RESPONSE OF WEEDS TO THE INTENSIFICATION OF KANSAS NO-TILL CROP ROTATIONS WITH COVER CROPPING

by

JUSTIN SCOTT PETROSINO

B.S., Baldwin-Wallace College, 2007

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

2010

Approved by:

Major Professor
J. Anita Dille

Abstract

No-till producers can manage weeds by including cover crops during the fallow phase as part of an integrated weed management plan. Field experiments were conducted between 2007 and 2009 to quantify the influence of cover crops on weed emergence, biomass accumulation, and seed production. Field experiments were established near Garden City, KS with winter wheat or fallow as main plots and cover crop treatments as subplots including five spring- and five fall-sown individual or mixtures of crop species and a no-cover chemical fallow. Separate1-m^2 quadrats were seeded with kochia or downy brome at 500 seed/m^2. Kochia density was reduced by 75% and biomass reduced by 88% in fall-sown cover crops compared to chemical fallow across growing seasons. Spring-sown cover crop mixtures reduced kochia biomass in 2009 when kochia emergence was delayed. Downy brome biomass decreased exponentially as cover crop biomass increased. A second field experiment was established near Manhattan, KS with soybean, winter wheat, or grain sorghum phases of the rotation as main plots and six cover crop treatments as subplots sown after winter wheat harvest. Paired Palmer amaranth 1-m^2 quadrats were seeded with 500 seed/m^2 in each cover crop subplot. One quadrat was protected from any herbicide application made to the cover crop or to the grain sorghum. Combining burndown application with high biomass-producing cover crops reduced Palmer amaranth emergence and biomass. Influence of cover crop presence reduced early season Palmer amaranth emergence in the subsequent grain sorghum phase. Optimal seeding rate of forage soybean sown in winter wheat stubble and its impact on Palmer amaranth and downy brome emergence and growth were evaluated in field studies established near Manhattan and Hesston, KS in 2008 and 2009. Soybean was no-till drilled after wheat harvest at five rates ranging from 100,000 to 600,000 seeds/ha. A no-cover chemical fallow treatment was included. Separate 0.5-m^2 quadrats were seeded with Palmer amaranth at 100 seed/0.5 m^2 or with downy brome at 250 seed/0.5 m^2. Three termination methods evaluated were killing frost, glyphosate application, or crop rolling. Palmer amaranth density was not affected by treatments but biomass decreased as soybean seeding rate and crop biomass increased. Downy brome emergence was less with rolled or sprayed termination methods in one site year as timing of termination was optimal. High biomass producing cover crops sown during the fallow phase of a crop rotation reduced weed emergence, density, and biomass accumulation. Cover crops can be part of an integrated weed management plan in Kansas.

Table of Contents

List of Figures

List of Tables

Acknowledgements

Above all I would like to thank Dr. Anita Dille for her guidance, wisdom, and support during my time at Kansas State University. Without outstanding major professors like her graduate school would not be the same. I would also like to thank Dr. Kraig Roozeboom and Dr. John Holman for serving on my committee. I would like to extend a special thanks to Kraig for all the times his door was open for statistical questions and discussions. I would also like to thank John for sharing the big house down in Garden City, nights are a little less boring at the field station with someone to talk to. I would like to thank the entire faculty and staff in the department of agronomy with special thanks to Dr. William Schapaugh, Dr. Lloyd Stone, Dr. Kassim Al-Khatib, Dr. Gerard Kluitenberg, Dr. Mark Claassen, and Dr. David Mengel for their support and wisdom in my research efforts. I would like to thank the weeds group, Haydee Ramirez, Meshack Ndou, Joi Abit, J.D. Riffel, Bryan Unruh, Brandon Hulse, and Bethany Porter for all their help both in and out of the field season. I would like to thank Kevin Arnet and Aaron Sindelar for their work on the Ashland Bottoms and soybean studies. I extend a special thanks to Kevin and Lowell down at Hesston for their help and a few great lunches at El Cerrito. Thank you to Dr. Bill Heer at Hutchinson, and Scott Maxwell at Garden City for all their help in experiment preparations. I would like to thank Tyler Rider for providing a plot of ground and doing most of the grunt work at the Ness City location. Of course I thank all of our great student workers, without them none of this work would be possible. Thank you Jessie Vipham, Chelsey Weeden, Sydney Jannsen, Kevin Hecht, Brett Retta, and Josey Steeples. I would also like to thank all of my fellow grad students for the great times at Kansas State, thanks Holly, Swenson, Jason, Dooley, Stamper, Levi, Grant, Nathan, and Badger. Thank you to the Department of Agronomy at Kansas State University and to the USDA CSREES North Central IPM Grant No. 2007-4530-02801 and 2007-34103-18104.

Dedication

This thesis is dedicated to God for every blessing and opportunity He has bestowed upon me and for the experiences He has given me to help me grow. This thesis is also dedicated to the countless family and friends who supported me and my goals. Thank you Mom, Phil, and Krista for all your support. Thank you Alex and Megan for all your phone calls and support and also thanks to all the guys back home. Thank you to Dr. Natalie Barratt for bolstering my interest in plant sciences. To the Grande, Bouch, and Schaffer families for feeding my interest in agriculture thank you very much. This thesis is also dedicated to Anita for all of her strength and persistence in the last year. You are an inspiration to us all.

CHAPTER 1 - Literature Review

The intensification of a crop rotation with cover crops can improve nutrient management, water use efficiency, and weed control. Volatile input costs and the increase in herbicide resistant weeds add to the incentive for producers to diversify their cropping systems and to adopt new practices. Intensification of rotations can be difficult in water-limited cropping environments found in the Great Plains region. Replacing fallow periods with cover crops produced for forage or ground cover instead of a grain crop is a unique way to intensify a rotation while limiting water loss from a system. Cover crops can fit into an existing rotation, providing diversity as well as ancillary benefits such as weed suppression to the rotation.

Hartwig and Ammon (2002) described a cover crop as a plant introduced during or directly after the main cropping phase of a system and terminated before the next crop is planted. Although cover crops are divided into many classes such as summer or winter cover or grown for residue cover or forage harvest, they are planted to serve distinct roles in a cropping system. As their name implies cover crops provide ground cover between cropping phases, normally replacing a portion or all of a fallow period. Although recent research highlights the benefits of cover cropping, their addition to the fallow phase of a rotation is not a novel idea and can be traced back through the literature for over two thousand years. The earliest writings on cover crops appeared in 500 and 300 BC (Paine and Harrison 1993, Pieters 1927, Weston 2005). Chinese and Roman scholars commented on the abilities of cover crops in rotation. Often these writings praised the increases seen in yields that followed cover crops. The negative impacts of some cover crops were also recorded. Pliny II, a Roman scholar, commented in 1 AD that some cover crops had the ability to destroy or burn up farmland (Weston 2005). The increase in use of cover crops in European agriculture during the 18th and 19th centuries followed agricultural advancements like the invention and adoption of mechanical tillage and seed drills (Paine and Harrison 1993). The use of cover crops in the United States was limited to the "settled" Eastern portions of the country in the 19th century (Allen 1852, Paine and Harrison 1993).

Like many ideas in history, cover crops emerged periodically in the agricultural literature as a novel means to solve a problem. Before the advent of chemical herbicides and fertilizers cover crops and manures were used to add nutrients like nitrogen into a system (McKnee 1931, Paine and Harrison 1993). McKnee noted in 1931 that “the practice of using such crops [legumes] in rotation as standard cash crops and also for green manure is not new…[and that more recently] efforts have been made to procure legumes that would make superior growth during the winter months”. From his *recent* research in the 1920s and 1930s, Austrian winter pea emerged as a favorable winter cover crop (McKnee 1931). The original research McKnee mentioned dated back to the previous century (McKnee 1931, Paine and Harrison 1993).

Although the addition of cover crops to a system can be traced through history the past century saw several spikes in interest where this idea, somehow forgotten, returned as the saving grace of farmers. The 1930s saw the emergence of cover crops as a means to introduce additional nitrogen into a system while providing cover to reduce the soil erosion that resulted in many dust storms in that decade (McKnee 1931, Troeh et al. 2004). The 1940s saw leguminous cover crops as a means to reduce the amount of nitrogen fertilizers applied in America in response to nitrogen fertilizer shortages resulting from the war (Aamodt 1943). In the late 1940s and 1950s cover crops were replaced with chemical fertilizers and herbicides that allowed farmers to reduce tillage operations while adding beneficial nitrogen at a determined rate (Hartwig and Ammon 2002). It wasn’t until the oil embargos of the 1970s that cover crops reemerged as a way to combat rising fertilizer and fuel costs by reducing chemical nitrogen input paired with reduced tillage practices to decrease fuel usage (Hartwig and Ammon 2002). More recently environmental concerns combined with volatile input costs have raised interest in cover crops as a viable means to reduce inputs into a system while preventing losses of herbicides, plant-available nitrogen, and surface soil.

Historical research on the topic has shown that replacing fallow periods with cover crops provides many benefits to producers. Cover crops, whether alive or dead as residue benefit the soils from which they grow. Established roots and residues of cover crops can help decrease soil erosion while increasing water infiltration rates (Dabney 1998, Hartwig and Ammon 2002, McVay et al. 1989, Troeh et al. 2004). Tall, thin stemmed, standing cover crops like wheat or triticale provide excellent protection against wind or water soil erosion (Troeh et al. 2004). The crop acts as a physical barrier absorbing the impact force of precipitation and raising the wind profile (Dabney 1998, Troeh et al. 2004). Although cereal crops like wheat and triticale provide excellent soil erosion protection, other crop types like hairy vetch, afford adequate protection to the soil while contributing nutrients to the soil through residue decomposition (McVay et al. 1989).

Planting leguminous cover crops like Austrian winter pea, hairy vetch, and forage soybeans offer ground cover as well as the added advantage of nitrogen fixation (Leikam et al. 2007, McKnee 1931, McVay et al. 1989). The bacterial conversion of gaseous nitrogen to plant available forms like nitrate in root nodules of these plant species can provide on average 34 kg/ha of nitrogen for the succeeding crop (Leikam et al. 2007). Planting non-leguminous crops can reduce nitrogen leaching out of the soil over a fallow period, giving cover crops a two-fold benefit to the addition of nitrogen to a system (Al-Khatib et al. 1997). Along with affording protection against soil degradation and providing nitrogen to the proceeding crop, cover crops can be useful in suppressing weed species (Al-Khatib et al. 1997, Leikman et al. 2007, Teasdale et al. 2005, Troeh et al. 2004)

These benefits are only part of the decision making process that goes into incorporating cover crops. The implementation of a cover crop is dependent upon many producer-determined and environmental factors. Availability of crop seed, planting and harvesting conflicts, and the need for new planting equipment are factors that influence the producer's choice of a cover crop. Financially, a cover crop needs to provide a monetary benefit equal to or greater than the cost of the extra planting operation in order for it to be viable in a system. When added to a rotation many cover crops can increase crop yields through nitrogen contribution, weed suppression, and other ancillary benefits such as soil erosion prevention and breaking pest cycles. Some of these benefits are hard to quantify which makes basing a decision on them difficult.

Logistical and financial viability of a cropping system can be important in determining which cover cropping system to select. However, climate can determine if intensification of a system is locally feasible. Arid regions like the Southern Great Plains are water-limited areas where the fallow periods are important times for recharging soil water stores. Research in the arid regions of the Great Plains has shown both positive and negative effects of cover crops on the successive main crop based on the amount of water that enters the system and the amount of water used by the cover crop (Clark et al. 1995, Nielsen and Vigil 2005, Schlegel and Havlin 1997).

To be economically viable these cover crops must provide measurable weed control while not significantly impacting the stored soil water needed by the main crop that will follow

(Schelgel and Havlin 1997). While intensifying a rotation increases the water use efficiency and precipitation use efficiency of a field, excessive water use by a cover crop can negatively affect the yields of the subsequent crop (Nielsen and Vigil 2005, Clark et al. 1995). Nielsen and Vigil (2005) found that the growth of a leguminous cover crop in a conventionally-tilled winter wheat – fallow rotation in an arid region of the Great Plains negatively impacted the following wheat crop by depleting the soil water available at planting by a range of 55 to 105 mm. Winter wheat yields following the cover crop averaged 67% of the wheat yields of the conventional wheat – fallow rotation. The range of soil water depletion at winter wheat planting came from delaying termination dates of the cover crop. A linear correlation was observed between the delay in termination date and the decrease in available soil water for the following crop. Similar results have been recorded for corn and grain sorghum in the area (Schlegel and Havlin 1997, Sweeney and Moyer 1994). A sheltered environment study in Maryland supported these findings with delayed termination dates of hairy vetch negatively affecting available soil water at planting and subsequent corn yields (Clark et al. 1995). However the water used by a cover crop only affected the next crop in rotation. Grain sorghum planted after winter wheat that was affected by water use from a cover crop showed no decrease in yields compared to a fallow-winter wheat-grain sorghum rotation.

Forage production is a novel way to limit the impact of moisture stress on a cover crop while still gaining some benefit from the crop other than weed suppression. Forage production allows a producer to grow a crop without any critical growth stages like tasseling in corn that plague similar crops grown to grain. Moisture stress at critical growth periods of a grain crop's lifecycle can negatively impact grain yields (Shroyer et al. 1998). Compared to grain and stover produced by grain sorghum, Unger (1988) found that the right forage sorghum variety could produce as much crude protein, total digestible energy, and metabolizable energy as grain sorghum while avoiding critical growth stages. More importantly forage sorghums used less water more efficiently than grain sorghum (Unger 1988). Forage crop selection also plays a role in dry matter production (Nielsen et al. 2006). In a comparison between forage corn, foxtail millet *(Setaria italica),* and winter triticale (*Triticale hexaploide*)under the highly variable precipitation patterns of Akron, CO, winter triticale was the most efficient water user and the most likely to produce over 4000 kg/ha of dry matter in a seven year study (Nielsen et al. 2006). The water savings afforded by adopting no tillage practices, planting a water efficient forage crop and promptly terminating the crop may allow the introduction of a cover crop in the fallow phase of a rotation in a semiarid region.

Kansas, a Great Plains state, possesses a varied climate depending on the geographic location in the state. In the south western portion where Garden City is located, a semiarid environment has lead to the adoption of the winter wheat – fallow rotation to stabilize wheat yields (Haas et al. 1974, Hinze and Smika 1983). Located in Finney County, Garden City averaged 455 mm of precipitation from 1961-1990 (NCDC 2007). The majority of the precipitation falls in the months from April to August, peaking in the month of May, which has a 30-yr average of only 80 mm (NCDC 2007).

Manhattan, KS is located in the more arable northeastern portion of the state in Riley County. Like most areas in the eastern portion Manhattan receives a 30-yr average precipitation level above 762 mm (Shroyer et al. 1998). The NCDC reported that from 1961 to 1990 Manhattan averaged 859 mm of annual precipitation. The annual amount of precipitation is nearly twice that recorded at Garden City. The precipitation is also distributed differently such that Manhattan has two peaks in its annual precipitation pattern, one in June and one in September (NCDC 2007). These precipitation spikes fall relative to planting dates for both summer and winter crops grown in the area, possibly providing supplemental water to replace the water removed by the cover crops.

The different precipitation patterns have led to the adoption of different crop rotations in each area. Crops that are more tolerant of water stress such as winter wheat and grain sorghum are more prevalent in the rainfed rotations around Garden City, while more diverse crops can be produced in the Manhattan area with more annual precipitation. Winter wheat and grain sorghum are still present in rotations but soybeans and corn are also grown in the area. The different cropping systems provide fallow periods of different lengths. These periods can be as short as the few weeks between soybean harvest and winter wheat planting in the Manhattan area to a maximum of 14 months found in the winter wheat – fallow rotations of Garden City.

These periods of rest for the land, if long enough, require input from the farmer to control weeds either in the form of herbicides or tillage. The adoption of no-till practices benefit producers in the Garden City area with an average of 43 mm of saved soil water compared to stubble mulch tillage (Stone and Schlegel 2006). No-till practices leave producers with few control options for weeds other than herbicides. With extra water stored from adopting no-tillage it may be possible for farmers to manage weeds culturally with the introduction of cover crops in the fallow phase of the rotation.

