plants were measured for height every 10 days. Plastic bags were secured over the plants when plots were sprayed on 9 July 2014 to prevent damage from the applied herbicides. Plants were harvested following seed set on 20 August 2014. Total plant dry weight, total seed weight, and triplicate 200-seed weights were obtained for each horseweed plant. Total horseweed seed production per plant was calculated by dividing the 200-seed weight by 200 to obtain an average weight per seed, and the total seed weight was divided by this number.

Analysis of variance (ANOVA) was used to determine differences between main effects and interactions using the GLIMMIX procedure in SAS 9.2 (SAS Institute, 2004). Replication was treated as a random effect. This experiment contained three varying sizes of experimental units which in turn resulted in three experimental errors. Before termination, cover crops/herbicide treatments were whole plots; after termination, termination method became the whole plot and the subplot was the interaction between the cover crop/herbicide treatment and termination method. Analysis for horseweed biomass and suppression ratings and cover crop biomass before termination used the different cover crop/herbicide treatments and replicates as sources of variation. Analysis of post-termination horseweed biomass and suppression, soybean biomass, soybean stand counts, and soybean yields used the cover crop/herbicide treatments, replicates, and termination method as sources of variation. In 2014, final horseweed biomass, horseweed heights, and seed production data also used the cover crop/herbicide treatments, replicates, and termination method as sources of variation. If there was an interaction detected, treatment means were separated where appropriate using pairwise t tests at $\alpha = 0.1$.

Results and Discussion

Average yearly precipitation for Manhattan, KS is 905 mm, however, Manhattan received only 478 mm in 2012, 617 mm in 2013 and 668 mm in 2014 (Figure 2.1 and Figure 2.2). Temperatures were generally more temperate compared to normal during the first year of the study and slightly cooler during the second year of the study (Table 2.1). Rainfall amounts and timing appeared to have impacted the growth of both cover crops and horseweed in both years. During the cover cropping period (from fall planting to termination), plots received 238 mm precipitation in 2012/2013 and 214 mm in 2013/2014, compared to a normal precipitation of 317 mm. The first year of this study, cover crops were planted late but received a majority of precipitation in the spring, leading to more vigorous growth in the spring of 2013 (Figure 2.1). Rainfall was less during the cover cropping period of the second year (Figure 2.2), likely causing the reduced amounts of cover crop biomass. Rainfall for the 2013 soybean crop from late May to mid-October was 328 mm and during the 2014 soybean season was 447 mm (Figure 2.1) compared to a 20-year normal amount of 519 mm. Rainfall likely impacted soybean yield, as yields in 2014 were greater than yields in 2013 (Figure 2.2).

All data are presented by year due to a treatment by year interaction ($\alpha = 0.1$). Horseweed biomass was greatest in the untreated control plots in both 2013 and 2014, with 53.8 m^{-2} and 6.5 g m^{-2}, respectively (Table 2.2). No horseweed were present in plots treated with fall-residual herbicide in 2013 or in 2014. The fall no-residual and both versions of the spring residual (with and without winter rye) herbicide treatments reached a similarly reduced amount of biomass, <1 g m^{-2}. Spring oats and annual ryegrass reduced horseweed biomass to approximately 30 g m^{-2} in 2013 and all other treatments had reduced biomass in 2013. In 2014, the untreated control treatment and fall non-residual treatment had more horseweed biomass compared to all other treatments (Table 2.2).

Cover crop biomass varied greatly between 2013 and 2014 (Table 2.3). In 2013, winter rye, winter rye/spring non-residual combination, winter barley, and winter wheat all produced the greatest amounts of dry biomass, and annual ryegrass and spring oats produced significantly less biomass (Table 2.3). Overall in 2014, cover crops were less productive than in 2013, with winter rye producing 229.6 g m^{-2} in 2013 and 36.5 g m^{-2}. However, cover crops producing the greatest amount of biomass in 2014 were winter rye, winter wheat and the winter rye/spring non-residual combination.

Greater amounts of cover crop biomass resulted in less horseweed biomass in 2013, while cover crop and horseweed biomass were both greatly reduced in 2014 (Figure 2.3). Plots were found to be weed free in cover crop biomass situations ranging from 98 to 234 g m^{-2}. This is in agreement with the findings of Petrosino et al. (2015), who found that increasing levels of cover crop biomass were able to decrease biomass of kochia [*Kochia scoparia* (L.)] but in contrast to Wortman et al. (2013), who did not find a correlation between cover crop biomass and weed biomass.

The differences in both weed and crop biomass from year to year can be attributed to timely rainfall events. The first year of this study, cover crops were planted late in the fall due to extremely dry conditions but received a majority of precipitation in the spring. Cover crops were planted earlier in year two of the study due to more adequate moisture conditions. Planting date typically depends on the species being planted. Depending on a producer's needs, cereals like wheat, rye, barley and oats could be either fall or spring planted. For instance, cover crop distributors recommend that cover crops that winter kill should be planted 4-8 weeks before frost (with first frost in KS generally occurring between 10 October and 10 November), but winter hardy varieties, such as medium red clover [*Trifolium pratense* (L.)] can be planted after the first frost or frost seeded (Anonymous 2015).

Horseweed suppression evaluated before cover crop termination was excellent in 2013 with the all herbicide treatments, the winter rye/spring non-residual combination, and the winter rye treatment all providing high levels (>94%) of weed suppression (Table 2.4). The winter barley, annual ryegrass, winter wheat, and spring oats plots provided the least suppression (< 35%). Horseweed suppression was excellent (85 to 100%) in 2014 in the winter rye/spring non-residual, spring non-residual, fall residual, winter rye, winter wheat, winter barley, spring rye, and spring residual treatments. Annual ryegrass and fall non-residual herbicide treatments showed intermediate suppression (59 to 75%). It is important to note that the 2013/2014 site had fewer horseweed present compared to the previous year's site, leading to overall increased suppression horseweed and biomass production for the second year of the study (Table 2.2). Biomass production by cover crops (Table 2.3) may have also contributed to the reduction of horseweed. Cover crops, such as winter rye, produced greater amounts of biomass relative to other cover crops, leading to reduced weed competition.

Soybean stand counts were taken in both years to quantify plant density and to determine whether cover crop residue had a negative impact on the establishment of the crop. Soybean stand densities in 2013 were generally greater overall than counts in 2014 (Table 2.5). Overall, soybean stand densities in 2013 were greatest in the fall residual treatments, and in 2014 stand densities were greatest in the winter rye cover crop plots. Soybean stands in plots planted after spring-planted cover crops and annual ryegrass were reduced in 2013, likely by incomplete cover crop termination in those plots. In 2014, soybean plant density was reduced in the untreated control and annual ryegrass plots when compared to the winter rye plots. There was not an impact between any other cover crop on soybean stand counts in either termination method (Table 2.5).

Horseweed suppression ratings were taken again at soybean R1 to quantify the weed response to previous cover crop treatments and termination method. Suppression ratings tended to be greater in plots that received the spray termination (Table 2.6). In 2013, the greatest levels of suppression for both termination methods were in the rye/spring non-residual, fall residual, and spring residual treatments with greater than 89% suppression. The spray terminated fall non-residual and spring non-residual treatments suppressed horseweed by more than 88%, but suppression was less than 30% in the same plots with rolled termination. Of the spray terminated treatments, the control, annual ryegrass and spring oats provided the some suppression, < 25%. The roller terminated untreated control and spring oats provided little horseweed suppression < 5%. In 2014, suppression for all spray terminated treatments was greater than 94%. In the rolled treatments, the untreated control had less than 25% suppression. The spring residual and fall residual treatments provided intermediate suppression (74 to 78%), but all other treatments obtained levels of suppression greater than 85%. Differences in levels of suppression were likely due to variability in the amount of cover crop biomass accumulated and the number of herbicide applications applied to plots.