Weed Species

Palmer amaranth (*Amaranthus palmeri)* is an aggressive pigweed species related to both redroot pigweed (*A. retroflexus*) and common waterhemp (*A. rudis*) (Stubbendieck et al. 2003). It is distributed across the southern United States with different accessions being located as far west as New Mexico and as far east as Georgia (Bond and Oliver 2006). Like most members of the *Amaranthaceae* family Palmer amaranth is a small seeded summer annual weed species. Pigweed seed germination is triggered by a cold period at or below 5 C followed by a warming period with alternating temperatures and aided by the presence of light at lower temperatures (Gallagher and Cardina 1998, Steckel et al. 2004, Taylorson and Hendricks 1969). Steckel et al. (2004) found that temperature fluctuations around 30 C optimized Palmer amaranth germination to 83%. Once Palmer amaranth emerges, it grows quickly to heights of 0.2 to 2.8 m (Bond and Oliver 2006, Ehleringer 1983, Stubbendieck et al. 2003). Mature female members of this dioecious species flower from July to October and produce as many as 600,000 seeds / plant (Keely et al 1987, Stubbendieck et al. 2003). Without control Palmer amaranth can double its population size in one year (Vancill and Banks 1984). The quick growth habit and fertile reproduction of Palmer amaranth make it a fierce competitor with common summer annual crops like corn, soybean, and grain sorghum (Klingaman and Oliver 1994, Massinga et al. 2001, Moore et al. 2004). Although Palmer amaranth tends to negatively effects crop yields, Moore et al. (2004) found a unique case where Palmer amaranth material actually decreased the number of split grain sorghum seed by acting as a buffer through a combine, however this did not significantly increase yields. Along with its weedy nature of interfering with crop growth and yield production glyphosate-resistant Palmer amaranth accessions have been discovered in Georgia (Culpepper et al. 2006). Stands were able to survive three times the normal use rate of glyphosate with only 17% control (Culpepper et al. 2006). With its intrusive nature and accessions that are herbicide resistant, methods other than chemical control need to be researched for Palmer amaranth control.

Kochia (*Kochia scoparia*) is an annual C4 broadleaf plant that is well adapted to arid conditions (Nord et al. 1999). Kochia is an early emerging weed in spring and has a high water use, which makes the weed fiercely competitive with winter wheat in the spring (Schwinghamer and Van Acker 2008). Kochia has been reported to cause yield losses as great as 58% in spring wheat at densities of 75 kochia plants/m^2 (Dahl et al. 1994). Water use by kochia during the fallow phase of the rotation can also deplete stored soil reservoirs of water. If allowed to grow to seed, the fecundity of kochia can reach 14,000 seeds per plant (Thill et al. 1991). However, seed burial and a naturally short survival time with little dormancy can deplete kochia seed in the seedbank (Schwinghamer and Van Acker 2008). In addition to its competitive nature and water use kochia accessions can be resistant to many classes of herbicides including growth regulators, sulfonylureas, and imidazolinones (Bell et al. 1972, Primiani et al. 1990). Kochia is responsive to crop competition. Fischer et al. (2000) found several kochia accessions responded to wheat and barley canopies with a decrease in dry biomass ranging from 75 to 90%. Therefore the potential exists to reduce kochia growth with a competitive cover crop.

Downy brome (*Bromus tectorum*) is a winter annual grass that infests many winter annual crops including wheat (Stubbendieck et al. 2003). Downy brome can cause wheat yield losses ranging from 9 to 41% depending on the severity of the infestation (Challaiah et al. 1986). Not only can downy brome decrease yield through competition with wheat but it also can play a role in wheat pest lifecycles. Perez-Mendoza et al. (2006) found that wheat stem sawfly populations were sustained and two-fold higher on downy brome in a wheat field. Management of downy brome in wheat is limited by the availability of few effective herbicides and the ability of downy brome seed to stay dormant for up to six years (Schillinger et al. 2007, Swan and Whitesides 1988). However downy brome does respond to cultural methods for control. Blackshaw (2004) found that nitrogen placement in bands rather than broadcast reduced both downy brome density and biomass. A rotation between several cereal grain crops and yellow mustard with winter wheat reduced downy brome densities as well (Blackshaw 1994),

Cover Crop and Weed Interactions

The introduction of cover crops into the fallow phase of a rotation can greatly affect the dynamics of a weed community or population. Cover crops can impose fitness and mortality events upon weeds that would not normally occur during a fallow phase. These events can shape the community structure by selecting weed species that are capable of dealing with the selective pressures (Gallandt et al. 2005, Moonen and Barberi 2004, Reddy 2001, Teasdale et al. 2005).

The ecologically fit weeds that emerge represent a small portion of the diverse community that existed before cover crop implementation (Barberi and Mazzoncini 2001). Selection of weed species can be exacerbated by other control factors imposed on the system including herbicide use and tillage (Davis et al. 2005, Ngouajio et al. 2003). A weed community dominated by very few or even a single weed species possesses a greater risk of containing competitive weeds or even weed biotypes that are resistant to herbicides (Derksen et al. 2002, Dyck et al. 1995). Cover crops can also reduce the density of weeds found in the seedbank or emerged in a given area (Anderson 1999, Moonen and Barberi 2004, Williams II et al. 1998). This reduction in density can favor crop growth resulting in increased crop yields (Carrera et al. 2004). Similar interactions occur between cover crops and individual weed population densities (Reddy 2001).

Cover crops influences weed community and population dynamics by acting upon key events in the weed lifecycle. Cover crops impose selective pressures on the weed seedbank, weed seed germination, emergence from the seedbank, and weed biomass accumulation (Dyck et al. 1995, Facelli and Pickett 1991a, Norsworthy et al. 2007).

Cover Crop Effects on the Weed Seedbank

Cover crops can decrease the potential of a weed seed to enter and persist in the seedbank. Presence of a cover crop can reduce seed production and therefore the amount of seed rain that may occur (Anderson 1997). Viable seed that does fall can be blocked from reaching the soil surface by cover crop residue (Facelli and Pickett 1991a). Residue prevented musk thistle seed from reaching the soil surface and reduced its potential to enter the seedbank (Hamrick and Lee 1987). Seeds trapped by residues on the soil's surface are subject to increased seed predation compared to bare soil (Cardina et al. 1996, Teasdale et al. 2005). The optimal habitat for predators provided by cover crops and their residues led to seed losses of 56 and 58% of small weed seeds like pigweeds on the soil surface in a two-year study (Teasdale et al. 2005). Through these and other selective pressures cover crops can reduce the density and distribution of seeds in a seedbank (Moonen and Barberi 2004).

Cover Crop Effects on Weed Seed Germination and Emergence

Weed seed germination can be influenced by many factors including the presence of water, nitrogen, light, and soil temperature (Gallagher and Cardina 1998, Moonen and Barberi

2004, Steckel et al. 2004, Taylorson and Hendricks 1969). Cover crops have the potential to limit all of these factors. Cover crop residue on the soil surface can increase soil water availability by blocking solar radiation and buffering temperatures that can increase evaporation (Facelli and Picket 1991b). The water retained by cover crop residue can potentially increase the ability of a weed seed to germinate (Facelli and Picket 1991a). Nitrogen has the potential to both suppress and intensify weed seed germination depending on the species (Moonen and Barberi 2004). Cover crops can both increase and decrease nitrogen levels in the soil by introducing nitrogen through fixation or by removal through immobilization in residues (Al-Khatib and Boydston 1997, Leikam 2007). Dyck et al. (1995) found that plant-available nitrogen at planting was reduced 52% by the previous crimson clover cover crop, however that nitrogen was returned to the system later in the growing season. Cover crops and their residues can also block the transmittance of light to the soil surface (Facelli and Picket 1991b, Teasdale and Mohler 1993). This can affect the ability of seeds to germinate that belong to light sensitive species (Facelli and Picket 1991, Taylorson and Hendricks 1969). Finally cover crops and their residues moderate soil temperatures by buffering the effects of atmospheric temperatures and solar radiation (Facelli and Picket 1991). Teasdale (1993) found that residues can reduce soil temperature and the amplitude of temperature change. The resulting cooler temperatures could inhibit or delay seed germination (Steckel et al. 2004).

Cover crops can affect the emergence patterns of weeds in many ways including reducing the number of emerged seedlings, delaying emergence, and even increasing the susceptibility of emerged seedlings to control measures (Haramoto and Gallandt 2005b, Norsworthy et al. 2007, Teasdale et al. 2005). Cover crops alter the soil environment of the weed seed preventing germination and reducing the number of seedlings that emerge (Mohler and Calloway 1992). The reduction in emergence depends on the cover crop and weed species, but could be reduced greatly, anywhere from 37 to 79% for Palmer amaranth emerging after a *Brassica* crop (Norsworthy et al. (2007) or by 19 to 39% for redroot pigweed emerging after a *Brassica* cover crop (Haramoto and Gallandt 2005a). Haramoto and Gallandt (2005a) also found that cover crops delayed the emergence of several weed species. Teasdale et al. (2005) and Crutchfield et al. (1986) found that crop residue increased the susceptibility of emerging weed seedlings to herbicides. This was attributed to depletion of the weeds' carbohydrates stores while trying to break through residues left by cover crops (Teasdale et al. 2005). The seedlings were not able to replenish their carbohydrate reserves since the residue blocked light transmittance leaving the seedlings unable to fix carbon through photosynthesis (Teasdale et al. 2006).

Cover Crop Effects on Weed Biomass

Cover crops have varying effects on weed biomass accumulation. Reductions in early season weed densities do not necessarily limit weed biomass accumulation. Several researchers reported that cover crops can negatively influence weed biomass. Dyck et al. (1995) found that nitrogen immobilization by cover crop residues limited common lambsquarters dry matter accumulation throughout the season without impacting corn yields. Fisk et al. (2001) found similar results with weed biomass being reduced 27 to 60% by the presence of leguminous cover crops. In a study of integrated weed management (IWM) techniques in a spring wheat – oilseed crop rotation Blackshaw et al. (2005) found that early planting of crops paired with a preplant herbicide application and increased seeding rates of crops reduced weed biomass over four years. Isik et al. (2009) found that cover crops can suppress weed biomass in both living and residue forms. They found that hairy vetch, ryegrass, common vetch, and oat cover crops reduced weed biomass from 87 to 91% over a two-year experiment. Once the cover crops were terminated their residues reduced weed biomass for 14 days after incorporation.

Limitations of Weed Suppression by Cover Crops

Cover crops, although sometimes effective, are limited in their ability to control weeds. One of the major limitations of cover crops is the variation of suppression effects (Reddy 2001, Swanton et al. 1999). Several explanations are proposed including weed fitness to cropping systems, crop residue degradation and the need for minimum levels of crop residues to limit weed growth (Derksen et al. 2002, Moonen and Barberi 2004, Teasdale and Mohler 1993, Williams II 1998). Moonen and Barberi (2004) found rye was more effective than subterranean clover at suppressing weeds in a tillage system; however it was less effective than subterranean clover in a no-till system. Derksen et al. (2002) reported that a minimum of 3000 kg/ha of cover crop residue was needed for weed control. Ineffectiveness of cover crop species to control weeds may be related to the amount of time residues take to degrade. Teasdale and Mohler (1993) found that hairy vetch residue decomposed more quickly than rye residue allowing increased light transmittance to the soil surface that may increase weed emergence.

Length of control is the second major limitation to cover crop weed suppression. Cover crops were reported to depress weed emergence from 21 to 42 days after planting (Norsworthy et al. 2007, Williams et al. 1998). Weed control by cover crops decreases as plants are terminated and residues break down (Barberi and Mazzoncini 2001, Teasdale and Molher 1993). Barberi and Mazzoncini (2001) found that weed suppression by cover crops was sufficient until the later growth stages of corn. Norsworthy et al. (2007) found that weed suppression by cover crops was insufficient for full season weed control. The lack of late season weed control may require a late season weed mortality event such as an herbicide application.

Implications of Cover Crop Weed Management

In general cover crops potentially can decrease the emergence and density of weed species occurring during the fallow period after winter wheat compared to no-cover fallow. The extent of weed suppression will depend on the amount of cover crop biomass produced, the amount of nitrogen produced by the cover crops that is available to the weeds, and the fitness of the weed species to the cropping system. The objective of this research was to quantify how the addition of cover crops to common crop rotations in Kansas impacts the emergence, density, and biomass production of problem weed species. Experiments were conducted in the various climate regions of Kansas. A cover cropping study in arid Garden City had the objectives to (1) quantify the response of kochia density and biomass accumulation to an intensified winter wheat-cover crop rotation compared to a winter wheat-fallow rotation, (2) quantify the response of downy brome biomass accumulation to the intensification of the rotation, and (3) measure weed mortality in response to herbicide treatments in standing cover crops. A cover cropping study in the more arable region near Manhattan had the objectives to (1) examine the response of Palmer amaranth density, biomass, and fecundity to direct competition of cover crops and herbicide management and (2) determine the residual effects of herbicide and cover crop treatments on Palmer amaranth emergence and growth in the following grain sorghum crop. A final study with multiple locations throughout the state was established to (1) monitor the response of Palmer amaranth emergence and biomass production to different forage soybean seeding rates after winter wheat harvest, (2) monitor the growing environment by measuring light availability at the soil surface, and (3) determine if forage soybean seeding rate and termination method affect downy brome emergence in the fall. This research will aid producers in selecting competitive cover crops that will successfully suppress weeds as part of an IWM plan.

References

Aamodt, O. S. 1943. The seed situation and the war. American Society of Agronomy Journal. 35:85-100.

Al-Khatib, K., C. Libbey, and R. Boydston. 1997. Weed suppression with *Brassica* green manure crops in green pea. Weed Science 45:439-445.

Allen, R. L. 1852. The American farm book or a compend of American agriculture. C.M. Saxton and Company: New York.

Anderson, R. L. 1997. Cultural systems can reduce reproductive potential of winter annual grasses. Weed Technology 11:608-613.

Anderson, R. L. 1999. Cultural strategies to reduce weed densities in summer annual crops. Weed Technology 13:314-319.

Barberi, P. and M. Mazzoncini. 2001. Changes in weed community composition as influenced by cover crop and management system in continuous corn. Weed Science 49:491-499

Bell, A. R., J. D. Nalewaja, and A. B. Scoder. 1972. Response of kochia to selections of 2,4-D, dicamba, and picloram. Weed Science 20:458-462.

Blackshaw, R. E. 1994. Rotation affects downy brome (*Bromus tectorum*) in winter wheat (*Triticum aestivum*). Weed Technology 8:728-732.

Blackshaw, R. E. 2004. Application method of nitrogen fertilizer affects weed growth and competition with winter wheat. Weed Biology and Management 4:103-113.

Blackshaw, R. E., H. J. Beckie, L. J. Molnar, T. Entz, and J. R. Moyer. 2005. Combining agronomic practices and herbicides improves weed management in wheat-canola rotations within zero-tillage production systems. Weed Science 53:528-535.

Bond, J. A. and L. R. Oliver. 2006. Comparative growth of Palmer amaranth (*Amaranthus palmeri*) accessions. Weed Science 54:121-126.

Cardina, J., H. M. Norquay, B. R. Stinner, and D. A. McCartney. 1996. Postdispersal predation of velvetleaf (*Abutilon theophrasti*) seeds. Weed Science 44:534-539.

Carrera, L. M., A. A. Abdul-Baki, and J. R. Teasdale. 2004. Cover crop management and weed suppression in no-tillage sweet corn production. Hort. Science 39:1262-1266.

Challaiah, O. C. Burnside, G. A. Wicks, and V. A. Johnson. 1986. Competition between winter wheat (*Triticum aestivum*) cultivars and downy brome (*Bromus tectorum*). Weed Science 34:689-693.

Clark, A.J., A. M. Decker, J. J. Meisinger, F. R. Mulford, and M. S. McIntosh. 1995. Hairy vetch kill date effects on soil water and corn production. Agronomy Journal 87:579-585.

Crutchfield, D. A., G. A. Wicks, and O. C. Burnside. 1986. Effect of winter wheat (*Triticum aestivum*) straw mulch level on weed control. Weed Science 34.110-114.

Culpepper, A. S., T. L. Grey, W. K. Vencill, J. M. Kichler, and T. M. Webster. 2006. Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) confirmed in Georgia. Weed Science 54:620-626.

Dabney, S. M. 1998. Cover crop impacts on watershed hydrology. Journal of Soil and Water Conservation 53:207-213.

Dahl, G. K., A. G. Dexter, and J. D. Nalewaja. 1994. Kochia competition and control in wheat. Proc. NCWSS volume: 15-16.

Davis, A.S., K. A. Renner, and K. L. Gross. 2005. Weed seedbank and community shifts in a long-term cropping systems experiment. Weed Science 53:296-306.

Defelice, M. S., W. B. Brown, R. J. Aldrich, B. D. Sims, D. T. Judy, and D. R. Guethle. 1989. Weed control in soybeans (*Glycine max*) with reduced rates of postemergence herbicides. Weed Science 37:365-374.

Derksen, D.A., R. L. Anderson, R. E. Blackshaw, and B. Maxwell. 2002. Weed dynamics and management strategies for cropping systems in the Northern Great Plains. Agronomy Journal 94:174-185.