Horseweed suppression was documented before soybean harvest in 2013 only (Table 2.6). All spray treatments obtained levels of suppression greater than 55%, but rolled termination resulted in much more variable levels of suppression. In general, levels of suppression for individual treatments were considerably reduced in rolled termination when compared to sprayed termination. In spray terminated plots of barley, rye, rye/spring non-residual, and all herbicide treatments suppression levels were greater than 78%. In roller terminated plots the rye, rye/spring non-residual, fall residual, and spring residual treatments suppressed the greatest amount of horseweed. All other treatments showed reduced levels of suppression.

In 2013, above-ground biomass of horseweed at soybean R6.5 in the untreated control that was rolled was more than two times greater (145.5 g m^{-2}) than any other treatment that year (Table 2.7), likely because the roller did not effectively terminate weeds that were present at the time of termination and there had previously been no cover crops to compete with the weeds. Spray-terminated plots in 2013 generally had less horseweed biomass than the roller-terminated plots. For example, 2014 winter wheat plots contained 40.3 g m^{-2} biomass, compared to 8.1 g m^{-2}

in 2013. Annual ryegrass and spring oats also suppressed horseweed poorly in rolled plots, with levels of biomass reaching 47.6 to 62.2 g m^{-2}. The untreated control and annual ryegrass plots contained the greatest amount of horseweed biomass, with both 31.3 to 38.9 g m^{-2}. Spray terminated rye, the rye/non-residual herbicide combination, and all other herbicide treatments all contained less than 2 g m^{-2} biomass at soybean R6.5. In 2014, there was no effect of termination method on amount of horseweed biomass accumulation and no interaction with cover crop/herbicide treatment. The untreated control plots contained the greatest amount of horseweed biomass (70.0 g m^{-2}) compared to other treatments, and three times greater than the amount found in any other treatment that year. All other treatments contained reduced levels of horseweed biomass, <18 g m^{-2}, by soybean R6.5.

Soybean biomass at R6.5 was highly variable among all treatments in both years and from year to year but was not affected by termination method or the interaction of termination with cover crop/herbicide treatments (Table 2.8). In 2013, the greatest soybean biomass (484.3 g m^{-2}) was achieved in the spring residual plots. The least biomass was in the untreated control, annual ryegrass, and winter wheat plots with less than 221 g m^{-2} produced. This was likely due to competition by cover crops attributed to incomplete termination. In 2014, the greatest biomass amounts (>312 g m^{-2}) were obtained in the spring rye/spring non-residual and all herbicide treatments. The untreated control had soybean biomass of less than 265 g m^{-2}, likely due to horseweed competition.

Soybean yields for 2013 and 2014 were highly variable both within and between years (Table 2.9). Soybeans yielded more in spray-terminated plots than in roller-terminated plots in 2013, likely due to complete cover crop kill and reduced weed pressure. Spray terminated spring residual, spring non-residual, fall residual, and fall non-residual treatments had the greatest yields in 2013, again due to lack of competition from cover crops and uncontrolled horseweed. The roller terminated untreated control and spring oats treatments had severely reduced yields due to lack of herbicide application or incomplete kill of the spring oats. In 2014 termination method did not affect soybean yield, but winter wheat, barley, spring oats, rye/spring non-residual, and fall residual treatments had the greatest yields (>1407 kg ha^{-1}). Yields were poorest in the untreated control. Overall, there was no effect of cover crop biomass on soybean yield (Figure 2.4). Moisture consumption by cover crops may have reduced soybean yields relative to herbicide-treated plots, as plots without growing crops likely had greater soil water content at the time of soybean planting. Harvested soybean seed protein, oil, and visual seed quality were not affected by any of the cover crop/herbicide treatments or termination methods ($\alpha = 0.1$, data not shown).

Three different cover crop treatments were selected to document horseweed height, biomass accumulation, and seed production in 2014. Winter rye was selected because of its high biomass potential, winter wheat was selected because it is commonly grown in Kansas, and the untreated control plot was selected as a baseline. Horseweed plants in the untreated control plots were three to 20 cm taller (depending on sampling date) than those in the winter wheat and winter rye plots for the first five of the nine measurement dates (Figure 2.5). After the 2 July 2014 measurement, the growth of the untreated control plants appears to have slowed, but horseweed in winter wheat and winter rye plots did not slow as much, allowing for horseweed plants in these plots to be as tall as the plants in the untreated control. Horseweed heights were not different among treatments at the final four measurement dates.

Total horseweed aboveground biomass was greatest for plants in the untreated control treatments (220 g per plant) compared to winter wheat or winter rye treatments (≤141 g per plant) (Table 2.10). There were no differences in the 200-seed weights for the three treatments, with means ranging from 4.75 to 5.41 mg. Total plant seed production was greatest in the untreated control treatment (>1,150,000 seeds per plant). Seed production in both winter wheat and winter rye plots was less than in the control treatment, with production less than 780,000 seeds per plant (Table 2.10). However, these seed production numbers are substantially greater than the 200,000 seeds per plant reported by Bhowmik and Bekech (1993) and greater than the 92,000 seeds per plant reported by Regeher and Bazzaz (1979). Differences could have occurred due to different cropping systems, weed density, weed biotype and lab procedures. Growing season length and levels of precipitation also could have impacted the number of seeds produced per plant, as Bhowmik and Bekech (1993) was conducted in South Deerfield, Massachusetts and Regeher and Bazzaz (1979) was conducted in Urbana, Indiana, both locations that receive greater rainfall and have shorter growing seasons compared Manhattan, KS.

Conclusions

In this study, the level of horseweed suppression tended to be greatest in herbicide treatments, the winter rye cover crop treatment, and the rye/spring non-residual combination treatment. Cover crop plots that were terminated via glyphosate spray applications obtained greater levels of horseweed suppression than roller terminated plots. Soybean growth and yield were greatest in herbicide systems in 2013, while soybean yields were maximized in barley and spring rye in 2014. Though not explicitly studied, producers should keep cover crop water consumption in mind when determine the utility of planting cover crops and the possible impact on subsequent. Soybean crops. Spring and early summer horseweed height was slowed by winter wheat and winter rye cover crops, but by mid-season there was no difference in the heights among the three treatments. Horseweed plant biomass and total seed production were greatest for plants in the untreated control plots, and plants harvested from the winter wheat and winter rye plots had reduced biomass and seed production. Overall, combining cover crops with an herbicide application (either during the cover cropping period or as a termination method) or planting high biomass producing cover crops, such as rye, should be a viable option to producers looking for alternative methods of weed suppression.