Dyck, E., M. Liebman, and M. S. Erich. 1995. Crop-weed interference as influenced by a leguminous or synthetic fertilizer nitrogen source: I. Doublecropping experiments with crimson clover, sweet corn, and lambsquarters. Agriculture, Ecosystems and Environment 56:93-108.

Elheringer, J. 1983. Ecophysiology of *Amaranthus palmeri*, a Sonoran Desert summer annual. Oceologia 57:107-112.

Facelli, J. and M. Picket. 1991a. Plant litter: Its dynamics and effects on plant community structure. The Botanical Review 57:1-32.

Facelli, J. and M. Picket. 1991b. Plant litter: Light interception and effects on an old-field plant community. Ecology 72:1024-1031.

Fischer, A. J., C. G. Messersmith, and J. D. Nalewaja. 2000. Interference between spring cereals and *Kochia scoparia* related to environment and photosynthetic pathways. Agronomy Journal 92:173-181

Fisk, J. W., O. B. Hesterman, Shrestha, J. J. Kells, R. R. Harwood, J. M. Squire, and C. C. Sheaffer. 2001. Weed suppression by annual legume cover crops in no-tillage corn. Agronomy Journal 93:319-325.

Gallagher, R. S. and J. Cardina. 1998. Phytochrome-mediated *Amaranthus* germination I: effect of seed burial and germination temperature. Weed Science 46:48-52.

Gallandt, E. R., T. Molloy, R. P. Lynch, and F. A. Drummond. 2005. Effect of cover-cropping systems on invertebrate seed predation. Weed Science 53:69-76.

Gross, K. L. and K. A. Renner. 1989. A new method for estimating seed numbers in soil. Weed Science 37:836-839.

Haas, H. J., W. O. Willis, and J. J. Bond. 1974. Summer fallow in the Western United States. USDA-ARS Conservation Res. Rep. 17. U.S. Government Print Office. Washington, DC.

Hamrick, J. L. and J. M. Lee. 1987. Effects of soil surface topography and litter cover on germination, survival, and growth of musk thistle. American Journal of Botany 74:451-457.

Haramoto, E.R. and E. R. Gallandt. 2005a. Brassica cover cropping I: Effects on weed and crop establishment. Weed Science 53:695-701.

Haramoto, E. R. and E. R. Gallandt. 2005b. Brassica cover cropping II: Effects on growth and interference of green bean (*Phaseolus vulgaris*) and redroot pigweed (*Amaranthus retroflexus*). Weed Science 53:702-708.

Hartwig, N. L. and H. U. Ammon. 2002. Cover crops and living mulches. Weed Science 50:688-699.

Hinze, G.O. and D. E. Smika. 1983. Cropping practices: Central Great Plains. Pages 387-395 in: H.E. Dregne and W.O. Willis (ed.) Dryland Agriculture. Agronomy Monogr. 23. ASA, CSSAA, and SSSA. Madison, WI.

Isik, D., W. Kaya, M. Ngouajio, and H. Mennan. 2009. Weed suppression in organic pepper (*Capsicum annuum* L.) with winter cover crops. Crop Protection 28:356-363.

Keely, P. E., C. H. Carter, and R. J. Thullen. 1987. Influence of planting date on growth of Palmer amaranth (*Amaranthus palmeri*). Weed Science 35:199-204.

Klingaman, T.E. and L. R. Oliver. 1994. Palmer amaranth (*Amaranthus palmeri*) interference in soybean (*Glycine max*). Weed Science 42:523-527.

Leikam, D., R. E. Lamond, L. C. Banczkowski, J. S. Hickman, and D. A. Whitney. 2007. Using legumes in crop rotations. Publication L-778 Cooperative Extension Service, Kansas State University, Manhattan, KS.

Masin, R., M. C. Zuin, S. Otto, and G. Zanin. 2006. Seed longevity and dormancy of four summer annual grass weeds in turf. Weed Research 46:362-370.

Massinga, R.A., R. S. Currie, M. J. Horak, and J. Boyer Jr. 2001. Interference of Palmer amaranth in corn. Weed Science 49:202-208.

McKnee, R. 1931. Austrian winter pea has superior value as a green manure crop. Yearbook of Agriculture 1931:104-106.

McVay, K. A., D. E. Radcliffe, and W. L. Hargrove. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. Soil Science Society of America Journal 53:1856-1862.

Mohler, C. L. and M. B. Calloway. 1992. Effects of tillage and mulch on the emergence and survival of weeds in sweet corn. Journal of Applied Ecology 29:21-34.

Moonen, A. C. and P. Barberi. 2004. Size and composition of the weed seedbank after 7 years of different cover-crop-maize management systems. Weed Research 44:163-177.

Moore, J. W., D. S. Murray, and R. B. Westerman. 2004. Palmer amaranth (*Amaranthus palmeri*) effects on the harvest and yield of grain sorghum (*Sorghum bicolor*). Weed Technology 18:23-29.

NCDC (National Climatic Data Center). 2007. Historical Climate Data. [Online]. Available from: http://hprcc.unl.edu/. Accessed January 17, 2008.

Ngouajio, M., M. E. McGiffen Jr, and C. M. Hutchinson. 2003. Effect of cover crop and management system on weed populations in lettuce. Crop Production 22:57-64.

Nielsen, D. C. and M. F. Vigil. 2005. Legume green fallow effect on soil water content at wheat planting and wheat yield. Agronomy Journal 97:684-689.

Nielsen, D. C., M. F. Vigil, and J. G. Benjamin. 2006. Forage yield response to water use for dryland corn, millet, and triticale in the central Great Plains. Agronomy Journal 98:992-998.

Nord, C. A., C. G. Messersmith, and J. D. Nalewaja. 1999. Growth of *Kochia scoparia*, *Salsola iberica*, and *Triticum aestivum* varies with temperature. Weed Science 47:435-439.

Norsworthy, J. K., M. S. Malik, P. Jha, and M. B. Riley. 2007. Suppression of *Digitaria sanguinalis* and *Amaranthus palmeri* using autumn-sown glucosinolate-producing cover crops in organically grown bell pepper. Weed Research 47:425-432.

Paine, K. J. and H. Harrison. 1993. The historical roots of living mulch and related practices. HortTechnology 3:136-142.

Perez-Mendoza, J., D. K. Weaver, and W. L. Morrill. 2006. Infestation of wheat and downy brome grass by wheat stem sawfly and subsequent larval performance. Environmental Entomology 35:1279-1285.

Pieters, A. J. 1927. Green manuring, principles and practice. Wiley: New York.

Primiani, M. M., J. C. Cotterman, and L. L. Saari. 1990. Resistance of kochia (*Kochia scoparia*) to sulfonylurea and imidazolinone herbicides. Weed Technology 4:169-172.

Reddy, K. N. 2001. Effects of cereal and legume cover crops residues on weeds, yield, and net return in soybean (*Glycine max*). Weed Technology 15:660-668.

Schlegel, A. J. and J. L. Havlin. 1997. Green fallow for the Central Great Plains. Agronomy Journal 89:762-767.

Schillinger, W. F., A. C. Kennedy, and D. L. Young. 2007. Eight years of annual no-till cropping in Washington’s winter wheat-summer fallow region. Agriculture, Ecosystems and Environment 120:345-358.

Schwinghamer, T. D. and R. C. Van Acker. 2008. Emergence timing and persistence of kochia (*Kochia scoparia*). Weed Science 56:37-41.

Shroyer, J., H. Kok, and D. Fjell. 1998. Seedbed preparation and planting practices. P. 5-10. Grain Sorghum Production Handbook. Kansas State University Publication C-687. Cooperative Extension Service, Kansas State University, Manhattan, KS.

Steckel, L. W., C. L. Sprague, E. W. Stoller, and L. M. Wax. 2004. Temperature effects on germination of nine *Amaranthus* species. Weed Science 52:217-221.

Stone, L. R. and A. J. Schlegel. 2006. Yield-water supply relationships of grains sorghum and winter wheat. Agronomy Journal 98:1359-1366.

Stubbendieck, J., M. J. Coffin, and L. M. Landholt. 2003. Weeds of the Great Plains. Nebraska Department of Agriculture. Lincoln, Nebraska.

Swan, D. G. and R. E. Whitesides. 1988. Downy brome (*Bromus tectorum*) control in wheat. Weed Technology 2:481-485.

Swanton, C. J., A. Shrestha, R. C. Roy, B. R. Ball-Coelho, and S. Z. Knezevic. 1999. Effect of tillage systems, N, and cover crop on the composition of weed flora. Weed Science 47:454-461.

Sweeney, D. W. and J. L. Moyer. 1994. Legume green manures and conservation tillage for grain sorghum production on prairie soil. Soil Science Society of America Journal 58:1518-1524.

Taylorson, R. B. and S. B. Hendricks. 1969. Action of phytochrome during prechilling of *Amaranthus retroflexus* L. seeds. Plant Physiology 44:821-825.

Teasdale, J. R. and C. L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agronomy Journal 85: 673-680.

Teasdale, J. R. and P. Pillai, R. T. Collins. 2005. Synergism between cover crop residue and herbicide activity on emergence and early growth of weeds. Weed Science 53:521-527.

Thill, D., C. Mallory-Smith, L. Saari, J. Cotterman, M. Primiani, and J. Saladini. 1991. Sulfonylurea herbicide resistant weeds: Discovery, distribution, biology, mechanism, and management. Pages 115–128 in J. Caseley, G. Cussans, and R. Atkin, eds. Herbicide Resistance in Weeds and Crops. Oxford, UK:Butterworth-Heinemann.

Troeh, F. R., J. A. Hobbs, and R. L. Donahue. 2004. Soil and water conservation for productivity and environmental protection. Fourth Edition. Pearson Education. Upper Saddle River, New Jersey.

Unger, P. W. 1988. Grain and forage sorghum production with no-tillage on dryland. Agronomy Journal 80:193-197.

Vencill, W. K. and P. A. Banks. 1984. Effects of tillage systems and weed management on weed populations in grain sorghum (*Sorghum bicolor*). Weed Science 42:541-547.

Weston, L. A. 2005. History and current trends in the use of allelopathy for weed management. HortTechnology 15:529-534.

Williams II, M. M., D. A. Mortensen, and J. W. Doran. 1998. Assessment of weed and crop fitness in cover crop residues for integrated weed management. Weed Science 46:595-603.

CHAPTER 2 - Response of kochia and downy brome to cover cropping

Abstract

Cover crops possess the ability to affect key points in weed lifecycles, reducing emergence and growth. Field experiments were conducted during the 2007-2008 and 2008-2009 growing season at the Kansas State University Southwest Research and Extension Center in Garden City, KS. The objectives were to quantify kochia or downy brome density and biomass accumulation in response to an intensified winter wheat-cover crop rotation compared to a winter wheat-fallow rotation, and to measure weed mortality in response to herbicide in standing cover crops. The experiment was a split-plot design with winter wheat and fallow phases as main plots, eleven cover crops and a no cover control treatment as subplots and cover crop termination method as sub-subplots. Cover crops were grouped into five fall-sown, including Austrian winter pea (*Lathyrus hirsutus*), hairy vetch (*Vicia villosa subsp. Villosa*), winter triticale (*Triticale hexaploide*) and two mixtures of winter triticale and each legume and five spring-sown, including spring pea (*Pisum sativum*), lentil (*Lens culinaris*), spring triticale (*Triticale hexaploide*) and two mixtures of a legume and spring triticale. Kochia density was reduced by fall-sown cover crops compared to the no cover control because the kochia emerged after the fall-sown cover crops began to establish canopies. No kochia density response to the spring-sown cover crops was observed. Kochia biomass was reduced by fall-sown cover crops compared to the no cover control in both years. In the 2008-2009 growing season kochia emergence was delayed and two spring sown cover crop mixtures reduced kochia biomass. Kochia density and biomass were negatively affected by increasing cover crop biomass in the fall-sown cover crops. The 2008-2009 growing season was confounded by volunteer wheat that resulted from a hailstorm prior to winter wheat harvest in the 2007-2008 growing season. Volunteer wheat supplemented cover crop biomass and together the two reduced the proportion of downy brome biomass produced. Across all treatments cover crop mixtures consistently produced the most biomass and caused the greatest reduction in weed density and biomass compared to single species cover crops. The information gathered in this study will be used as a part of a decision matrix for selecting cover crops for Kansas.

Introduction

Cover crops possess the ability to suppress both weed emergence and biomass accumulation during the fallow periods of many rotations. Cover crops can reduce the number of emerged seedlings, delay emergence, and even increase the susceptibility of emerged seedlings to control measures (Haramoto and Gallandt 2005a, Norsworthy et al. 2007, Teasdale et al. 2005). Isik et al. (2009) found that cover crops can suppress weed biomass in both living and residue forms. They found hairy vetch (*Vicia villosa*), ryegrass (*Lolium multiflorum*), common vetch (*Vicia villosa*), and oat (*Avena sativa*) cover crops reduced weed biomass from 87 to 91% over a two year experiment, and once the cover crops were terminated their residues reduced weed biomass for 14 days after incorporation. Early planting and establishment of the cover crops in April provided better control of weeds compared to planting a month later in May (Isik et al. 2009). Residues left by the cover crops increased the susceptibility of emerging weed seedlings to herbicides (Crutchfield et al.1986, Teasdale et al. 2005). Depletion of the weeds' carbohydrate stores while trying to break through residues left by cover crops explained this (Teasdale et al. 2005). The seedlings were not able to replenish their carbohydrate reserves since the residue blocked light transmittance leaving the seedlings unable to fix carbon through photosynthesis (Teasdale et al. 2005). Therefore weeds in competition with the cover crops and their residues during the fallow phase may be more susceptible to herbicide applications.

The wheat-fallow rotation was developed in arid regions to stabilize yields (Haas et al. 1974, Hinze and Smika 1983). Nielsen and Vigil (2005) found that the growth of a leguminous cover crop in the fallow portion of a conventionally tilled winter wheat–fallow rotation in Akron, CO negatively impacted the following winter wheat crop by depleting the soil water available at planting by 55 to 105 mm. Winter wheat yields following the cover crop averaged 67% of the winter wheat yields of the conventional winter wheat–fallow rotation. The range of soil water depletion at winter wheat planting came from delay in termination date of the cover crop. A linear correlation was observed between the delay in termination date and the decrease in available soil water for the following winter wheat crop. Akron, CO averages 100 mm of precipitation less than Garden City, KS. The adoption of no-till practices could conserve up to 43 mm of soil-stored water compared to conventional tillage. The replacement of mechanical tillage for weed control during the 14 month fallow periods used to build soil water in the winter wheat-fallow rotation common to southwest Kansas leaves producers heavily dependent upon herbicides for weed control and potentially selecting herbicide-resistant weeds (Stone and Schlegel 2006).

Kochia (*Kochia scoparia*) is a problem weed in dryland winter wheat-fallow conditions. Kochia is an annual broadleaf plant that is well adapted to the arid conditions of southwest Kansas (Nord et al. 1999). Kochia is an early spring emerging weed and its prodigious water use makes the weed fiercely competitive with winter wheat in the spring (Schwinghamer and Van Acker 2008). Kochia has been reported to cause yield losses as great as 58% in spring wheat at densities of 75 kochia plants/m^2 (Dahl et al. 1994). Water use by kochia during the fallow phase of the rotation can also deplete stored soil moisture reserves. Therefore, it is important to control kochia in both the winter wheat and fallow phases of the rotation. Control of kochia is further confounded by biotypes identified as resistant to glyphosate, dicamba, and ALS herbicides commonly used in winter wheat production and fallow control (Bell et al. 1972, Primiani et al. 1990, Waite and Al-Khatib 2009). Kochia does respond to cultural control through crop competition. Fischer et al. (2000) found that several kochia accessions responded to winter wheat and barley canopies with a decrease in dry biomass ranging from 75 to 90%. Therefore the potential exists to reduce kochia growth with a competitive cover crop.

Downy brome (*Bromus tectorum*) is a winter annual grass that infests many winter annual crops including winter wheat (Stubbendieck et al 2003). Downy brome can cause winter wheat yield losses ranging from 9 to 41% depending upon the severity of the infestation (Challaiah et al. 1986). Not only can downy brome decrease yield through competition with winter wheat but it also can play a role in winter wheat pest lifecycles. Perez-Mendoza et al. (2006) found that wheat stem sawfly populations were sustained by downy brome in a winter wheat field. Management of downy brome in winter wheat is limited by the availability of few effective herbicides and the ability of downy brome seed to stay dormant for up to six years (Schillinger et al. 2007, Swan and Whitesides 1988). Downy brome does respond to cultural methods for control. Blackshaw (2004) found that nitrogen placement in bands rather than broadcast reduced both downy brome density and biomass. Crop rotation among several cereal grains and yellow mustard with winter wheat reduced downy brome density (Blackshaw 1994). Both downy brome and kochia show responses to the inclusion of cultural practices like cover cropping to supplement chemical and physical control. Therefore the inclusion of a cover crop in the no-till winter wheat-fallow rotation in Garden City, KS with an early spring termination date may impact problem weed lifecycles without decreasing the yield of the following winter wheat crop and improve the effectiveness of herbicides on problem weeds.

The objectives of this study were to (1) quantify cover crop biomass accumulation, (2) quantify the response of kochia density and biomass accumulation to an intensified winter wheat-cover crop rotation compared to a wheat-fallow rotation, (3) quantify the response of downy brome biomass to the intensification of the rotation, and (4) measure mortality of weeds to herbicide treatments in standing cover crops.

Materials and Methods

In the fall of 2006 a long-term experiment was established at the Kansas State University Southwest Research and Extension Center, Garden City, KS, to assess the viability of including cover crops in the fallow phase of a no-tillage winter wheat-fallow rotation system. In the 2007-2008 and 2008-2009 growing seasons, field experiments were conducted to determine the response of kochia and downy brome to cover cropping. The long-term experiment was established on a field with Ulysses silt loam and Ulysses-Colby silt loam soils with a pH of 7.7 and 1.5% organic matter.

Main plots were 137 m by 41 m and were winter wheat or fallow phases of the crop rotation. In the fallow phase eleven cover crop treatments were established in subplots 9 m by 41 m. Treatments included five fall and five spring sown cover crops drilled on 0.25 -m row spacing, and a no-cover control (chemical fallow). Fall-sown cover crops were winter triticale (WT) planted at 71 kg seed/ha, Austrian winter pea (AWP) sown at 109 kg seed/ha, hairy vetch (V) sown at 28 kg seed/ha, mixture of Austrian winter pea-winter triticale (AWP-WT) sown at the ratio of 21/53 kg seed/ha, and mixture of hairy vetch-winter triticale (V-WT) sown at 82/53 kg seed/ha. Spring-sown cover crops were spring triticale (ST) sown at 85 kg seed/ha, spring pea (SP) sown at 134 kg seed/ha, spring lentil (L) sown at 28 kg seed/ha and mixtures of spring pea-spring triticale (SP-ST) sown at 101/64 kg seed/ha and spring lentil-spring triticale (L-ST) sown at 21/64 kg seed/ha. Fall cover crops were sown on October 3, 2007 and October 3, 2008 and spring cover crops were sown on March 8, 2008 and March 9, 2009.

Each subplot was split lengthwise by termination method, either forage harvest or chemical termination. A 1-m^2 quadrat of kochia was sown into each sub-subplot at 500 seeds/m^2 on March 11, 2008 and March 14, 2009. Downy brome was sown at 500 seeds/m^2 on October 18, 2008. The quadrats in the forage harvest sub-subplots were used to gather weed density and biomass information while the quadrats in the chemical termination sub-subplots were used to gather information on weed mortality caused by cover crop termination with glyphosate applied at 408 g ae/ha. Quadrats were monitored over the growing season for weed density, end of season weed and cover crop biomass, and weed mortality. Weed free biomass estimates were obtained with a self propelled forage harvester with a 1 m swath width. Two passes were made lengthwise in each forage harvest sub-subplot. Sub-samples were taken from each forage sample and dried at 60 C for 48 hours to obtain percent moisture reduction.

Early season kochia density was recorded on April 28, 2008 for each quadrat in every treatment. An early season observation was not completed in 2009 because of delayed kochia emergence resulting in no plants to count in the last week of April. End of season kochia density counts were taken on May 13, 2008 and May 13, 2009 for the quadrats in the fall-sown cover crops and May 28, 2008 and May 28, 2009 for the quadrats in the spring-sown cover crops. All quadrats in each subplot of either fall- or spring-sown cover crops were counted on their respective dates. Density information from the forage harvest termination sub-subplot was used to quantify the response of kochia density to cover crop. Density information from the chemical termination sub-subplots was used to quantify weed mortality to herbicide termination. Kochia and downy brome densities from the chemical termination quadrats obtained at harvest of fall-sown and spring-sown cover crops were obtained prior to glyphosate application at 408 g ae/ha on June 3, 2008, May 21, 2009, and June 2, 2009. Follow up counts were taken in the chemical termination quadrats on June 26, 2008 and June 23, 2009. Percent weed mortality was calculated as the difference in density before and several weeks after herbicide application.

Kochia and cover crop end of season biomass were determined by destructive hand harvesting of quadrats in the forage harvest sub-subplots. Harvest occurred on the same dates as end of season kochia density measurements. Kochia and cover crop plant parts were bagged separately for each quadrat and dried at 60 C for 48 hours and weighed.

Downy brome density was determined on May 13, 2009 and May 28, 2009 in the chemical termination sub-subplot. Downy brome harvest was handled similarly to kochia harvest but quadrat harvest was confounded by the presence of volunteer wheat. The 2007-2008 winter wheat crop suffered a loss to hail damage on June 28, 2008. Much of this lodged wheat emerged in the 2008-2009 growing season as volunteer wheat mixed in the cover crops. Volunteer wheat was controlled in the fall of 2008 with an application of clethodim at 45 g ai/ha. Downy brome plots were covered during the application to prevent damage. In 2009 downy brome quadrats were harvested by hand and downy brome, cover crop, and volunteer wheat were bagged separately per quadrat. Samples were dried at 60 C for 48 hours and weighed.

The cover crop, kochia, and downy brome biomass, kochia density, and weed mortality data were analyzed using Proc Mixed in SAS v9.13. Least-squared means estimates, least-squared standard errors, and pairwise comparisons were generated using Proc Mixed. In the data analysis of the downy brome quadrats volunteer winter wheat dry biomass was combined with cover crop dry biomass. Differences in the establishment of the cover crop compared to the weed species led to fall- and spring-sown cover crop biomass and weed responses to be analyzed separately.

Reduction of kochia density in each cover crop subplot was expressed as a proportion of kochia density in the chemical fallow treatment computed as:

$$D_{ri} = [(D_f - D_i)/D_f] \qquad \text{Equation 2.1}$$

where D_{ri} is reduction in kochia density for each subplot, D_f is the average density across chemical fallow treatments, and D_i is the density at the i^{th} subplot. This was done separately for fall- and spring-sown cover crops in each growing season. Data for each year was plotted separately as the reduction of kochia density compared to fallow against cover crop biomass using Sigma-Plot 10.0 software and a rectangular hyperbola model (Cousens 1985) was fit to the data:

$$D_r = (I*X)/[1 + ((I*X)/A)] \qquad \text{Equation 2.2}$$

where D_r is the reduction of kochia density compared to fallow, I is the initial slope of kochia density reduction as cover crop biomass (X) approaches 0, and A is the maximum reduction of kochia density compared to fallow as cover crop biomass approaches infinity.

Reduction of kochia biomass in each cover crop subplot relative to kochia biomass in the chemical fallow treatment was calculated similarly to reduction in kochia density. Data were plotted as the proportional reduction of kochia biomass compared to no-cover chemical fallow against cover crop biomass using Sigma-Plot 10.0 software and the rectangular hyperbola model (Cousens 1985) was fit to the data:

$$B_r = (I*X)/[1 +((I*X)/A)] \qquad \text{Equation 2.3}$$

where B_r is the proportional reduction of kochia biomass compared to no-cover chemical fallow, I is the initial slope of kochia biomass reduction as cover crop biomass (X) approaches 0, and A is the maximum reduction of kochia biomass compared to fallow as cover crop biomass approaches infinity.

The response of downy brome biomass to cover crop biomass in the 2008-2009 growing season was determined by converting downy brome biomass to a proportion of total plot biomass and graphed over combined cover crop and volunteer wheat biomass in Sigma Plot 10.0. Non-linear regression fit an exponential decay model:

$$DB_{pro} = R*\exp(-0.0077*(x)) \qquad \text{Equation 2.4}$$

where DB_{pro} is the proportion of downy brome biomass per subplot, R is the reduction in the proportion of downy brome biomass by the presence of a cover crop and volunteer winter wheat biomass and the exponential value is the reduction of the proportion of downy brome biomass by each g/m^2 of cover crop and volunteer winter wheat biomass, and x is the combination of cover crop and volunteer wheat biomass.

Weather data were compiled from the online Kansas State Weather Data Library (http://wdl.agron.ksu.edu) and 30-yr precipitation and temperature values were obtained from the High Plains Regional Climate Center Database (http://www.hprcc.unl.edu/).

Results and Discussion

Weather was similar between both growing seasons but two distinct patterns led to variability between the years and they differed from the 30-yr normal. In the 2008-2009 growing season warmer than average temperatures (above 20 C) occurred for several days in February 2009 which was followed by drastic drops to below freezing temperatures (Table 2.1). These temperature events coupled with a lack of significant precipitation from November 2008 until March 2009 impacted both cover crop and weed establishment and development. The 2007-2008 growing season had 230 mm of rain while 411 mm of rain fell in the 2008-2009 growing season (Table 2.2).This was below the 30-yr normal rainfall of 455 mm. During the 2007-2008 growing season every month had lower precipitation than the 30-yr normal. In the 2008-2009 growing season more than average precipitation was received in October 2008 (4.8 times the normal value) and April 2009 (2.2 times the normal value). In both growing seasons extremely dry conditions occurred (<5 mm per month) from November until April.

Over the two growing seasons individual fall- and spring-sown cover crops varied in their ability to produce biomass when grown in competition with kochia (Figures 2.1 and 2.2). Fall-sown cover crops grown in competition with kochia produced an average of 224 (SE 18) g/m^2 of biomass. This was greater than the average of 153 (SE 18) g/m^2 of biomass produced by the spring-sown cover crops in competition with kochia. Fall- and spring-sown cover crop biomasses were analyzed separately because of these differences.

Fall-sown cover crops varied in biomass production in competition with kochia by growing season and cover crop treatment (Figure 2.1). In comparing the two growing seasons, winter triticale produced significantly less biomass in 2007-2008 than in the following growing season. In the 2008-2009 growing season broadleaf cover crops suffered from poor growing conditions and the hairy vetch was winter-killed and produced no biomass. Austrian winter pea biomass production was reduced in the 2008-2009 growing season to only 10% of the 2007-2008 growing season's production. In the 2008-2009 growing season, biomass production by both hairy vetch and Austrian winter pea were not different from the chemical fallow which produced no biomass. The cover crop mixtures hairy vetch-winter triticale and Austrian winter pea-winter triticale produced similar biomass across both growing seasons. Winter survival of broadleaf cover crops was better when grown in mixture with winter triticale in the 2008-2009 growing season (data not shown).

Spring-sown cover crop biomass production in competition with kochia was different across growing seasons and cover crop treatments (Figure 2.1). In the 2007-2008 growing season spring cover crops produced an average of 188 (SE 18) g biomass/m^2 compared to 113 (SE 18) g biomass/m^2 in the 2008-2009 growing season. There were obvious differences in biomass production among individual cover crops between growing seasons. The broadleaf crops of spring lentil and spring pea produced the lowest amount of biomass in 2007-2008, while the spring pea-spring triticale mixture and spring triticale alone produced the most biomass. Spring lentil-spring triticale was intermediate in biomass production. In the 2008-2009 growing season both spring triticale and spring lentil had less biomass production compared to the 2007-2008 growing season and were grouped similarly to the spring pea. The mixtures of spring lentil-spring triticale and spring pea-spring triticale produced the greatest amount of biomass compared to the other three cover crops.

Kochia density was reduced in the presence of fall-sown cover crops compared to kochia grown under no-cover chemical fallow conditions (Figure 2.2). There was an interaction of growing season by fall-sown cover crop treatments on kochia density. In the 2007-2008 growing season kochia density was reduced by all fall-sown cover crops compared to no-cover chemical fallow while in 2008-2009 growing season overall kochia density was less than the 2007-2008 growing season and none of the fall-sown cover crops resulted in kochia densities that were different than no-cover chemical fallow treatment (Figure 2.2). In 2007-2008, hairy vetch had the highest kochia density (117 plants/m^2) but it was half that of the no-cover chemical fallow (220 plants/m^2). Austrian winter pea, winter triticale, hairy vetch-winter triticale, and Austrian winter pea-winter triticale had the lowest kochia densities. The mixture of Austrian winter pea-winter triticale reduced kochia density the most to 14 plants/m^2. Dry environmental conditions in early April 2008 delayed kochia emergence compared to the 2007-2008 growing (data not shown) resulting in lower densities.

Reduction in kochia density relative to the no-cover chemical fallow treatment increased as cover crop biomass increased, that is, fewer kochia plants were present with more cover crop biomass (Figures 2.3 and 2.4). In 2007-2008 growing season as cover crop biomass increased the proportional reduction of kochia density compared to fallow reached 0.99 (Figure 2.3) and in the 2008-2009 growing season proportional reduction of kochia density compared to fallow reached 0.87 (Figure 2.4). This indicates that at sufficiently large cover crop biomass levels, kochia density can be reduced between 87 and 99%. Kochia density was reduced at very low cover crop biomass levels in 2008-2009 growing season because of delayed emergence of kochia relative to establishment and subsequent growth of the cover crops (Figure 2.4).

Kochia biomass was reduced in the presence of fall-sown cover crops in both growing seasons (Figure 2.5). Winter triticale and mixtures of triticale with hairy vetch or Austrian winter pea significantly reduced kochia biomass in 2008-2009 growing season (Figure 2.5). Proportional reduction of kochia biomass relative to no-cover chemical fallow occurred in both growing seasons (Figures 2.6 and 2.7). Maximum reduction of kochia biomass with large cover crop biomass was equivalent for both growing seasons. Even though there were differences in kochia density between growing seasons (Figure 2.2), there were no differences in kochia biomass across growing seasons in the presence of fall-sown cover crops (Figure 2.5).

Planting of both the spring-sown cover crops and kochia in early March meant both crop and weeds emerged in the same time frame and neither could establish itself as the dominant species in the plot. No differences in kochia biomass were observed among spring-sown cover crops in 2007-2008 growing season while more kochia biomass was produced in spring lentil plots (Figure 2.8). Spring lentil produced very little biomass to compete with kochia in 2008-2009 growing season (Figure 2.1). The other spring-sown cover crops reduced kochia biomass similarly with more cover crop biomass produced in combination with delayed kochia emergence. By April 28, 2008, 80% of the kochia had emerged but by the same date in the 2008-2009 growing season very little kochia had emerged (data not shown). The spring-sown cover crop mixtures produced the same biomass and did so before the kochia could become established in the 2008-2009 growing season.

Downy brome biomass decreased exponentially as fall-sown cover crop, spring-sown cover crop, and volunteer wheat biomass increased in the 2008-2009 growing season (Figure 2.9). Volunteer wheat occurred throughout the study as a result of a hail storm in April 2008 prior to winter wheat harvest. No differences in downy brome biomass were observed between spring-sown and fall-sown cover crops, thus data were pooled. The presence of the cover crop and volunteer winter wheat reduced the proportion of downy brome biomass in each plot by 77% (Figure 2.9). The volunteer winter wheat acted as a supplement to the cover crop by providing competing biomass against the downy brome. There was little growth of volunteer winter wheat in the spring-sown cover crops and the combination of spring-sown cover crops and volunteer wheat was limited to below 200 g/m^2 (data not shown). The extra growth of volunteer winter wheat in the fall-sown cover crops helped push total cover crop and volunteer winter wheat biomass production above 300 g/m^2 and increased their ability to suppress downy brome growth to below 20% of the total quadrat biomass (data not shown).

Mortality of weeds from herbicide application in the presence of the cover crops depended upon the weed species and the season in which the cover crop was planted. Downy brome and volunteer winter wheat control with glyphosate for both fall-sown and spring-sown cover crops was 100% (data not shown). The response of kochia to cover crop termination varied by cover crop treatment in the fall-sown cover crops such that kochia mortality was 100% in all fall-sown cover crops except for only 89% in Austrian winter pea. An infield observation noted that the pea plants did cover some of the kochia plants and may have intercepted the herbicide. An earlier application of glyphosate in one year on May 21, 2009 did not increase weed control compared to the later application date in the other year of June 3, 2008. Mortality of kochia in the spring-sown cover crops varied with 99% control in the 2007-2008 growing season when glyphosate was applied on June 3, 2008 and 78% in the 2008-2009 growing season when glyphosate was applied on June 2, 2009. No environmental factors could explain the reduction of control since at the application timings, temperature, and precipitation patterns of both years were similar. Follow up herbicide applications over the shortened fallow period of glyphosate at 408 g ae/ha mixed with dicamba at 90 g/ha and a summer application of paraquat at 180 g/ha controlled all survivors and any new weeds that emerged after the final termination application during the cover crop phase.