Tables and Figures

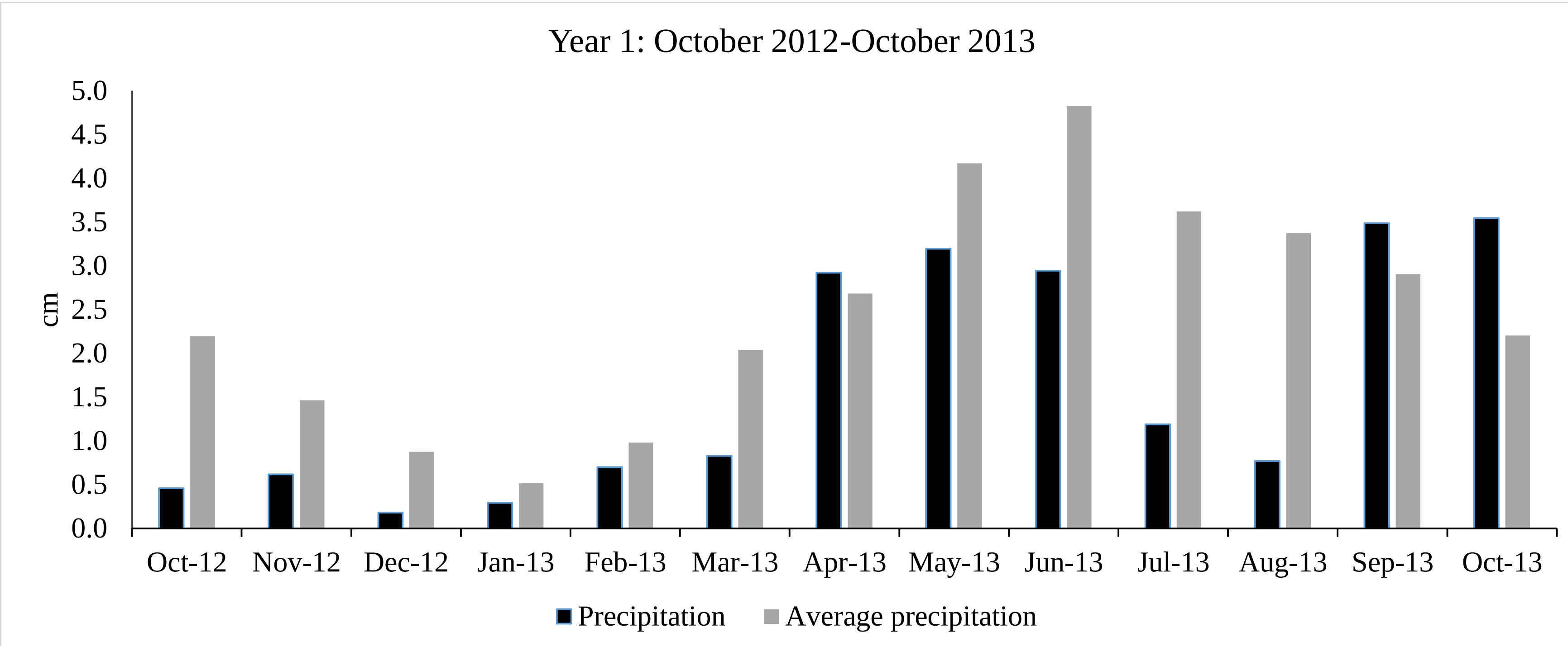

Figure 2.1 Total monthly precipitation for the cover crop/soybean crop year from October 2012 through October 2013.

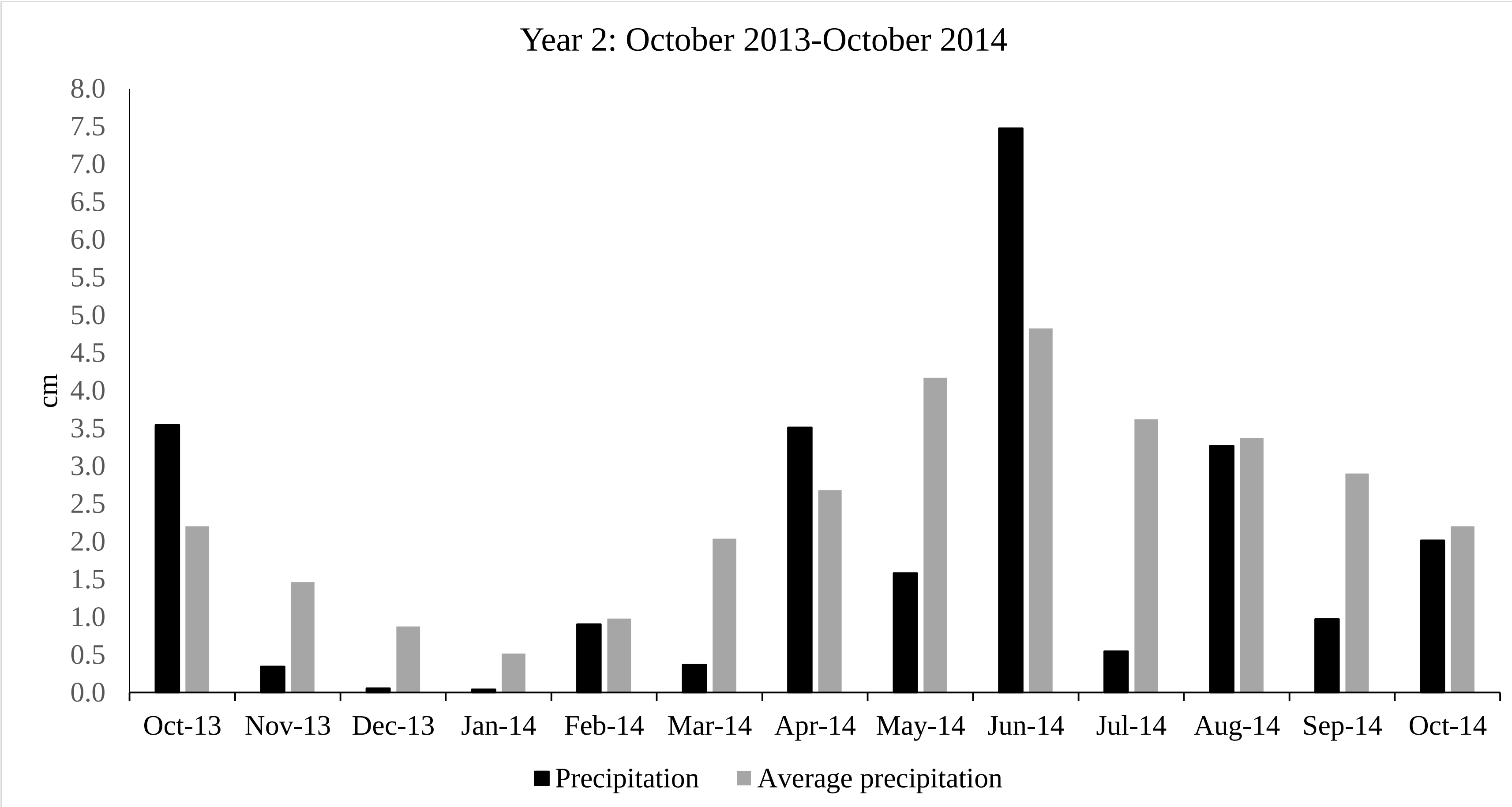

Figure 2.2 Total monthly precipitation for the cover crop/soybean crop year from October 2013 through October 2014