Over the two growing seasons fall-sown cover crops provided suppression of kochia density and biomass by establishing a canopy earlier than the spring-sown cover crops. Lenssen (2008) found similar results with the use of an herbicide-free barley crop in Montana. As planting dates were delayed from April into May and June weed density and biomass increased in the first year of the study (Lenssen 2008). April-planted barley did not require an herbicide treatment since crop competition was enough to suppress the weeds. Results in the following year were less conclusive since weed densities were drastically lower (Lenssen 2008). The earlier establishment of fall-sown cover crops and greater biomass production makes them a likely candidate for use in the dryland winter wheat-fallow systems of southwest Kansas for weed management. No direct comparison can be made between fall- and spring-sown cover crops because of the loss of the kochia plots in the chemical fallow treatment in the spring-sown cover crops in both growing seasons. It is hard to draw conclusions on the ability of cover crops to compete with downy brome after one season's data that were confounded by volunteer winter wheat. Other research on the intensification of the winter wheat-fallow system has shown that *Brassica* crops can decrease downy brome densities from 970 to 100 plants/m^2 (Blackshaw 1994). The reduction in downy brome density and biomass by cover crops show that downy brome is responsive to cultural management.

The addition of volunteer winter wheat acted like the mixtures of winter triticale with broadleaf cover crop species which increased their winter survival and competitive nature. The cover crop mixtures, both fall- and spring-sown consistently produced the greatest amounts of biomass consistently during the experiment and are thus likely the most appropriate for arid growing conditions with erratic precipitation patterns. Sim et al. (2007) found that increasing seeding rate and therefore biomass of a winter oilseed rape (*Brassica napus*) crop increased crop biomass. As crop biomass increased crop competitiveness increased reducing Italian ryegrass (*Lolium multliflorum*) head density from 539 heads to 245 heads per m^2. The reduction in head density corresponded to reduced biomass of the weed as rape biomass increased. This was similar to our observation that kochia density and biomass decreased as cover crop biomass production increased in the fall-sown crops from the low biomass producing broadleaves to the high biomass producing cover crop mixtures. Greater biomass makes the crop more competitive.

Further research on the impacts of these cover crops on the succeeding winter wheat crop will be conducted to assess the viability of the rotation. If the cover crops do not significantly reduce wheat yield or the sale or use of forage produced by the crops makes up for any yield loss cover cropping with the use of properly timed herbicides will create an excellent IPM plan for the winter wheat-fallow rotations of southwest Kansas.

References

Anderson, R. L. 1997. Cultural systems can reduce reproductive potential of winter annual grasses. Weed Technology 11:608-613.

Bell, A. R., J. D. Nalewaja, and A. B. Scoder. 1972. Response of kochia to selections of 2,4-D, dicamba, and picloram. Weed Science 20:458-462.

Blackshaw, R. E. 1994. Rotation affects downy brome (*Bromus tectorum*) in winter wheat (*Triticum aestivum*). Weed Technology 8:728-732.

Blackshaw, R. E. 2004. Application method of nitrogen fertilizer affects weed growth and competition with winter wheat. Weed Biology and Management 4:103-113.

Challaiah, O. C. Burnside, G. A. Wicks, and V. A. Johnson. 1986. Competition between winter wheat (*Triticum aestivum*) cultivars and downy brome (*Bromus tectorum*). Weed Science 34:689-693.

Cousens, R. 1985. A simple model relating yield loss to weed density. Ann. App. Biol. 107:239-252.

Crutchfield, D. A., G. A. Wicks, and O. C. Burnside. 1986. Effect of winter wheat (*Triticum aestivum*) straw mulch level on weed control. Weed Science 34:110-114.

Dahl, G. K., A. G. Dexter, and J. D. Nalewaja. 1994. Kochia competition and control in wheat. Proc. NCWSS 49: 15-16.

Fischer, A. J., C. G. Messersmith, and J. D. Nalewaja. 2000. Interference between spring cereals and kochia scoparia related to environment and photosynthetic pathways. Agronomy Journal 92:173-181.

Haas, H. J., W. O. Willis, and J. J. Bond. 1974. Summer fallow in the Western United States. USDA-ARS Conservation Res. Rep. 17. U.S. Government Print Office. Washington, DC.

Haramoto, E.R. and E. R. Gallandt. 2005a Brassica cover cropping I: Effects on weed and crop establishment. Weed Science 53:695-701.

Haramoto, E. R. and E. R. Gallandt. 2005b. Brassica cover cropping II: Effects on growth and interference of green bean (*Phaseolus vulgaris*) and redroot pigweed (*Amaranthus retroflexus*). Weed Science 53:702-708.

Hinze, G. O. and D. E. Smika. 1983. Cropping practices: Central Great Plains. Pages 387-395 in: H.E. Dregne and W.O. Willis (ed.) Dryland Agriculture. Agronomy Monogr. 23. ASA, CSSA, and SSSA. Madison, WI.

Isik, D., W. Kaya, M. Ngouajio, and H. Mennan. 2009. Weed suppression in organic pepper (*Capsicum annuum* L.) with winter cover crops. Crop Protection 28: 356-363.

Lenssen, A. W. 2008. Planting date and preplant weed management influence yield, water use and weed seed production in herbicide-free forage barley. Weed Technology 22:486-489.

Norsworthy, J. K., M. S. Malik, P. Jha, and M. B. Riley. 2007. Suppression of *Digitaria sanguinalis* and *Amaranthus palmeri* using autumn-sown glucosinolate-producing cover crops in organically grown bell pepper. Weed Research 47:425-432.

Nielsen, D. C. and M. F. Vigil. 2005. Legume green fallow effect on soil water content at winter wheat planting and winter wheat yield. Agronomy Journal 97:684-689.

Nord, C. A., C. G. Messersmith, and J. D. Nalewaja. 1999. Growth of *Kochia scoparia*, *Salsola iberica*, and *Triticum aestivum* varies with temperature. Weed Science 47:435-439.

Perez-Mendoza, J., D. K. Weaver, and W. L. Morrill. 2006. Infestation of winter wheat and downy brome grass by winter wheat stem sawfly and subsequent larval performance. Environmental Entomology 35:1279-1285.

Primiani, M. M., J. C. Cotterman, and L. L. Saari. 1990. Resistance of kochia (*Kochia scoparia*) to sulfonylurea and imidazolinone herbicides. Weed Technology 4:169-172.

Schillinger W. F., A. C. Kennedy, and D. L. Young. 2007. Eight years of annual no-till cropping in Washington's winter wheat-summer fallow region. Agriculture, Ecosystems and Environment 120:345-358.

Schwinghamer, T. D. and R. C. Van Acker. 2008. Emergence timing and persistence of kochia (*Kochia scoparia*). Weed Science 56:37-41.

Sim, L. C., R. J. Froud-Williams and M. J. Gooding. 2007. The influence of winter oilseed rape (*Brassica napus ssp. oleifera var. biennis*) canopy size on grass weed growth and grass weed seed return. Journal of Agricultural Science 145:313-327.

Stone L. R. and A. J. Schlegel. 2006. Yield-water supply relationships of grains sorghum and winter wheat. Agronomy Journal 98:1359-1366.

Stubbendieck, J., M. J. Coffin, and L. M. Landholt. 2003. Weeds of the Great Plains. Nebraska Department of Agriculture. Lincoln, Nebraska.

Swan, D. G. and R. E. Whitesides. 1988. Downy brome (*Bromus tectorum*) control in winter wheat. Weed Technology 2:481-485.

Teasdale, J. R., P. Pillai, and R. T. Collins. 2005. Synergism between cover crop residue and herbicide activity on emergence and early growth of weeds. Weed Science 53:521-527.

Waite, J. and K. Al-Khatib. 2009. Kochia differential response to glyphosate. Proc. NCWSS 64:64.

Figures and Tables

Figure 2.1 Cover crop biomass of A.) no-cover chemical fallow (FAL) and fall-sown hairy vetch (VET), Austrian winter pea (AWP), winter triticale (WT), hairy vetch with winter triticale (VET-WT) and Austrian winter pea with winter triticale (AWP-WT) B.) spring-sown spring triticale (ST), spring lentil (SL), spring pea (SP), spring lentil-spring triticale (SL-ST), and spring pea-spring triticale (SP-ST) for 2007-2008 and 2008-2009 growing seasons. An * denotes a difference in biomass production between growing seasons for a given cover crop. Uppercase letters denote differences in biomass between cover crop treatments in the 2007-2008 growing season and lowercase letters correspond to the 2008-2009 growing season for fall-sown cover crops (A) and spring-sown cover crops (B).

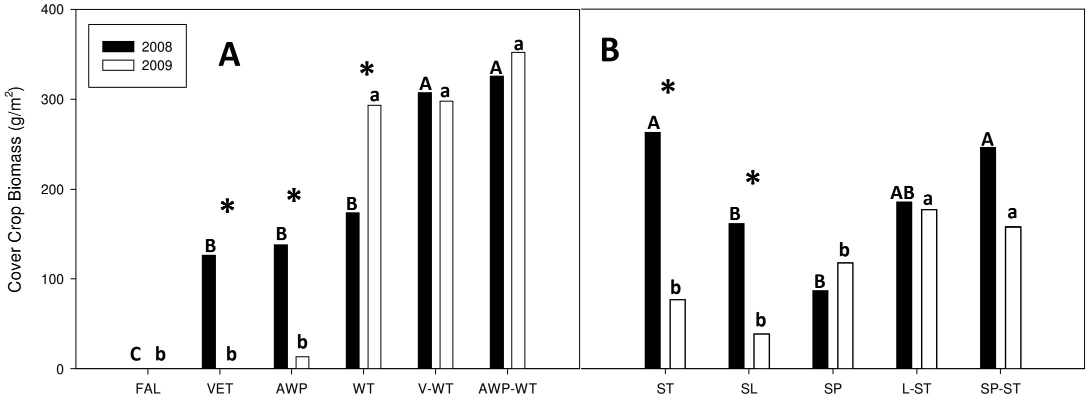

Figure 2.2 Kochia density in response to no-cover chemical fallow (FAL) and fall-sown hairy vetch (VET), Austrian winter pea (AWP), winter triticale (WT), hairy vetch-winter triticale (VET-WT), and Austrian winter pea-winter triticale (AWP-WT) for 2007-2008 and 2008-2009 growing seasons. An * denotes a significant difference in kochia density between growing seasons for a given cover crop treatment. Uppercase letters denote a difference in kochia density between cover crops in the 2007-2008 growing season and lowercase letters correspond to the 2008-2009 growing season.

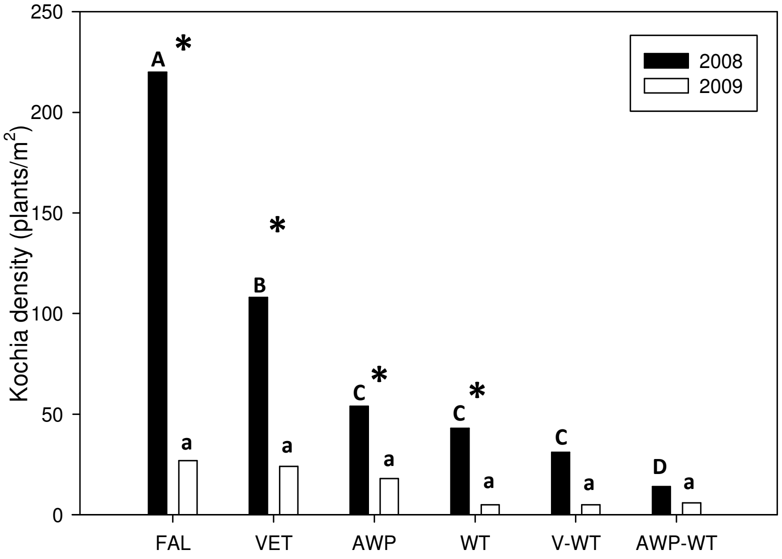

Figure 2.3 Proportional reduction of kochia density in each cover crop compared to no-cover chemical fallow as a function of cover crop biomass for the 2007-2008 growing season. Points represent observed proportional reduction in kochia density for each subplot and the line is the predicted fit of the rectangular hyperbola model to the data: $D_r = (0.191*X)/[1 +((0.191*X)/0.99)]$ (R^2=0.77).

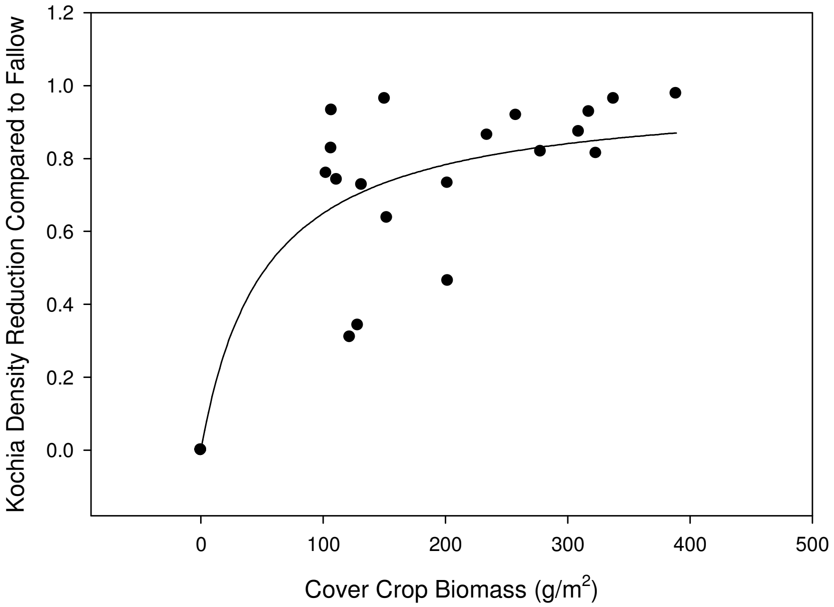

Figure 2.4 Proportional reduction of kochia density in each cover crop compared to no-cover chemical fallow as a function of cover crop biomass for the 2008-2009 growing season. Points represent observed proportional reduction in kochia density for each subplot and the line is the predicted fit of the rectangular hyperbola model to the data: $D_r = (1.04*X)/[1 + ((1.04*X)/0.87)]$ (R^2=0.86).

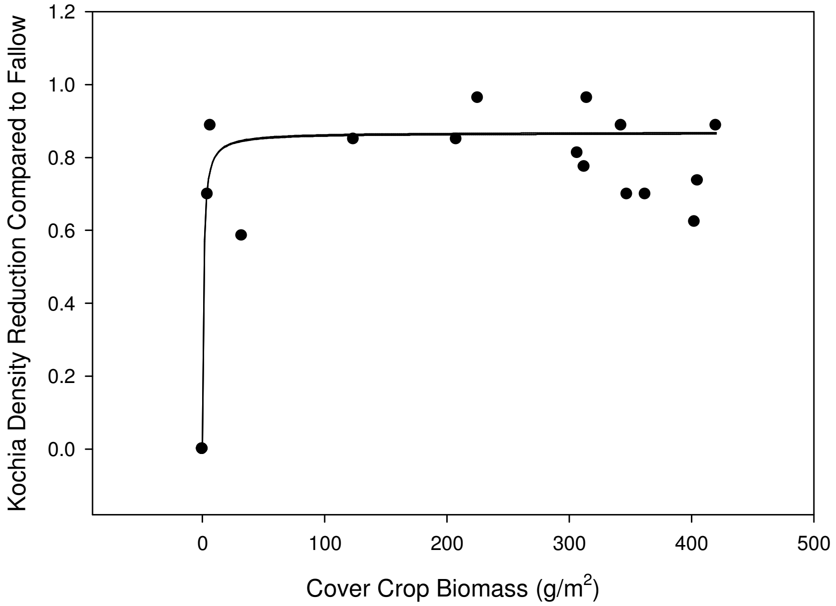

Figure 2.5 Kochia biomass in response to no-cover chemical fallow (FAL) and fall-sown hairy vetch (VET), Austrian winter pea (AWP), winter triticale (WT), hairy vetch-winter triticale (VET-WT), and Austrian winter pea-winter triticale (AWP-WT) across 2007-2008 and 2008-2009 growing seasons. An * denotes a significant difference in biomass production between growing seasons for a given cover crop treatment. Uppercase letters denote differences in kochia biomass between cover crop treatments in the 2007-2008 growing season and lowercase letters correspond to the 2008-2009 growing season.