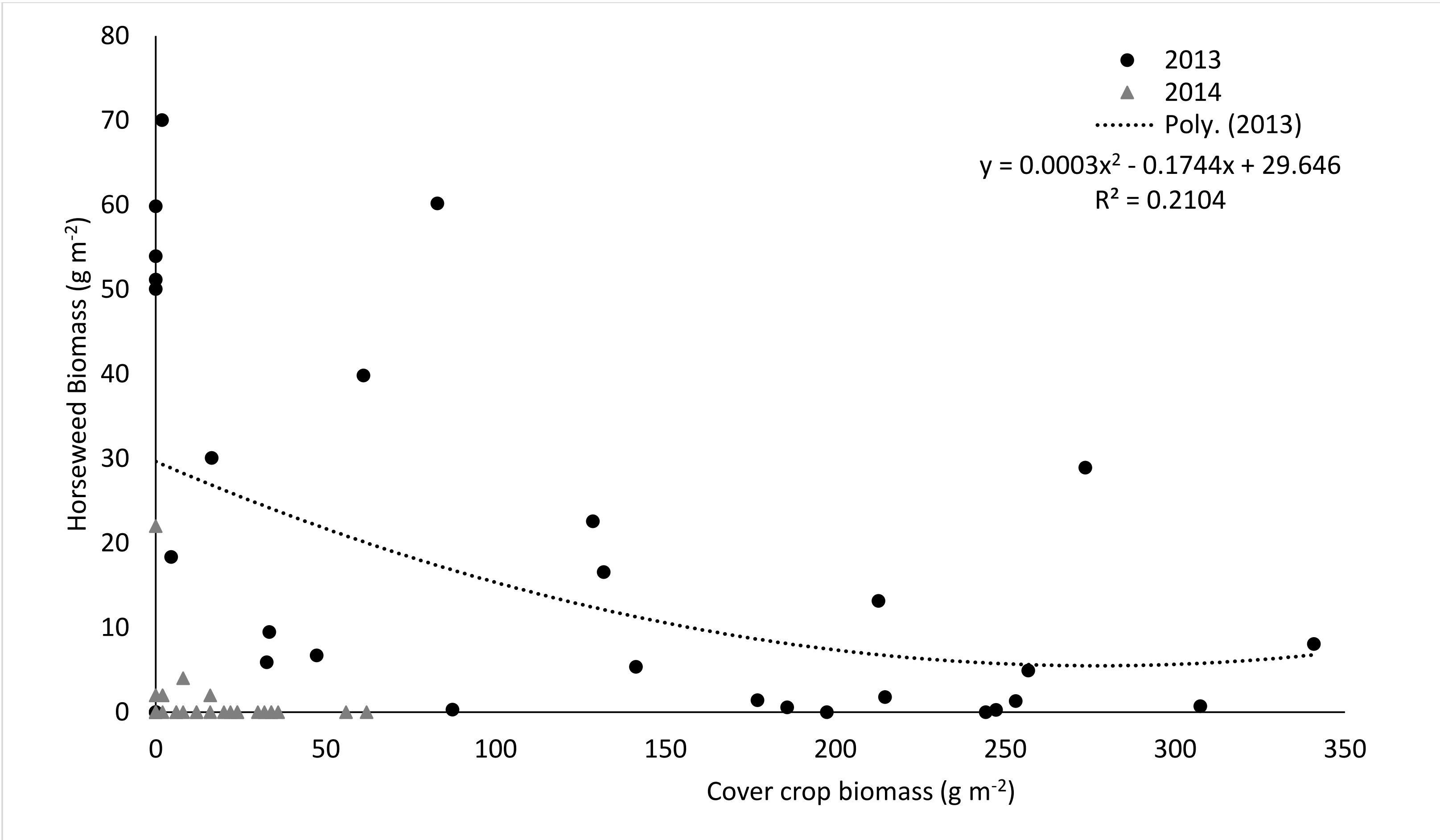

Figure 2.3 Cover crop biomass and its impact on horseweed biomass both measured prior to termination each year.

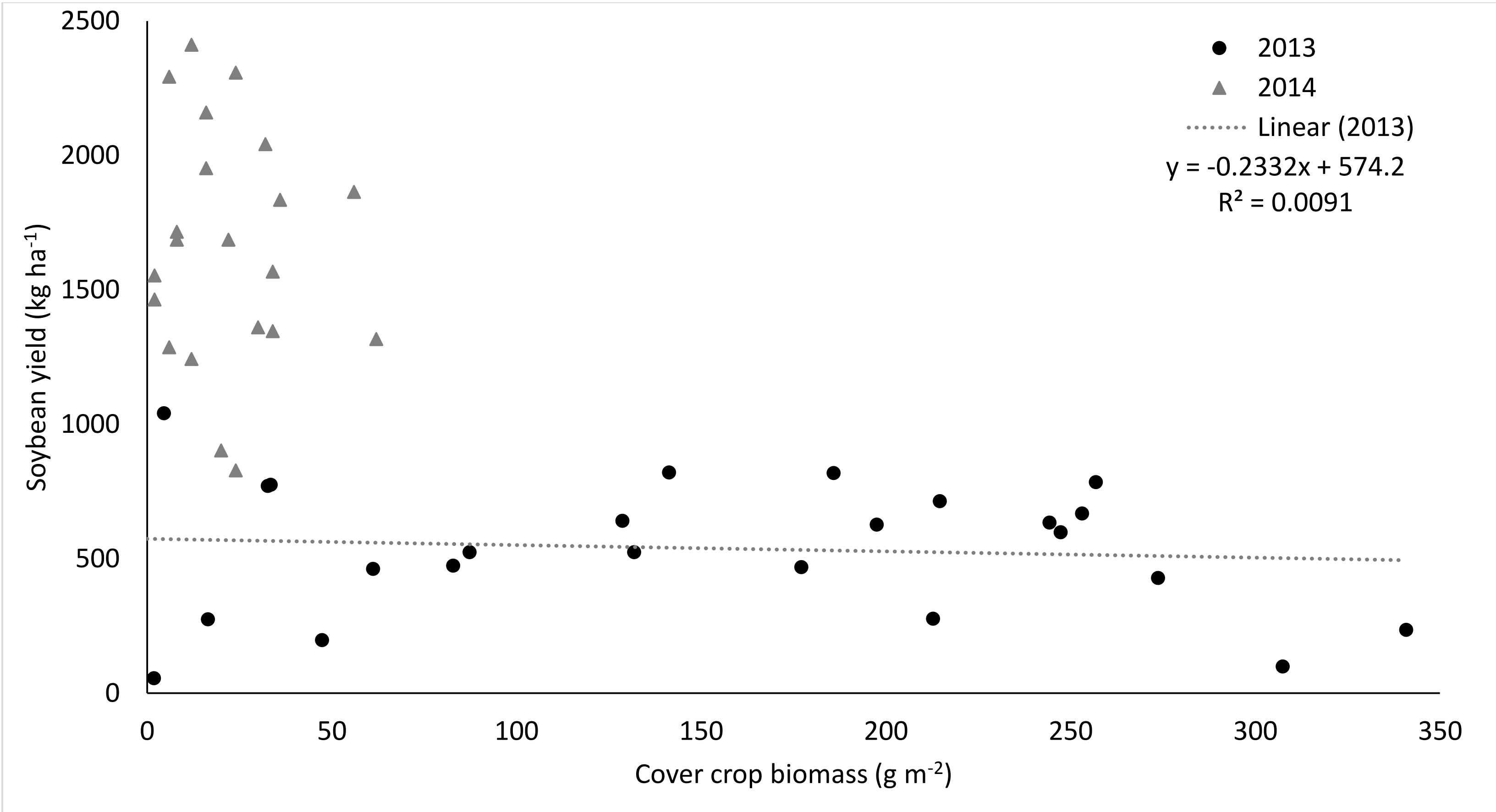

Figure 2.4 Cover crop biomass prior to termination and its impact on following soybean yield at end of growing season in both years. For each year, half of data points represent soybean yields from sprayed treatments and other half from rolled treatments.

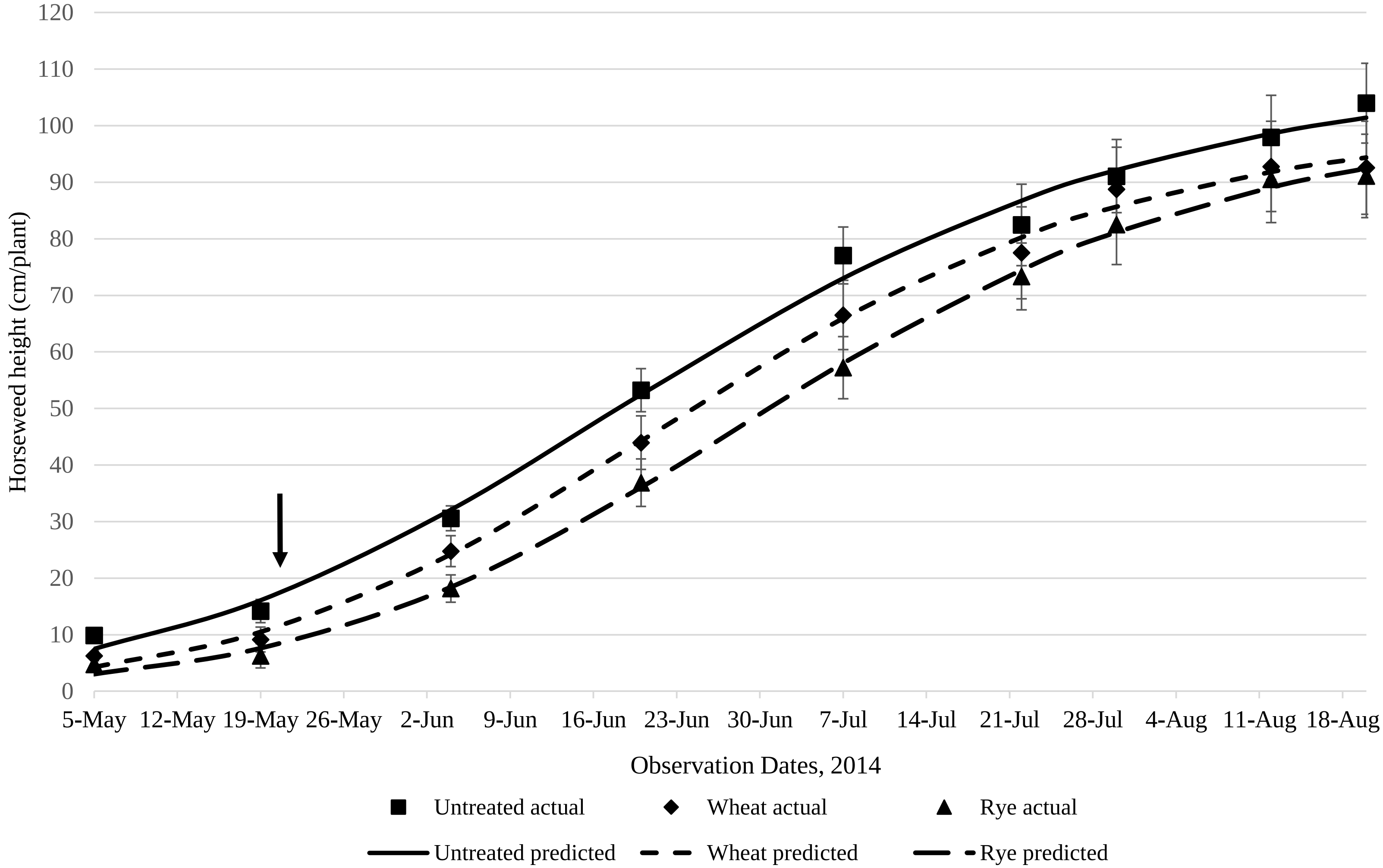

Figure 2.5 Horseweed height over time in spray terminated portions of untreated control, winter wheat, and winter rye plots from 5 May 2014 to 20 August 2014 at Manhattan, KS. Arrow indicates date of cover crop termination/beginning of horseweed bolting. Lines are fitted sigmoid curves ($y=1/(1+e^{-x})$).

Table 2.1 Monthly maximum and minimum air temperatures for each year of the study. Monthly 30-year average minimum and maximum air temperature are also presented.

	Maximum air temperature	30-year average maximum temperature	Minimum air temperature	30-year average minimum temperature
	C			
Year 1				
Oct-12	20.04	20.97	5.66	6.25
Nov-12	16.86	13.04	0.81	-0.63
Dec-12	7.63	5.86	-4.26	-6.63
Jan-13	7.30	4.82	-5.86	-8.08
Feb-13	7.10	8.13	-4.79	-5.91
Mar-13	10.53	13.87	-1.97	-0.91
Apr-13	16.35	19.65	3.71	5.41
May-13	23.84	24.86	11.69	11.99
Jun-13	30.01	30.13	17.80	17.26
Jul-13	31.13	33.15	19.16	20.23
Aug-13	30.63	32.37	19.53	18.80
Sep-13	29.72	27.67	15.63	13.26
Oct-13	20.17	20.97	6.66	6.25
Year 2				
Oct-13	20.17	20.97	6.66	6.25
Nov-13	12.13	13.04	-0.87	-0.63
Dec-13	4.77	5.86	-8.86	-6.63
Jan-14	3.97	4.82	-9.18	-8.08
Feb-14	2.71	8.13	-8.52	-5.91
Mar-14	12.98	13.87	-2.54	-0.91
Apr-14	19.74	19.65	5.77	5.41
May-14	26.07	24.86	12.19	11.99
Jun-14	29.30	30.13	18.22	17.26
Jul-14	31.58	33.15	17.97	20.23
Aug-14	33.04	32.37	20.25	18.80
Sep-14	26.85	27.67	13.76	13.26
Oct-14	21.82	20.97	7.88	6.25

Table 2.2 Horseweed above-ground dry biomass production in cover crop and herbicide treatments at Manhattan, KS in 2013 and 2014, collected prior to cover crop termination (early flowering for most cover crop species) and percent reduction of horseweed biomass relative to untreated control.

	Horseweed biomass				Reduction relative to untreated control	
Treatment	2013		2014		2013	2014
	——— $g\ m^{-2}$ ———				———%———	
Untreated control	53.8	a†	6.5	a	-	-
Annual ryegrass	29.1	b	1.0	b	45.9	99.8
Winter wheat	9.5	c	0.0	b	82.1	100
Winter barley	8.4	c	0.5	b	84.4	92.3
Winter rye	8.4	c	0.5	b	84.4	92.3
Spring oats	31.1	b	-		42.2	-
Spring rye	-		1.0	b	-	84.6
Winter rye/spring no residual	0.2	c	0.0	b	100	100
Fall residual	0.0	c	0.0	b	100	100
Fall no residual	0.4	c	4.5	ab	100	30.8
Spring residual	0.3	c	0.5	b	100	92.3
Spring no residual	4.7	c	0.0	b	99.1	100

† Values within a column followed by the same letter are not significantly different at α=0.1.
'-' treatment not included in study that year

Table 2.3 Cover crop above-ground dry biomass production at Manhattan, KS in 2013 and 2014, collected prior to cover crop termination (early flowering for a majority of cover crop species).

	Cover crop biomass			
Treatment	2013		2014	
	——— g m^{-2} ———			
Annual ryegrass	56.2	b†	3.0	c
Winter wheat	193.2	a	33.0	a
Winter barley	208.6	a	14.0	bc
Winter rye	229.6	a	36.5	a
Spring oats	13.9	b	-	
Spring rye	-		13.0	bc
Winter rye/spring no residual	218.7	a	25.5	ab

† Values within a column followed by the same letter are not significantly different at α=0.1.
'-' treatment not included in study that year

Table 2.4 Horseweed suppression (% of untreated control) by cover crops and herbicide treatments before cover crop termination (early flowering for a majority of cover crop species) in 2013 and 2014.

Treatment	Horseweed suppression 2013		2014	
	%			
Untreated control	0	d†	0	d
Annual ryegrass	21	cd	59	c
Winter wheat	20	cd	93	ab
Winter barley	35	c	90	ab
Winter rye	94	ab	96	a
Spring oats	14	cd	-	
Spring rye	-		89	ab
Winter rye/spring no residual	100	a	100	a
Fall residual	100	a	99	a
Fall no residual	94	ab	75	bc
Spring residual	98	a	85	ab
Spring no residual	97	ab	100	a

† Values within a column followed by the same letter are not significantly different at α=0.1.

'-' treatment not included in study that year

Table 2.5 Soybean plant density at the VC-V2 soybean growth stage in 2013 and 2014 at Manhattan, KS.

	Soybean plant density			
Treatment	2013		2014	
	——plants m^{-2}——			
Untreated control	32	bc†	29	b
Annual ryegrass	32	c	29	b
Winter wheat	30	cd	31	ab
Winter barley	31	c	31	ab
Winter rye	31	cd	32	a
Spring oats	29	d	-	
Spring rye	-		30	ab
Rye/spring no residual	31	cd	30	ab
Fall residual	35	a	29	ab
Fall no residual	32	bc	29	ab
Spring residual	34	ab	29	ab
Spring no residual	33	bc	30	ab

† Values within a column followed by the same letter are not significantly different at α=0.1.
'-' treatment not included in study that year

Table 2.6 Horseweed above-ground biomass production at soybean R6.5 in 2013 and 2014 at Manhattan, KS.

	Horseweed biomass		
	2013		2014
Treatment	Sprayed	Rolled	
	g m^{-2}		
Untreated control	38.9 cde†	145.5 a	70.0 a
Annual ryegrass	31.3 cde	62.2 b	13.2 b
Winter wheat	8.1 fgh	40.3 cd	16.0 b
Winter barley	5.1 fgh	26.4 c-f	9.6 b
Winter rye	0.0 h	3.5 gh	6.1 b
Spring oats	17.5 e-h	47.6 bc	-
Spring rye	-	-	17.3 b
Winter rye/spring no residual	0.0 h	0.0 h	7.8 b
Fall residual	0.0 h	8.7 fgh	0.0 b
Fall no residual	0.0 h	25.1 d-g	1.9 b
Spring residual	0.4 h	4.6 gh	11.6 b
Spring no residual	1.7 h	21.4 d-h	6.8 b

† Values within a column followed by the same letter are not significantly different at α=0.1.
'-' treatment not included in study that year

Table 2.7 Horseweed suppression by cover crop and herbicide treatments in sprayed and rolled termination treatments at soybean R1 in 2013 and 2014 and at soybean R6.5 in 2013 at Manhattan, KS.