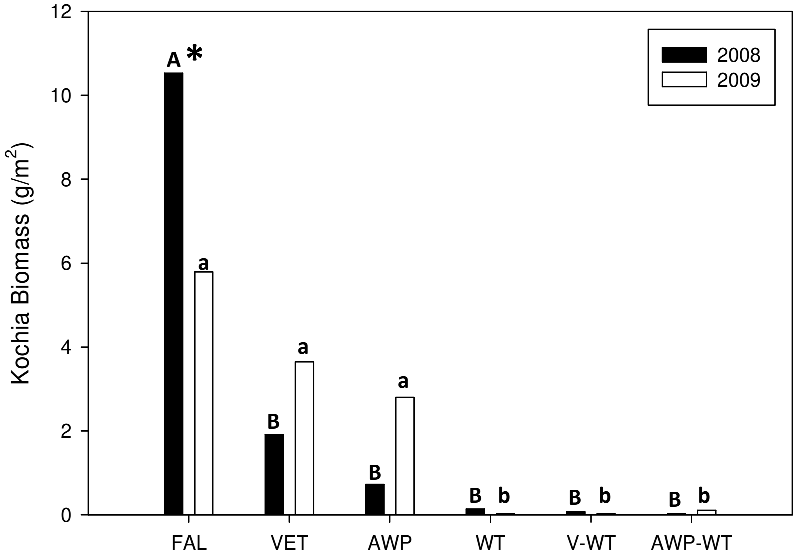

Figure 2.6 Proportional reduction of kochia biomass in each cover crop compared to no-cover chemical fallow as a function of cover crop biomass for the 2007-2008 growing season. Points represent observed proportional reduction in kochia biomass for each subplot and the line is the predicted fit of the rectangular hyperbola model to the data: R = (0.086*X)/[1 +((0.086*X)/1)] (R^2=0.97).

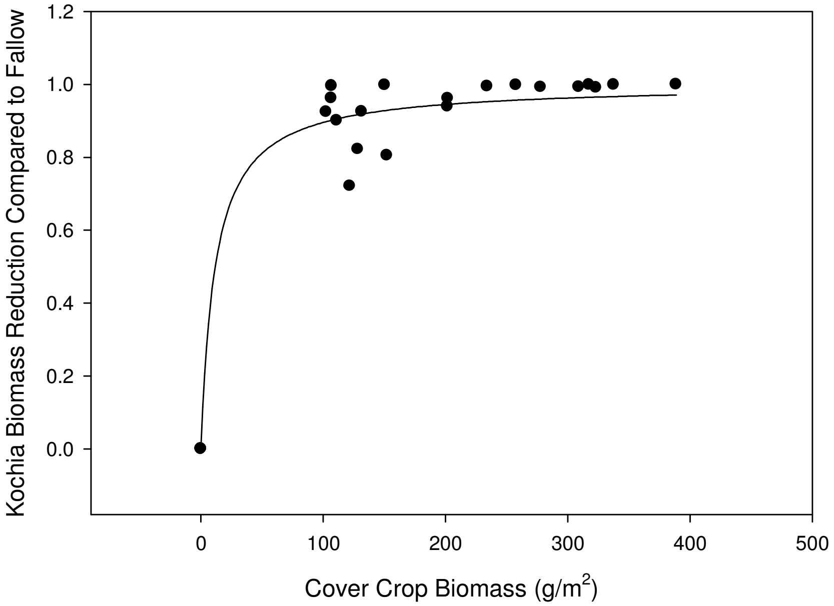

Figure 2.7 Proportional reduction of kochia biomass in each cover crop compared to no-cover chemical fallow as a function of cover crop biomass for the 2008-2009 growing season. Points represent observed proportional reduction in kochia biomass for each subplot and the line is the predicted fit of the rectangular hyperbola model to the data: R = (0.623*X)/[1 +((0.623*X)/0.99)] (R^2=0.98).

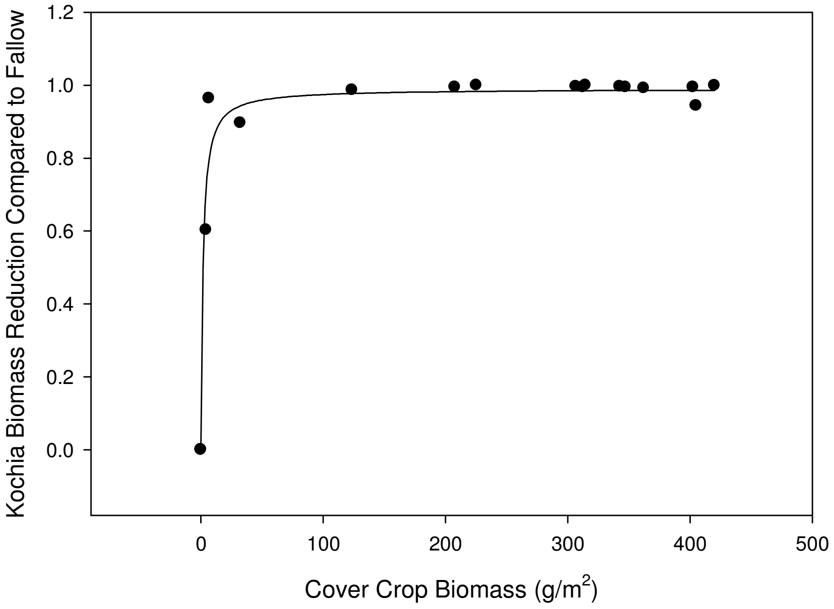

Figure 2.8 Kochia biomass in response to spring-sown cover crops of spring triticale (ST), spring lentil (SL), spring pea (SP), spring lentil-spring triticale (SL-ST), and spring pea-spring triticale (SP-ST) for 2007-2008 and 2008-2009 growing seasons. An * denotes a difference in kochia biomass between growing seasons for a given cover crop. Uppercase letters denote a difference in kochia biomass between cover crops in 2007-2008 growing season and lowercase letters correspond to the 2008-2009 growing season

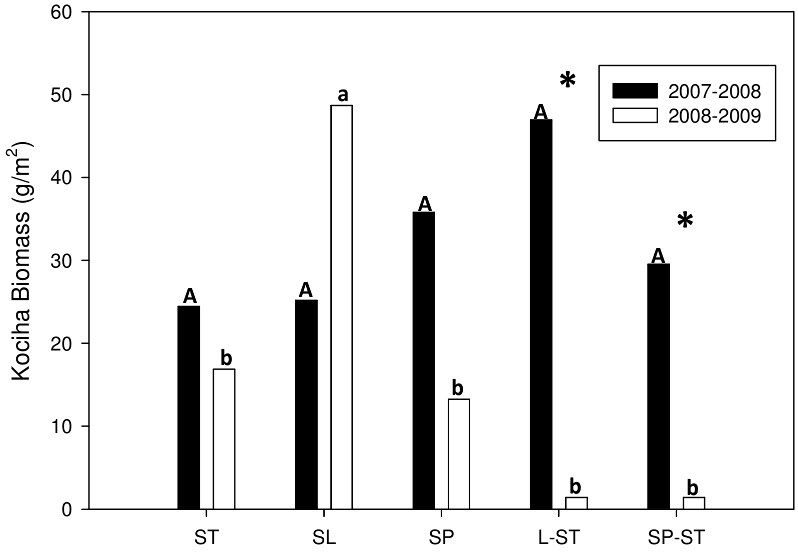

Figure 2.9 Proportional biomass of downy brome relative to total plot biomass as a function of fall- and spring-sown cover crops and volunteer winter wheat biomass (g/m^2). Points represent average proportional downy brome biomass and line is fit to data: $DB_{pro} = 0.79*\exp(-0.0077*X)$ (R^2=0.63).

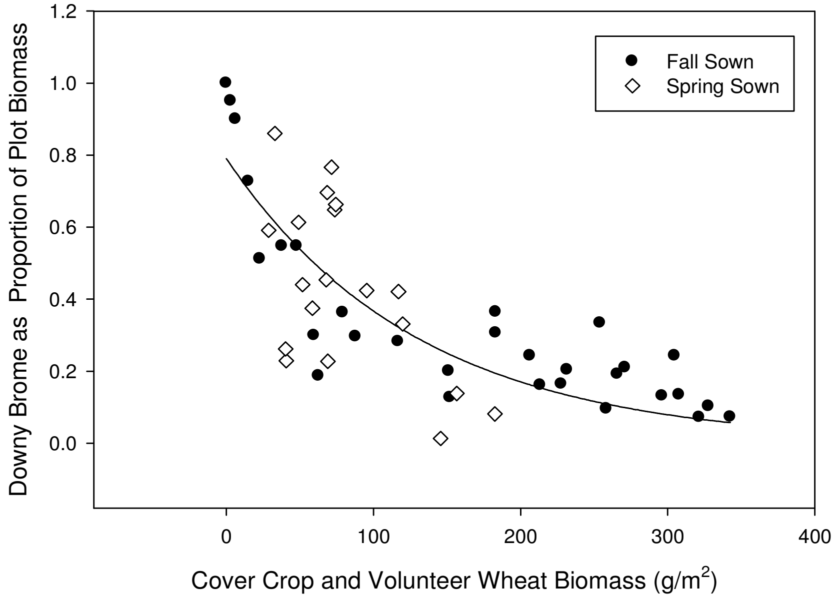

Table 2.1 Monthly average, high, low and 30-yr average temperatures over the 2007-2008 and 2008-2009 growing season for Garden City, KS.

Month	2007-2008			2008-2009			30-yr Normal
	Average	High	Low	Average	High	Low	
August	26.7	39.0	14.5	22.5	39.7	12.1	24.9
September	29.8	34.8	5.5	19.5	32.4	3.6	20.1
October	14.4	34.3	-1.6	12.3	32.1	-4.4	13.1
November	5.3	25.7	-0.1	6.5	26.5	-10.3	4.5
December	-1.3	23.0	-2.3	-0.18	22.1	-18.1	-0.2
January	-0.4	20.9	-1.6	0.5	21.6	-15.3	-1.6
February	1.3	18.0	-0.7	3.7	27.8	-12.5	1.7
March	5.7	27.4	-0.7	5.8	27.9	-12.6	6.7
April	9.8	32.5	-0.4	10.2	31.7	-7.8	11.9
May	16.7	33.7	-1.8	16.4	33.3	3.4	17.3
June	21.8	36.5	8.9	21.7	33.3	6.5	23.1
July	25.5	37.9	8.7	24.7	37.9	13.8	25.9

Table 2.2 Monthly and total precipitation for the 2007-2008 and 2008-2009 growing seasons and 30-yr normal at Garden City, KS.

Month	2007-2008	2008-2009	30-yr Normal
	-----------------mm-----------------		
August	45	44	66
September	48	13	38
October	5	111	23
November	1	4	23
December	0	1	12
January	2	0	11
February	3	0	15
March	3	0	37
April	38	106	49
May	41	41	80
June	60	80	83
July	28	55	84
Total	274	455	512

CHAPTER 3 - Palmer amaranth response to cover crop and herbicide application in a soybean - winter wheat - grain sorghum rotation

Abstract

Palmer amaranth is a competitive weed with many herbicide resistant biotypes occurring during the fallow periods of the soybean - winter wheat - grain sorghum rotation common to eastern Kansas. An integrated weed management plan that includes cover cropping and herbicide use in the fallow phase may provide adequate weed control. Field experiments were carried out at the Ashland Bottoms Research Farm in 2008 and 2009 to quantify the response of Palmer amaranth emergence, biomass accumulation, and fecundity to summer- and fall-sown cover crops in the fallow phase between winter wheat harvest and grain sorghum planting. The experiment was a split plot design with three main plots being crop phase. Into the winter wheat-fallow phase of the rotation six cover crop subplots were established. Palmer amaranth was seeded at 500 seeds/m^2 into two quadrats in each subplot. One quadrat was covered during the preplant burndown treatment in the cover crop phase and in the preemergence herbicide treatment in the grain sorghum phase. Palmer amaranth density differed between years with a ten-fold increase in density in 2009. Cover crop impacts were limited to 2008 where sudangrass reduced August Palmer amaranth densities in the burndown treated plots compared to the no-cover control. Burndown application reduced end of season Palmer amaranth density by 67% compared to untreated plots in 2009 and biomass in both years. When glyphosate was paired with cover crops Palmer amaranth biomass was reduced 92% in 2008 and in 2009 a linear relationship was found between increasing cover crop biomass and decreasing Palmer amaranth biomass. Palmer amaranth fecundity was not impacted by cover crop treatment but was related to Palmer amaranth dry biomass. Residual effects of cover crop treatments reduced Palmer amaranth emergence in the grain sorghum phase but were negated by the end of the growing season.

Introduction

In the rainfed cropping systems of northcentral and northeast Kansas the three-year soybean - winter wheat - grain sorghum rotation is common. The nine-month fallow period between winter wheat harvest and grain sorghum planting requires several chemical or mechanical weed control applications and leaves the soil exposed to erosive forces of wind and water. The adoption of no-tillage practices in the area has reduced soil erosion but has increased dependence on herbicides for weed control (Shaner 2000, Troeh et al. 2004). The reliance on herbicides has led to the selection for herbicide-resistant weeds (Bell et al. 1972, Culpepper et al. 2006, Primiani et al. 1990). One of these weeds, Palmer amaranth, is competitive with the potential for tremendous seed production (Bond and Oliver 2006, Keely et al. 1987). To reduce the reliance on herbicides for weed control an integrated weed management (IWM) plan needs to be developed for the region that intensifies the rotation with cover crops as a cultural practice along with chemical control measures for weed management.

Cover crops provide many benefits during the growing season and to the following crop when ample water is available. The addition of cover crops during the fallow phase of a rotation can reduce soil erosion caused by wind and water with the cover crop acting as a barrier to falling and running rainfall and by standing crops and residues raising the wind profile above the soil surface (Dabney 1998, Hartwig and Ammon 2002, Troeh et al. 2004). In addition to the benefits to physical properties of soils cover crops can also retain and add nutrients to the soil. Planting leguminous cover crops like Austrian winter pea (*Lathyrus hirsutus*) and forage soybeans can add nitrogen to the soil through the bacterial conversion of gaseous nitrogen to plant available forms (Leikam et al. 2007, McKnee 1931, McVay et al. 1989). Most importantly cover crops can compete with weeds by impacting key points in the weed lifecycle. Cover crops can reduce the total number of and delay the emergence of weed seedlings (Haramoto and Gallandt 2005a, Norsworthy et al. 2007). Norsworthy et al. (2007) observed a reduction in Palmer amaranth emergence by 37 to 79% by Brassica cover crop residues. In addition to the reduction in weed emergence Fisk et al (2001) found weed biomass was reduced 27 to 60% by the presence of a cover crop. Cover crops have the potential to reduce Palmer amaranth emergence and growth during the fallow phase of a rotation together with the benefits of nitrogen accumulation and soil protection.

Reduction of Palmer amaranth in the fallow phase between winter wheat harvest and grain sorghum planting will benefit the grain sorghum crop immensely as well as the following soybean crop. Palmer amaranth reduces yields of both crops (Klingaman and Oliver 1994, Moore et al. 2004). The weed uses water-efficient C4 photosynthesis to grow to heights of 0.8 to 2.8 m during the warm Kansas summers (Bond and Oliver 2006, Ehleringer 1983, Stubbendieck et al. 2003). With seed production as high as 600,000 seeds per female plant Palmer amaranth can more than double its population within a single growing season (Keely et al. 1987, Vencill and Banks 1984). Control of this prodigious seed producer is confounded by the discovery of many herbicide-resistant biotypes including resistance to glyphosate, an herbicide commonly used to control weeds in the fallow phase of this rotation (Culpepper et al. 2006). The glyphosate-resistant biotype discovered in Georgia could withstand use rates up to three times the normal rate with only 17% mortality (Culpepper et al. 2006). Cultural methods of cropping intensification and herbicide rotation are needed to reduce the prevalence of Palmer amaranth during fallow periods and prevent the selection for resistant biotypes.

The goals of the study were to (1) examine the response of Palmer amaranth density and biomass production (emergence and growth) to direct competition of cover crops and herbicide management in the fallow phase and (2) determine the residual effects of herbicide and cover crop treatments on Palmer amaranth emergence and growth in the following grain sorghum crop.