	Horseweed suppression at soybean R1				Horseweed suppression at R6.5	
	2013		2014		2013	
Treatment	Sprayed	Rolled	Sprayed	Rolled	Sprayed	Rolled
	%					
Untreated control	6 efg†	3 g	100 a	25 d	71 b-e	0 h
Annual ryegrass	13 d-g	11 d-g	98 a	90 abc	63 cde	21 gh
Winter wheat	56 b	26 cde	100 a	85 abc	58 def	38 fg
Winter barley	61 b	35 c	99 a	85 abc	78 a-d	45 efg
Winter rye	92 a	84 a	98 a	86 abc	94 ab	84 abc
Spring oats	25 c-f	5 fg	-	-	60 c-f	4 h
Spring rye	-	-	99 a	91 abc	-	-
Winter rye/spring no residual	100 a	100 a	99 a	91 abc	98 a	100 a
Fall residual	99 a	88 a	99 a	78 bc	100 a	100 a
Fall no residual	91 a	28 cd	94 ab	88 abc	94 ab	46 ef
Spring residual	93 a	89 a	100 a	74 c	99 a	94 ab
Spring no residual	88 a	28 cd	100 a	84 abc	98 a	68 cde

† Values within a column followed by the same letter are not significantly different at α=0.1.
'-' treatment not included in study that year

Table 2.8 Soybean above-ground biomass production averaged across termation methods at soybean R6.5 in 2013 and 2014 at Manhattan, KS.

Treatment	Soybean Biomass 2013		Soybean Biomass 2014	
	$g\ m^{-2}$			
Untreated control	124.9	f†	262.6	c
Annual ryegrass	186.0	ef	291.5	bc
Winter wheat	220.3	ef	300.7	bc
Winter barley	349.6	bc	289.5	bc
Winter rye	309.3	c	299.4	bc
Spring oats	228.3	de	-	
Spring rye	-		312.0	abc
Winter rye/spring no residual	304.1	cd	336.3	ab
Fall residual	395.8	b	336.3	ab
Fall no residual	362.8	bc	327.5	ab
Spring residual	484.3	a	327.2	ab
Spring no residual	355.0	bc	372.3	a

† Values within a column followed by the same letter are not significantly different at α=0.1.
'-' treatment not included in study that year

Table 2.9 Soybean yields in response to treatments in both sprayed and rolled termination in 2013 and averaged across termination in 2014 Manhattan, KS.

	Soybean yield					
	2013				2014	
Treatment	Sprayed		Rolled			
	kg ha^{-1}					
Untreated control	806	de†	126	h	702	c
Annual ryegrass	844	de	302	gh	1151	b
Winter wheat	780	def	287	gh	1460	ab
Winter barley	893	d	586	ef	1829	a
Winter rye	899	d	535	fg	1285	b
Spring oats	911	d	113	h	-	
Spring rye	-		-		1578	ab
Rye/spring no residual	911	d	686	def	1451	ab
Fall residual	1654	a	1240	c	1407	ab
Fall no residual	1532	ab	539	fg	1358	b
Spring residual	1684	a	1278	bc	1239	b
Spring no residual	1674	a	826	de	1329	b

† Values across termination method followed by the same letter are not significantly different at α=0.1.
'-' treatment not included in study that year

Table 2.10 Horseweed total aboveground biomass production, 200-seed weight, and total seed perduction per plant in 2014 at Manhattan, KS.

Treatment	Horseweed biomass	200-seed weight	Total horseweed seed production
	—— g per plant ——	—— mg ——	—no. per plant—
Untreated control	220 a†	5.23 a	1,153,000 a
Winter wheat	125 b	5.41 a	702,000 b
Winter rye	141 b	4.75 a	776,000 b

† Treatment means within a column followed by the same lower case letter are not different, α=0.1.

References

Anonymous (2015) Table 11: Soybean Area, Yield and Production. www.fas.usda.gov. Accessed: March 24, 2015

Anonymous (2015) Cover Crop Seed Planting Guide. www.covercropsolutions.com Accessed: April 1, 2015

Anonymous (2013) 2012 Kansas Soybean County Estimates. www.nass.usda.gov. Accessed: March 22, 2015

Anonymous (2013) 2012-2013 Cover Crop Survey. www.ctic.org. Accessed: March 22, 2015

Anonymous (2014) 2013-2014 Cover Crop Survey Report. www.sare.org Accessed: March 22, 2015

Bhowmik PC, Bekech MM (1993) Horseweed (*Conyza canadensis*) seed production, emergence, and distribution in no-tillage and conventional-tillage corn (*Zea mays*). Trends Agric. Sci 1:67-71

Davis VM, Gibson KD, Bauman TT, Weller SC, Johnson WG (2009) Influence of weed management practices and crop rotation on glyphosate-resistant horseweed (*Conyza canadensis*) population dynamics and crop yields-years III and IV. Weed Sci 57:417-426

Heap I (2015) The International Survey of Herbicide Resistant Weeds. www.weedscience.org. Accessed: March 16, 2015

Petrosino JS, Dille JA, Holman JD, Roozeboom KL (2015) Kochia suppression with cover crops in Southwest Kansas. Crop, Forage & Turfgrass Management. 1:1-8

Regeher DL, Bazzaz FA (1979) The population dynamics of *Erigeron canadensis*, a successional winter annual. J of Ecol 67:923-933

Shrestha A, Hanson BD, Fidelibus MW, Alcorta M (2010) Growth, phenology, and intraspecific competition between glyphosate-resistant and glyphosate-susceptible horseweeds (*Conyza canadensis*) in the San Joaquin Valley of California. Weed Sci 58:147-153

Teasdale JR, Brandsaeter LO, Calegari A, Neto FS (2007) Cover Crops and Weed Management. Pages 49-64 *in* Upadhyaya MK, Blachshaw RE, eds. Non-Chemical Weed Management: Principles, Concepts and Technology. CABI Publishing

Weston LA (1990) Cover crop and herbicide influence on row crop seedling establishment in no-tillage culture. Weed Sci 38:166-171

Wortman SE, Francis CA, Bernards MA, Blankenship EE, Lindquist, JL (2013) Mechanical termination of diverse cover crop mixtures for improved weed suppression in organic cropping systems. Weed Sci 61:162-170

Appendix A - **Additional Figures, Tables, and Raw Data**

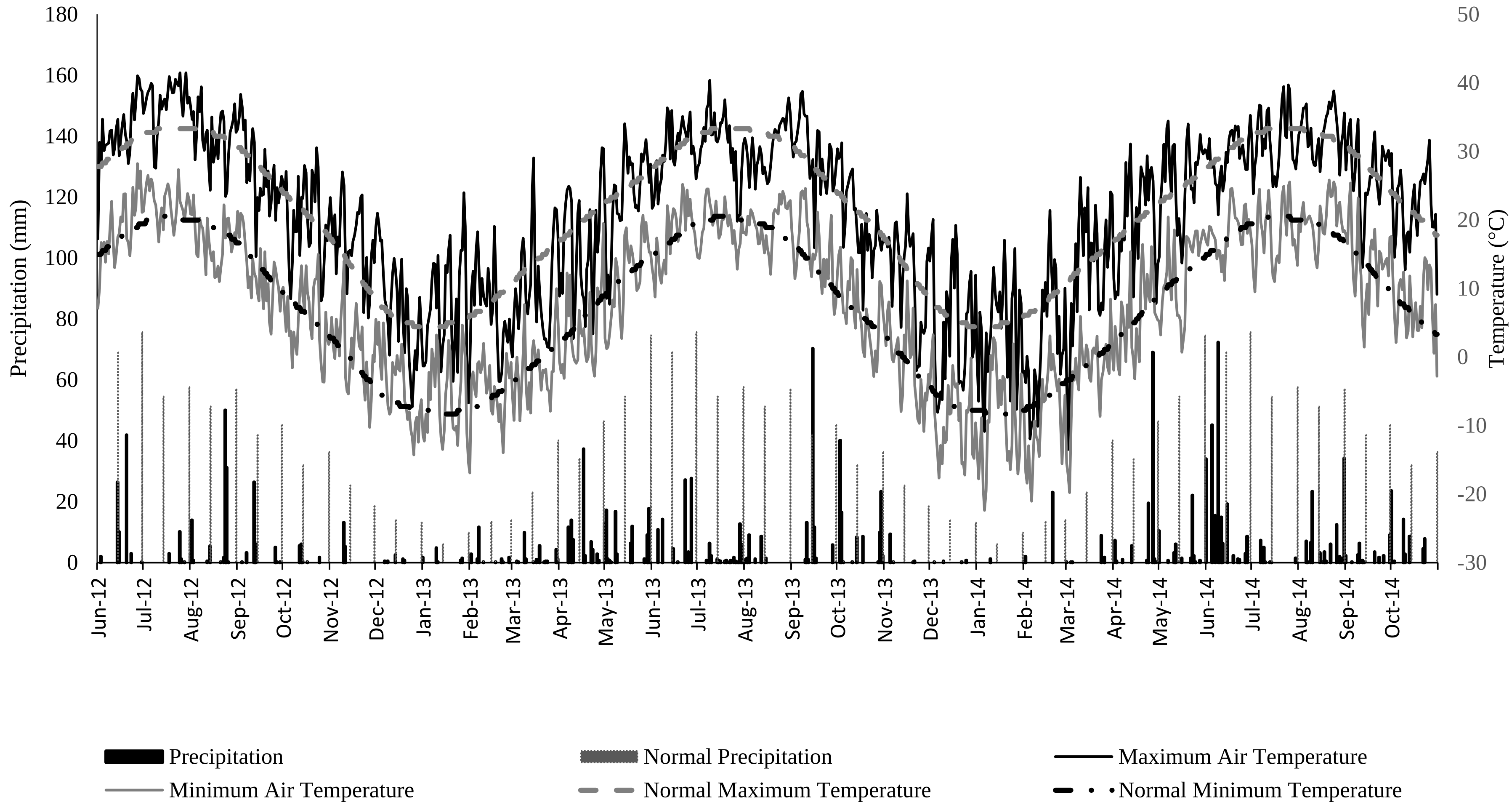

Figure A.1 Daily/normal precipitation, minimum, and maximum temperature for Manhattan, KS.

Table A.1 Horseweed height in spray terminated portions of the untreated control, winter wheat, and winter rye plots from 5 May 2014 to 20 August 2014 at Manhattan, KS.

	Horseweed height																	
Treatment	5 May		19 May		4 June		20 June		2 July		22 July		30 July		12 Aug		20 Aug	
	cm																	
Untreated control	9.9†	a	14.2	a	30.6	a	53.2	a	77.1	a	82.5	a	91.1	A	97.9	a	104	a
Winter wheat	6.3	b	9.2	b	24.8	a	43.9	ab	66.5	ab	77.5	a	88.8	A	92.8	a	92.6	a
Winter rye	4.8	b	6.3	c	18.2	b	36.9	b	57.2	b	73.4	a	82.6	A	90.6	a	91.1	a

† Interaction means for each date followed by the same lower case letter are not different, α=0.1.

Table A.2 Growth of selected horseweed plants in cover crops and soybeans in 2014.

crop	Rep	Plant	5 May	19 May	4 June	20 June	2 July	22 July	30 July	12 Aug	20 Aug
			cm								
winter wheat	1	1	5.4	9.6	34.0	59.0	84.0	102.0	110.0	110.0	111.0
winter wheat	1	2	7.2	13.9	22.0	38.5	58.0	70.0	75.0	78.0	79.0
winter wheat	1	3	9.0	15.0	25.5	49.5	72.0	93.0	107.0	115.0	116.0
winter rye	1	1	5.1	8.2	20.0	43.0	60.5	88.0	89.5	90.0	82.0
winter rye	1	2	4.1	6.6	15.0	27.0	40.0	-	-	-	-
winter rye	1	3	9.0	12.7	27.5	54.5	85.5	85.0	84.0	85.0	85.0
untreated control	1	1	7.6	12.2	22.0	45.0	72.0	110.0	122.0	121.5	122.0
untreated control	1	2	12.8	19.0	35.5	42.0	62.5	68.0	71.0	69.5	74.0
untreated control	1	3	8.3	17.6	28.0	49.0	65.0	82.0	82.0	-	-
winter rye	2	1	4.7	8.9	22.5	42.5	63.5	89.0	102.5	110.0	111.0
winter rye	2	2	4.6	6.8	15.5	31.5	52.0	61.0	73.0	97.5	99.0
winter rye	2	3	3.2	8.1	12.0	21.5	36.0	57.0	69.5	78.0	81.0
winter wheat	2	2	4.8	9.4	16.0	26.0	51.0	41.0	60.0	65.0	-
winter wheat	2	3	5.4	8.8	24.0	41.5	62.0	81.0	91.0	106.0	107.0
untreated control	2	1	8.4	16.3	35.0	61.0	85.0	-	-	-	-
untreated control	2	2	13.3	19.8	44.5	71.0	96.5	81.0	110.0	80.0	63.0
untreated control	2	3	11.6	21.6	33.5	61.5	89.5	87.0	93.0	101.0	111.0
untreated control	3	1	14.2	6.8	16.5	31.5	55.5	46.0	60.0	67.0	69.0
untreated control	3	3	4.7	9.2	32.5	68.5	102.0	97.0	103.0	109.0	111.0
winter rye	4	1	3.9	6.4	15.0	30.0	44.5	50.0	61.0	82.5	72.0
winter rye	4	2	2.8	4.8	13.0	29.5	50.0	61.5	73.5	97.0	103.0
winter rye	4	3	5.4	8.6	23.0	52.5	83.0	103.0	111.5	111.0	113.0
untreated control	4	1	9.8	15.9	43.0	69.5	92.5	96.0	109.0	115.0	117.0
untreated control	4	2	11.0	10.5	20.5	40.0	60.0	75.0	75.0	70.0	70.0
untreated control	4	3	7.2	12.1	25.5	47.0	69.0	90.0	88.0	82.0	83.0
winter wheat	4	1	4.9	7.6	21.0	38.0	62.0	69.0	85.0	106.0	110.0
winter wheat	4	2	7.1	12.3	31.0	55.0	75.0	85.0	89.0	97.0	101.0

On Farm Data Collection

Introduction

Data in the following tables were collected in collaboration with Justin Knopf in Gypsum, KS and Kevin Wiltse in Timken, KS as part of an ongoing study with the Kansas Agricultural Research and Technology Association (KARTA). Members of this organization strive to use recent, relevant technology to best optimize their crop production. With the increasing popularity of cover crops, these producers sought to determine the efficacy of cover crops on their acres. The objective of this study was to examine the effect of cover crops with and without the addition of nitrogen on a subsequent soybean crop.

Materials and Methods

In addition to fallow, treatments at both locations included spring planted oats with and without the addition of 28 kg ha^{-1} nitrogen. The Timken location also included a mix of ten spring planted species of cover crops that mainly consisted of oats, barley and buckwheat at the time of cover crop biomass sampling. Cover crop biomass was sampled just prior to chemical termination and soybean plant density was recorded at V1-V2. Weed populations at both of the locations primarily consisted of low densities of field bindweed [*Convolvulus arvensis* (L.)], downy brome [*Bromus tectorum* (L.)], and Palmer amaranth [*Amaranthus palmeri* S. Wats.].