Materials and Methods

A no-tillage field experiment was established in the spring of 2007 at the Department of Agronomy Ashland Bottoms Research Farm, near Manhattan, KS to evaluate the response of Palmer amaranth to the inclusion of cover crops in a three-year crop rotation. Studies were conducted during the 2008 and 2009 growing seasons. The rotation was soybean – winter wheat – grain sorghum with cover crops being seeded after winter wheat harvest in July and terminated before grain sorghum planting in the following spring. The soil was a Wymore silty clay loam with a pH of 6.0 and an organic matter content of 2.4%. The experiment was a split plot design with whole plots being 36.6 m wide by 69.6 m long that represented each crop phase (soybean, winter wheat, and grain sorghum) replicated four times. Whole plots were divided into six 6.1 m by 69.6 m subplots that represented the cover crop treatments of no-cover chemical fallow (check), doublecrop soybean, two summer-sown cover crops of forage soybean and sudangrass, and two fall-sown cover crops of Austrian winter pea and canola. Each of these cover crop strips was split into five 6.1 m by 13.8 m sub-subplots for nitrogen rate treatments in the grain sorghum phase. Paired Palmer amaranth quadrats of 0.75 by 1.33 m were established in the 0 and 134 kg N/ha sub-subplots with one quadrat being untreated and the other exposed to all weed control activities.

Winter Wheat – Fallow (Cover Crop)

The winter wheat variety “2145” was seeded following soybean harvest on October 30, 2007 and the winter wheat variety “Overly” was seeded on November 3, 2008. After winter wheat harvest and before cover crop planting, an application of glyphosate at 408 g ae/ha was applied to the winter wheat stubble on July 10, 2008 and July 1, 2009. Three summer annual cover crops were sown in 0.25-m row spacing on July 11, 2008 and July 2, 2009 and included a mixture of varieties “AG7601” and “AG5301” for forage soybean in 2008 and a single variety “AG5301” in 2009 sown at 68 kg/ha, a doublecrop soybean variety “AG3852” sown at 68 kg/ha, and sudangrass sown at 28 kg/ha. Two fall cover crops were sown on August 27, 2007 and September 4, 2008 and included Austrian winter pea sown at 28 kg/ha and the canola variety “Wichita” sown at 11 kg/ha. An experimental check was established as a no cover chemical fallow treatment. Termination of summer annual cover crops occurred on September 22, 2008 with a flail-mower with a 3 m swath width and on September 18, 2009 with a 3 m wide roller-crimper. Fall cover crop termination occurred on April 22, 2008 and April 22, 2009 using a combination of glyphosate at 408 g ae/ha and mowing with a flail-mower. In all cases cover crop residue was left on the plot.

Prior to termination, cover crop biomass was determined by clipping 3 m of four rows. Sub-samples of one plant per row were dried to obtain biomass estimate for the plot. Doublecrop soybean seed yields were obtained using a combine and the following equation was used to calculate total plant dry biomass:

$$X= [(\ln((Y/4035.6)-1)/(-0.004848)]+53 \qquad \text{Equation 3.1}$$

where Y is soybean seed yield in kg/ha and X is total plant dry matter in g/m^2 (Board and Modali 2005).

Grain Sorghum

On June 9, 2008 and May 22, 2009 grain sorghum variety “DKS 54-00” was planted in 0.76-m rows into whole plots representing the grain sorghum phase of the three-year rotation. Following planting a preemergence treatment of the premix S-metolachlor + atrazine at 229 g ai/ha + 290 g ai/ha was applied in 2008 and in 2009, glyphosate at 408 g ae/ha was added to the premix. Grain sorghum whole plots measured 36.6 m wide by 69.6 m long. Subplots representing the previous year’s cover crop treatment measured 6.1 m wide by 69.6 m long and were divided lengthwise into five 6.1 m by 13.8 m sub-subplots for nitrogen rate treatments. Nitrogen was applied pre-emergence at 0, 45, 90, 134, and 179 kg N/ha rates of urea. The two center rows of each nitrogen sub-subplot were harvested on October 10, 2008 and November 13, 2009 to determine grain yield.

Palmer amaranth Populations

In March 2008 paired 1-m^2 quadrats of 0.75 m by 1.33 m were sown with 500 Palmer amaranth seed/m^2 in the sub-subplots scheduled to receive 0 and 134 kg N/ha during the grain sorghum phase across all whole plots. This single planting established Palmer amaranth quadrats across every phase of the rotation in March of 2008. Seed rain by female Palmer amaranth in the fall of 2008 reseeded quadrats. Quadrats were monitored starting in April of each year in the winter wheat phase of the rotation for weed emergence and density until Palmer amaranth harvest in August of each year before cover crop termination. When herbicide applications occurred in the cover crop or grain sorghum phases, one quadrat was covered with plastic sheeting in each sub-subplot. Herbicide treatment (burndown or preemergence) of the plots was maintained throughout each phase of the rotation, so plots sprayed during the cover crop phase were sprayed during the grain sorghum phase.

Palmer amaranth plants were harvested prior to cover crop termination or grain sorghum harvest to determine end of season density and biomass. Total quadrat density and biomass were obtained along with a subsample for weed height. The total number of male and female plants per plot was also determined. Four individual plants per plot were sampled for fecundity in the 2008 cover crop phase of the rotation. Individuals were dried at 60 C for 72 hours and reproductive parts were stripped from stems. The chaff was then separated from seed by airflow and total seed sample weights were determined. Five hundred seed weights were used to determine fecundity per plant. Palmer amaranth end of season density and biomass were analyzed in response to cover crop treatment and herbicide treatment during the cover crop phase of the rotation. Discrete data analysis was completed using PROC MIXED in SAS v9.13. PROC MIXED calculated least square means and least squared standard errors. The PDIFF procedure calculated pair-wise comparisons using adjusted P-values with a significance of $\alpha = 0.05$. In the grain sorghum phase initial emergence of Palmer amaranth as a response to previous year's cover crop and herbicide treatment was tested. End of season Palmer amaranth density and biomass in response to in-season nitrogen rate, herbicide treatment, and previous season cover crop was tested. Response of Palmer amaranth to herbicide treatments and to harvesting/planting operations were evaluated by calculating proportional plant mortality as the difference between density before and density two weeks after herbicide or harvesting/planting operations divided by density observed before operation occurred.

Impact of cover crop on Palmer amaranth biomass was estimated relative to the Palmer amaranth biomass observed in the chemical fallow treatment as:

$$\text{PA Red} = (\text{CF}-\text{PAbio})/\text{CF} \qquad \text{Equation 3.2}$$

where PA Red is the proportional reduction in Palmer amaranth biomass, CF is the average Palmer amaranth biomass in chemical fallow treatment (g/m^2), and PAbio is the individual Palmer amaranth biomass for each cover crop treatment (g/m^2). Reduction in Palmer amaranth biomass in response to cover crop biomass was determined using linear regression (Sigma Plot v10.0):

$$\text{PA Red} = m^{*}\ \text{CCbio} + b \qquad \text{Equation 3.3}$$

where PA Red is proportional reduction of Palmer amaranth biomass, b the proportional reduction of Palmer amaranth by the presence of a cover crop, m rate of the proportional reduction of Palmer amaranth biomass as cover crop biomass (CCbio, kg/ha) increases.

Peak Palmer amaranth density was determined for both the emergence period from May until July in the winter wheat phase of the rotation and from July to August in the cover crop phase of the rotation for each cover crop treatment. Density from each treatment was divided by the maximum density in the chemical fallow treatment to create a density proportion. In the cover crop phase of the rotation the date of peak density in herbicide treated and untreated plots were calculated separately. For each plot of each treatment and phase proportional density was calculated as Dn/Dpeak, where Dn is density of plot on given day n and Dpeak is maximum density in the chemical fallow plot or cover crop phase with or without herbicide application.

Weather data were compiled from the online Kansas State Weather Data Library (http://wdl.agron.ksu.edu) and 30-yr precipitation values were obtained from the High Plains Regional Climate Center Database (http://www.hprcc.unl.edu/).

Results and Discussion

For the 2008 and 2009 Palmer amaranth growing seasons from March until August average monthly temperatures were similar to the 30-year normal (Table 3.1). Overall precipitation was higher than the 30-yr normal of 597 mm with 782 mm in 2008 and 700 mm in 2009. The 2008 growing season had decreased precipitation in the month of April prior to Palmer amaranth emergence and increased precipitation in the months of June and August. The June 2008 precipitation value was 173 mm greater than the 30-yr normal affording Palmer amaranth ample moisture before the cover crops were planted. In 2009 increased precipitation was recorded in April, June, and August with 56, 76, and 48 mm of precipitation, respectively, that were greater than the 30-yr normal. These precipitation surpluses benefited the Palmer amaranth except for the August surplus which benefited both Palmer amaranth and cover crop. May 2009 was the only month during the growing season that had a rainfall deficit compared to the 30-yr normal and was only 10% of the 30-yr normal value for May. This deficit occurred early in the month of initial Palmer amaranth emergence which delayed peak emergence.

Cover crops were divided into summer and fall planting in accordance with the growth stage of Palmer amaranth they would compete with. Summer cover crops included sudangrass, doublecrop soybeans, and forage soybeans that competed directly with Palmer amaranth in the cover crop phase of the rotation. Fall planted canola and Austrian winter pea competed indirectly with Palmer amaranth through the residues they left behind when Palmer amaranth occurred in the grain sorghum phase. Across both years of the summer-sown cover crops, sudangrass produced the greatest amount of biomass followed by the forage soybeans and the doublecrop soybeans produced the least biomass (Table 3.2). Fall-sown cover crop biomass varied between years because of lack of winter survival. Austrian winter pea planted in the fall of 2007 produced 2,694 (SE 256) kg/ha of biomass in the spring of 2008, while canola was winter killed and only produced 709 (SE 256) kg/ha in the spring of 2008 with most in one replication. Fall-sown cover crops in 2008 had poor establishment and produced little biomass in the spring of 2009. Over the two year experiment summer planted cover crops consistently produced more biomass than the fall planted cover crops.

Palmer amaranth emergence varied by year with initial emergence occurring on May 31, 2008 and on May 19, 2009. Cooler soil temperatures and low precipitation in the first half of May 2008 delayed Palmer amaranth emergence. In the second half of May average soil temperatures increased and higher precipitation prompted Palmer amaranth emergence. Soil temperatures were warmer in early May 2009 while precipitation was less compared to both 2008 and the 30-yr normal. On May 31, 2008 in the winter wheat phase of the rotation average Palmer amaranth density was 11 (SE 3) plants/m^2 and on May 31, 2009 densities averaged 17 (SE 3) plants/m^2.

From May until July, before winter wheat harvest, Palmer amaranth continued to emerge and density increased as soil temperature increased and precipitation occurred. During the 2008 winter wheat phase, Palmer amaranth density in plots scheduled for sudangrass and chemical fallow treatments reached peak density early in the season on May 31, 2008 (Figure 3.1). The plots scheduled for the forage soybean and doublecrop soybean treatments reached peak density by June 18, 2008. Density during the 2009 winter wheat phase, after the initial lag in emergence between May 19, 2009 and June 1, 2009, steadily increased to a maximum density by June 24, 2009 (Figure 3.1). The variability in the timing of peak density may be attributed to differences in density between the seasons. By the end of the winter wheat phase of the rotation, just prior to harvest, weed densities had reached an average of 15 (SE 22) plants/m^2 in 2008 and 199 (SE 22) plants/m^2 in 2009. Very high Palmer amaranth densities in 2009 were a result of seed rain in the quadrats in the fall of 2008.

Weed mortality in response to burndown glyphosate applications was not different between years and averaged 97% across all treatments and years (data not shown). Mortality due to both winter wheat harvest and cover crop planting differed between years in plots not treated with glyphosate. In 2008 a 46% increase in density was observed across cover crop treatments indicating that another emergence flush of Palmer amaranth occurred during the period between the pre-harvest count on June 23, 2008 and the follow up count on July 25, 2008. In 2009 there was a 50% decrease in density over the harvest and planting period. Initial greater densities in

2009 compared to 2008 increased the likelihood of damage to the Palmer amaranth plants by field operations.

In all treatments (Palmer amaranth quadrats with and without glyphosate application) densities continued to increase until harvest of Palmer amaranth in August of both years (Figures 3.2 and 3.3). Date of peak emergence of Palmer amaranth, after the cover crop treatments were established, was later in the cover crop treatments compared to the chemical fallow treatments in 2008 in quadrats that did not receive a glyphosate application (Figure 3.3). An increase in density during the harvesting of winter wheat and planting of cover crops indicates that this delay in peak density was not attributed to equipment damage to plots but to the competition given by the cover crops. Cover crop competition did not impact final density of Palmer amaranth except in the sprayed quadrats in 2008. Sudangrass reduced densities to less than 1 plant/m^2 compared to the average of 7 plants/m^2 observed across the chemical fallow, double cropped soybean, and forage soybean treatments.

Overall end of season Palmer amaranth density was influenced by both year and herbicide treatment but not by cover crop treatments. Herbicide treatment with a burndown application of glyphosate did not impact end of season density in 2008 compared to untreated plots (Figure 3.4). Even though plots treated with glyphosate had half the density of the untreated, 2008 densities were only 7% of 2009 densities. In 2009, plots treated with a burndown application of glyphosate had average densities 67% lower than untreated plots, which were significantly different (alpha = 0.05).

Biomass of Palmer amaranth in quadrats that did not receive a burndown treatment of glyphosate was reduced in the sudangrass plots compared to other treatments in 2008 (Table 3.3). Palmer amaranth biomass was reduced in quadrats treated with glyphosate compared to untreated plots in both years. Since year and herbicide treatment interactions were significant regression analysis was conducted on the percent reduction of Palmer amaranth dry biomass compared to average fallow Palmer amaranth dry biomass to determine if a response of Palmer amaranth dry biomass to cover crop dry biomass existed.

Palmer amaranth biomass was reduced in quadrats treated with glyphosate and cover crops compared to fallow. In the 2008 burndown treated plot analysis showed that cover crops reduced Palmer amaranth dry biomass by 92% compared to fallow. The following year percent reduction of Palmer amaranth dry biomass compared to fallow showed that with the presence of a cover crop a 44% reduction in dry biomass was achieved. Regression analysis also showed that with every 100 g/m^2 increase in cover crop biomass Palmer amaranth dry biomass would be reduced by 4% compared to fallow (Figure 3.5).

Palmer amaranth fecundity that was measured in the cover crop phase of 2008 was not directly impacted by cover crop treatment or cover crop biomass. Individual plant fecundity was related to female Palmer amaranth biomass (Figure 3.6). Fecundity increased exponentially as plant biomass increased. The relationship stated earlier that increasing cover crop biomass can decrease Palmer amaranth biomass should carry through in that reducing Palmer amaranth biomass with a cover crop should reduce fecundity. Seed production by female Palmer amaranth plants was variable because of harvesting in late August before all seeds on the plant matured. A later harvest may have shown a relationship between mature seed production and cover crop treatments.

Fall-planted cover crops were terminated on March 22, 2008 and on April 14, 2009. The cover crop phase was followed by grain sorghum planting on June 9, 2008 and May 21, 2009. In both years Palmer amaranth emerged before grain sorghum planting. Initial emergence of Palmer amaranth was observed on May 31, 2008 and on May 19, 2009. In both years initial Palmer amaranth emergence was impacted by the previous year's cover crop treatment (Table 3.4). In 2008 the quadrats that were previously in Austrian winter pea or sudangrass had less Palmer amaranth emergence compared to the other previous year's cover crop treatments. Palmer amaranth emergence in the chemical fallow treatment was intermediate. Palmer amaranth emergence in 2009 was similar to 2008 except for more in the Austrian winter pea. This can be attributed to the reduced Austrian winter pea biomass production in 2009 compared to 2008 which left little residue for emerging Palmer amaranth with which to compete. Reduced Palmer amaranth emergence was attributed to high amounts of residue left by the sudangrass and Austrian winter pea (infield observation).

A combination of previous year's cover crop and burndown glyphosate application impacted initial Palmer amaranth emergence. Treatment responses were only significant in 2009 because this was the first year for grain sorghum to be rotated onto ground that had the herbicide treatment imposed in the previous year. A 70% decrease in emergence was observed on plots that were treated in the previous year's cropping system with a burndown application of glyphosate.

Weed mortality due to preemergence herbicides varied by year. In 2008 an application of S-metolachlor + atrazine provided 83% control of emerged Palmer amaranth in treated plots. Emerged Palmer amaranth mortality increased in 2009 to 100% with the addition of glyphosate as a tank mix with the S-metolachlor + atrazine.

Palmer amaranth plants were harvested mid-September 2008 and early September 2009 in the grain sorghum phase. Previous year's cover crop had no impact on Palmer amaranth density or biomass. End of season Palmer amaranth densities averaged 5 plants/m^2 in 2008 and 27 plants/m^2 in 2009 with a standard error of 4 plants/m^2. Preemergence herbicide treatment after grain sorghum planting impacted Palmer amaranth final density in 2009 with a 69% decrease in treated plots compared to untreated (Figure 3.7). Reduced control of emerged Palmer amaranth with the preemergence herbicide in 2008 compared to 2009 may also have impacted the end of season density. Preemergence herbicide did not impact Palmer amaranth end of season density in 2008 because of lower overall densities, reducing competition, and making it easier for later flushes of the weeds to repopulate the plots compared to the higher densities in 2009.