Results and Discussion

Precipitation at each of these locations likely impacted the biomass accumulation of both cover crops and weeds. Average yearly precipitation in Gypsum is 81.9 cm and 67.7 cm at Timken. As a result of this rainfall gradient, cover crop biomass was overall greater in Gypsum than at the Timken location. Within both locations, there was no difference in cover crop biomass when comparing oats with and without the addition of 28 kg ha^{-1} nitrogen. However, biomass production of the cover crop mix in Timken was reduced compared to the oat treatments, 24.0 g m^{-2} vs 30.63 g m^{-2} or 24.93 g m^{-2}.In both locations, weed biomass was reduced in oat plots that received the additional nitrogen, as well as the cover crop mixture treatment in Timken. It is unknown whether this reduction was due directly as a result of the addition of nitrogen or secondary due to increased early season growth of the oat cover crop. In Gypsum, the oat and fallow treatments both contained weeds with biomass in excess of 15.5 g m^{-2}. The fallow treatment in Timken contained greater weed biomass than any other treatment at that location, 14.2 g m^{-2}. There was no difference in soybean plant densities across any of the treatments at either location.

Conclusion

In summary, oat cover crops were able to obtain more biomass than the ten species mixture in these locations. Producers looking to plant cover crops purely for the benefit of weed suppression may find success in utilizing oars with the addition of 28 kg m^{-2}. The greatest weed biomass accumulation at both locations was in the fallow and oat plots, illustrating the necessity of utilizing a cover crop with the addition of nitrogen. Weed biomass was reduced at both locations by the addition of nitrogen to oat plots. Soybean stands were not affected by the planting of cover crops, which is key in ensuring that soybean yield losses do not occur as a result of cover crops.

Table A.3 On-farm data from Gypsum, KS: cover crop wet weight, cover crop dry weight, weed wet weight, weed dry weight and soybean stand density.

plot	rep	sample	cover crop	cover crop wet wt	cover crop dry wt	weed wet wt	weed dry wt	soybean stand density
				——g m^{-2}——				—plants m^{-2}—
101	1	1	oats + 28 kg ha^{-1} N	363.45	98.71	1.42	0.15	28
101	1	2	oats + 28 kg ha^{-1} N	263.61	66.59	.	.	28
101	1	3	oats + 28 kg ha^{-1} N	232.1	53.82	.	.	28
102	1	1	oats	261.23	60.62	.	.	31
102	1	2	oats	178.82	40.04	.	.	31
102	1	3	oats	343.73	86.15	.	.	31
103	1	1	fallow	.	.	14.42	4.35	29
103	1	2	fallow	.	.	39.9	13.2	29
103	1	3	fallow	.	.	53.41	6.72	29
201	2	1	oats	181.18	44.31	.	.	28
201	2	2	oats	98.7	25.21	.	.	28
201	2	3	oats	227.12	52.91	53.85	17.74	28
202	2	1	fallow	.	.	50.79	14.5	26
202	2	2	fallow	.	.	.	.	26
202	2	3	fallow	.	.	26.88	9.61	26
203	2	1	oats + 28 kg ha^{-1} N	186.24	51.17	.	.	31
203	2	2	oats + 28 kg ha^{-1} N	188.92	38.86	3.68	1.78	31
203	2	3	oats + 28 kg ha^{-1} N	90.34	21.87	3.27	0.02	31
301	3	1	fallow	.	26.5	112.09	26.5	29
301	3	2	fallow	.	28.84	122.72	28.84	29
301	3	3	fallow	.	.	.	.	29
302	3	1	oats	219.45	62.83	.	.	28
302	3	2	oats	144.75	37.68	.	.	28
302	3	3	oats	195.07	52.94	.	.	28
303	3	1	oats + 28 kg ha^{-1} N	172.8	48.44	31.55	4.29	26
303	3	2	oats + 28 kg ha^{-1} N	276.14	72.66	5.84	0.03	26
303	3	3	oats + 28 kg ha^{-1} N	227.93	65.79	.	.	26

Table A.4 On-farm data from Timken, KS: cover crop wet weight, cover crop dry weight, weed wet weight, weed dry weight and soybean stand density.

plot	rep	sample	cover crop	cover crop wet wt	cover crop dry wt	weed wet wt	weed dry wt	soybean stand density
				——g m^{-2}——				—plants m^{-2}—
101	1	1	mix	91	16.64	58	11.89	27
101	1	2	mix	82	14.16	90	22.58	27
101	1	3	mix	123	24.04	196	38.2	27
102	1	1	oats + 28 kg ha^{-1} N	111	19.13	63	14.45	26
102	1	2	oats + 28 kg ha^{-1} N	55	7.89	68	16.06	26
102	1	3	oats + 28 kg ha^{-1} N	117	22.32	122	28.7	26
103	1	1	oats	29	3.07	159	44.24	26
103	1	2	oats	134	24.37	98	25.52	26
103	1	3	oats	58	8.3	96	24.3	26
104	1	1	fallow	0	0	163	49.8	24
104	1	2	fallow	0	0	131	34.9	24
104	1	3	fallow	0	0	149	39.05	24
201	2	1	oats	124	28.52	88	25.7	24
201	2	2	oats	53	8.71	30	4.9	24
201	2	3	oats	61	13.66	31	8.47	24
202	2	1	fallow	0	0	93	21.69	29
202	2	2	fallow	0	0	27	4.6	29
202	2	3	fallow	0	0	41	6.83	29
203	2	1	oats + 28 kg ha^{-1} N	181	31.18	26	4.01	25
203	2	2	oats + 28 kg ha^{-1} N	193	36.76	14	0.36	25
203	2	3	oats + 28 kg ha^{-1} N	144	27.09	15	.	25
204	2	1	mix	118	23.35	45	8.61	24
204	2	2	mix	97	17.34	8	1.24	24
204	2	3	mix	140	27.68	0	0	24
301	3	1	mix	100	25.07	0	0	25
301	3	2	mix	74	17.8	0	0	25
301	3	3	mix	193	42.39	0	0	25
302	3	1	oats	160	29.35	0	0	27
302	3	2	oats	183	32.57	0	0	27
302	3	3	oats	248	44.32	0	0	27
303	3	1	oats + 28 kg ha^{-1} N	100	16.29	17	0.56	29
303	3	2	oats + 28 kg ha^{-1} N	253	45.51	0	0	29
303	3	3	oats + 28 kg ha^{-1} N	175	29.22	21	1.32	29
304	3	1	fallow	0	0	21	2.18	27
304	3	2	fallow	0	0	51	11.52	27
304	3	3	fallow	0	0	18	0.2	27
401	4	1	oats + 28 kg ha^{-1} N	257	46.52	0	0	24

401	4	2	oats + 28 kg ha^{-1} N	164	29.65	0	0	24
401	4	3	oats + 28 kg ha^{-1} N	304	55.98	0	0	24
402	4	1	fallow	0	0	0	0	24
402	4	2	fallow	0	0	0	0	24
402	4	3	fallow	0	0	0	0	24
403	4	1	oats	129	23.86	0	0	24
403	4	2	oats	236	43.3	0	0	24
403	4	3	oats	182	39.07	0	0	24
404	4	1	mix	111	21.04	0	0	25
404	4	2	mix	124	22.07	0	0	25
404	4	3	mix	196	36.39	0	0	25

Table A.5 On-farm data from Gypsum and Timken, KS: cover crop dry weight, weed dry weight and soybean stand density.

Treatment	cover crop dry weight		weed dry weight		soybean plant density	
	———————g m^{-2}		———————		—plants m^{-2}—	
Gypsum						
Oats + N	57.55†	a	0.33	b	28	a
Oats	51.41	a	18.92	a	29	a
Fallow			15.48	a	28	a
Timken						
Oats + N	30.63	a	5.77	c	26	a
Oats	24.93	a	11.10	ab	25	a
Fallow			14.23	a	26	a
Mix	24.00	b	6.88	bc	25	a

† Treatment means within a column for each location followed by the same lower case letter are not different, α=0.1.