End of season Palmer amaranth biomass in grain sorghum responded to both preemergence herbicide application and nitrogen rate. Preemergence herbicide application reduced Palmer amaranth biomass in 2009 (Figure 3.7). The response of Palmer amaranth biomass to nitrogen application varied by year because of differences in residual soil nitrogen levels. In 2008 quadrats with no nitrogen applied actually produced significantly more biomass than plots with 134 kg N/ha nitrogen applied. This can be attributed to soil nitrogen levels of both NH_4^+ and plant available $N0_3^-$ being significantly higher in 2008 than 2009 (data?). In 2009, when plant available nitrate was half that of 2008, dry biomass production by Palmer amaranth was reduced by 72% in plots with no nitrogen applied compared to plots with 134 kg N/ha nitrogen applied (Figure 3.8).

At the end of the season there were no effects of previous season's cover crop on Palmer amaranth density or emergence. This is consistent with other research where Haramoto and Gallandt (2005b) reported a decrease in the emergence and growth of redroot pigweed by cover crop residue up to 32 days after planting (DAP) of the main crop. Similar results have been reported were cover crop residues decreased weed emergence until 28 DAP of the main crop and incorporated *Brassica* residues decreased Palmer amaranth emergence until 42 DAP. Variability of length of control due to cover crop means residues cannot be used as a standalone management tool but must be incorporated with herbicide control measures and other cultural practices. This was proven in the experiment where cover crop residues did not impact Palmer amaranth throughout the entire season but application of herbicides reduced Palmer amaranth density that was observed at the end of the grain sorghum growing season.

In this study cover crops and herbicide application affected Palmer amaranth emergence, density, and biomass directly in season and into the next growing season. Cover crops delayed the timing of peak density of Palmer amaranth. End of season weed density was only impacted in 2008 by the sudangrass cover crop. Sim et al. (2007) observed that the presence of oilseed crops reduced weed density both in the fall and into end of the growing season in spring. Reddy and Koger (2004) reported that a live hairy vetch crop kept weed densities lower than a no-cover control up to seven weeks after planting. Herbicide control was needed beyond that time period to reduce weed populations. Application of glyphosate had greater impacts on weed density in the current study than cover cropping except for the sudangrass crop. Weed density reductions by cover crops were negated in 2009 by the extremely high densities of Palmer amaranth that resulted from seed rain from the previous year's weeds.

The presence of cover crops reduced Palmer amaranth end of season biomass by 44% in August of 2009 in plots treated with herbicide. The 92% reduction in Palmer amaranth biomass was greater with lower densities in 2008. At the lower Palmer amaranth densities in 2008 sudangrass successfully reduced Palmer amaranth biomass at harvest in late August in quadrats that were not treated with herbicide. Sudangrass had the highest biomass of all the cover crops which may suggest an interaction between biomass and weed suppression. Proportional reduction of Palmer amaranth biomass was positively and linearly related with the increase in cover crop biomass in 2008 quadrats treated with herbicide. A similar linear decrease of weed biomass in response to increasing cover crop biomass was reported (Saito et al. 2008).

Application of glyphosate prior to cover crop planting reduced both density and biomass of Palmer amaranth compared to untreated plots. Herbicide application was more beneficial in 2009 by reducing Palmer amaranth density compared to untreated plots because of extremely high initial densities of Palmer amaranth. Blackshaw et al. (2005) observed that combining agronomic practices such as increased seeding rates with herbicide applications had greater impacts on weed density and biomass than any practice on its own. Jha et al. (2008) observed cultural planting practices in soybean combined with glyphosate application provided the greatest Palmer amaranth control. Therefore it is important to pair cultural practices with chemical control for an IWM plan.

In the growing season following cover crop treatments Palmer amaranth had reduced emergence from both herbicide and cover crop treatments that resulted from competition with cover crop residue. Research has proven cover crop residues can lower weed emergence by blocking weed entrance into the seedbank and by reducing light transmittance to the soil surface affecting light sensitive species like Palmer amaranth (Facelli and Pickett 1991, Teasdale and Mohler 1993). Few studies have focused on no-till situations where in this current study residues were left on the soil surface. Williams et al. (1998) found emergence of *Amaranthus spp.* was delayed up to three weeks after cover crop termination. Rye and hairy vetch had more biomass than other cover crops in the study that resulted in delayed emergence whereas less biomass producers were similar to the no-residue control treatment (Williams et al. 1998).

The results indicate that cover crops can be effective at reducing weed density and biomass. High biomass producing cover crops like sudangrass had the greatest ability to suppress both weed density and biomass in the cover crop phase of the rotation and into the following grain sorghum phase of the rotation. Variability in cover crop management of Palmer amaranth in this study indicates that pairing cover cropping with other practices such as herbicide application into an IWM plan is important.

References

Bell, A. R., J. D. Nalewaja, and A. B. Scoder. 1972. Response of kochia to selections of 2,4-D, dicamba, and picloram. Weed Science 20:458-462.

Blackshaw, R. E., H. J. Beckie, L. J. Molnar, T. Entz, and J. R. Moyer. 2005. Combining agronomic practices and herbicides improves weed management in wheat-canola rotations within zero tillage productions systems. Weed Science 53: 528-535.

Board, J. E. and H. Modali. 2005. Dry matter accumulation predictors for optimal soybean yields. Crop Science 45:1750-1799.

Bond, J. A. and L. R. Oliver. 2006. Comparative growth of Palmer amaranth (*Amaranthus palmeri*) accessions. Weed Science 54:121-126.

Culpepper, A. S., T. L. Grey, W. K. Vencill, J. M. Kichler, and T. M. Webster. 2006. Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) confirmed in Georgia. Weed Science 54:620-626.

Dabney, S. M. 1998. Cover crop impacts on watershed hydrology. Journal of Soil and Water Conservation 53:207-213.

Elheringer, J. 1983. Ecophysiology of *Amaranthus palmeri*, a Sonoran Desert summer annual. Oceologia 57:107-112.

Facelli, J. and M. Picket. 1991. Plant litter: Light interception and effects on an old-field plant community. Ecology 72:1024-1031.

Haramoto, E. R. and E. R. Gallandt. 2005a. Brassica cover cropping I: Effects on weed and crop establishment. Weed Science 53:695-701.

Haramoto, E. R. and E. R. Gallandt. 2005b. Brassica cover cropping II: Effects on growth and interference of green bean (*Phaseolus vulgaris*) and redroot pigweed (*Amaranthus retroflexus*). Weed Science 53:702-708.

Jha, P., J. K. Norsworthy, W. Bridges Jr., and M. B. Riley. 2008. Influence of glyphosate timing and row width on Palmer amaranth (*Amaranthus palmeri*) and Pusley (*Richardia spp.*) demographics in glyphosate-resistant soybean. Weed Science 56:408-415.

Keely, P. E., C. H. Carter, and R. J. Thullen. 1987. Influence of planting date on growth of Palmer amaranth (*Amaranthus palmeri*). Weed Science 35:199-204.

Klingaman, T. E. and L. R. Oliver. 1994. Palmer amaranth (*Amaranthus palmeri*) interference in soybean (*Glycine max*). Weed Science 42:523-527.

Leikam, D., R. E. Lamond, L. C. Banczkowski, J. S. Hickman, and D. A. Whitney. 2007. Using legumes in crop rotations Publication L-778 Cooperative Extension Service, Kansas State University, Manhattan, KS.

McKnee, R. 1931. Austrian winter pea has superior value as a green manure crop. Yearbook of Agriculture 1931. P. 104-106.

McVay, K. A., D. E. Radcliffe, and W. L. Hargrove. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. Soil Science Society of America Journal 53:1856-1862.

Moore, J. W., D. S. Murray, and R. B. Westerman. 2004. Palmer amaranth (*Amaranthus palmeri*) effects on the harvest and yield of grain sorghum (*Sorghum bicolor*). Weed Technology 18:23-29.

Norsworthy, J. K., M. S. Malik, P. Jha, and M. B. Riley. 2007. Suppression of *Digitaria sanguinalis* and *Amaranthus palmeri* using autumn-sown glucosinolate-producing cover crops in organically grown bell pepper. Weed Research 47:425-432.

Primiani, M. M., J. C. Cotterman, and L. L. Saari. 1990. Resistance of kochia (*Kochia scoparia*) to sulfonylurea and imidazolinone herbicides. Weed Technology 4:169-172.

Reddy, K. N. and C. H. Koger. 2004. Live and killed hairy vetch cover crop effects on weeds and yield in glyphosate-resistant corn. Weed Technology 18:835-840.

Saito, K., B. Linquist, D. E. Johnson, S. Phenchanh, T. Shiraiwa, and T. Horie. 2008. Planted legume fallows reduce weeds and increase soil N and P contents but not upland rice yields. Agroforest Systems 74:63-72.

Shaner, D. L. 2000. The impact of glyphosate-tolerant crops on the use of other herbicides and on resistance management. Pest Management Science 56:320-326.

Stubbendieck, J., M. J. Coffin, and L. M. Landholt. 2003. Weeds of the Great Plains. Nebraska Department of Agriculture. Lincoln, Nebraska.

Teasdale, J. R. and C. L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agronomy Journal 85:673-680.

Troeh, F. R., J. A. Hobbs, and R. L. Donahue. 2004. Soil and water conservation for productivity and environmental protection. Fourth Edition. Pearson Education. Upper Saddle River, New Jersey.

Vencill, W. K. and P. A. Banks. 1984. Effects of tillage systems and weed management on weed populations in grain sorghum (*Sorghum bicolor*). Weed Science 42:541-547.

Williams II, M. M., D. A. Mortensen, and J. W. Doran. 1998. Assessment of weed and crop fitness in cover crop residues for integrated weed management. Weed Science 46:595-603.

Figures and Tables

Figure 3.1 Proportion of Palmer amaranth density for each cover crop treatment including no-cover chemical fallow (CF), doublecrop soybean (DSB), forage soybean (FB), and sudangrass (SG) relative to the proportion of peak density in chemical fallow during the winter wheat phase over days of the year starting on May 31, 2008 (DOY152) and May 10, 2009 (DOY139) at Manhattan, KS.

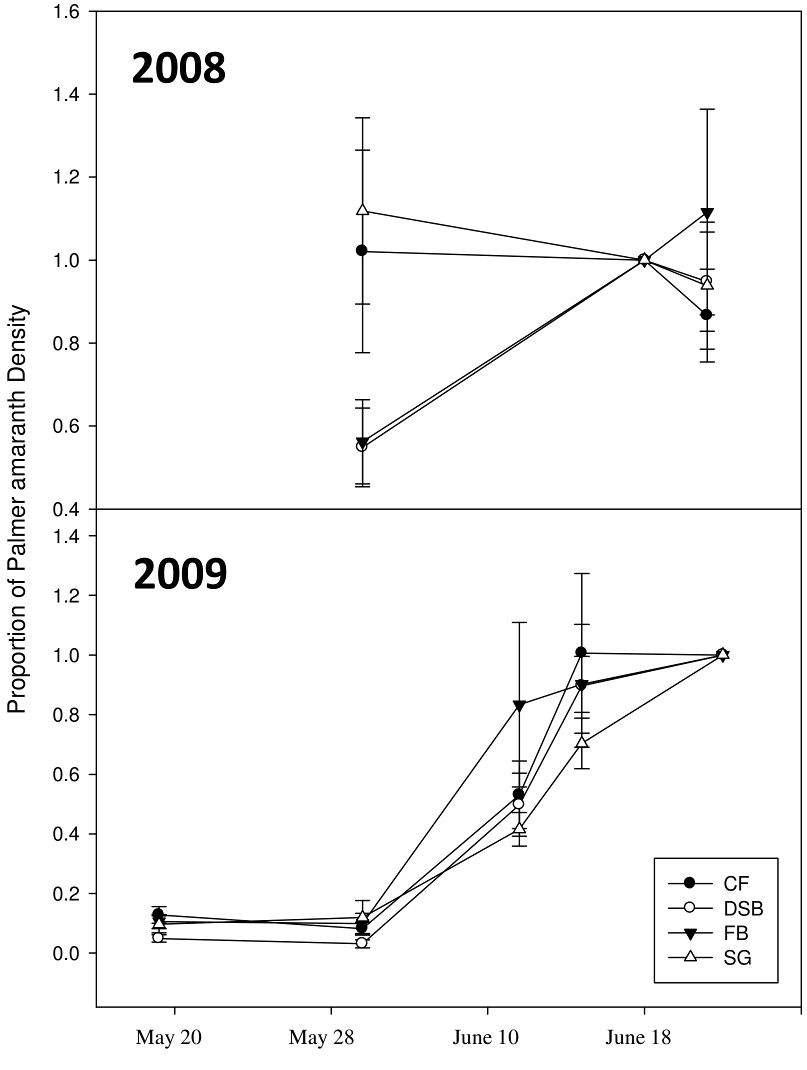

Figure 3.2 Proportion of Palmer amaranth density for each cover crop treatment including no-cover chemical fallow (CF), doublecrop soybean (DSB), forage soybean (FB), and sudangrass (SG) relative to the proportion of peak density in chemical fallow for the cover crop phase of the crop rotation that received a burndown application of glyphosate over days of the year starting at July 25, 2008 (DOY 207) and July 7, 2009 (DOY 187) at Manhattan, KS.

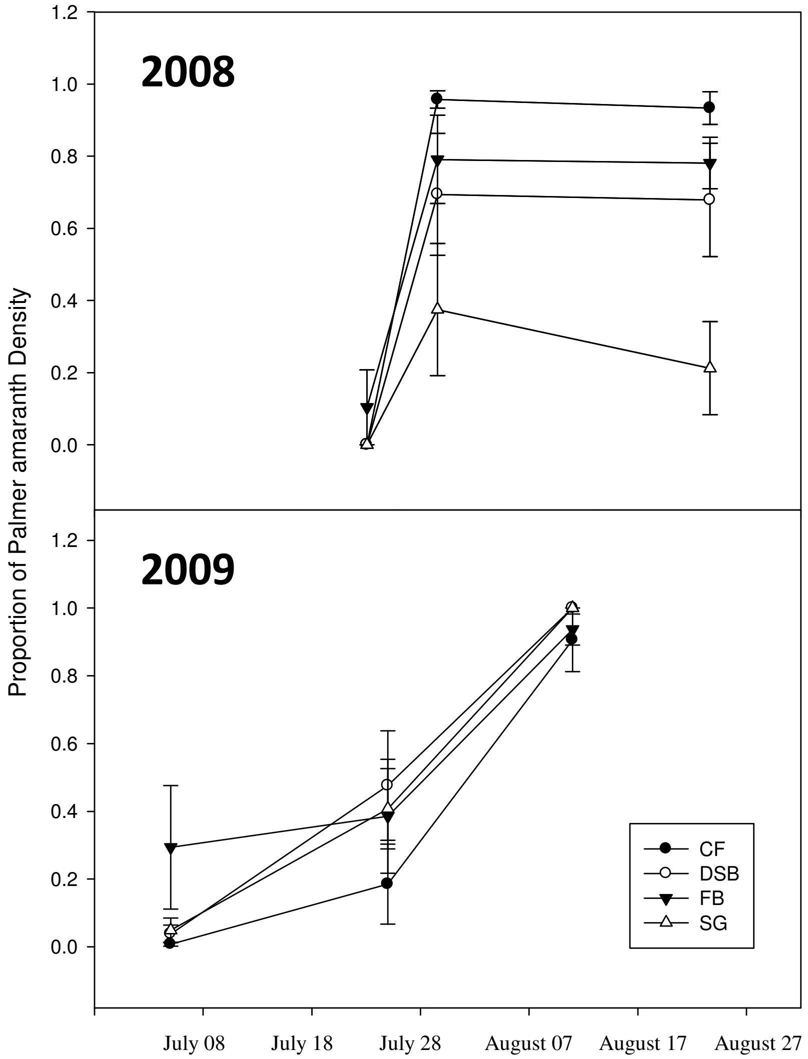

Figure 3.3 Proportion of Palmer amaranth density for each cover crop treatment including no-cover chemical fallow (CF), doublecrop soybean (DSB), forage soybean (FB), and sudangrass (SG) relative to the proportion of peak density in chemical fallow for the cover crop phase of the crop rotation that did not receive a burndown application of glyphosate over days of the year starting at July 25, 2008 (DOY 207) and July 7, 2009 (DOY 187) at Manhattan, KS.

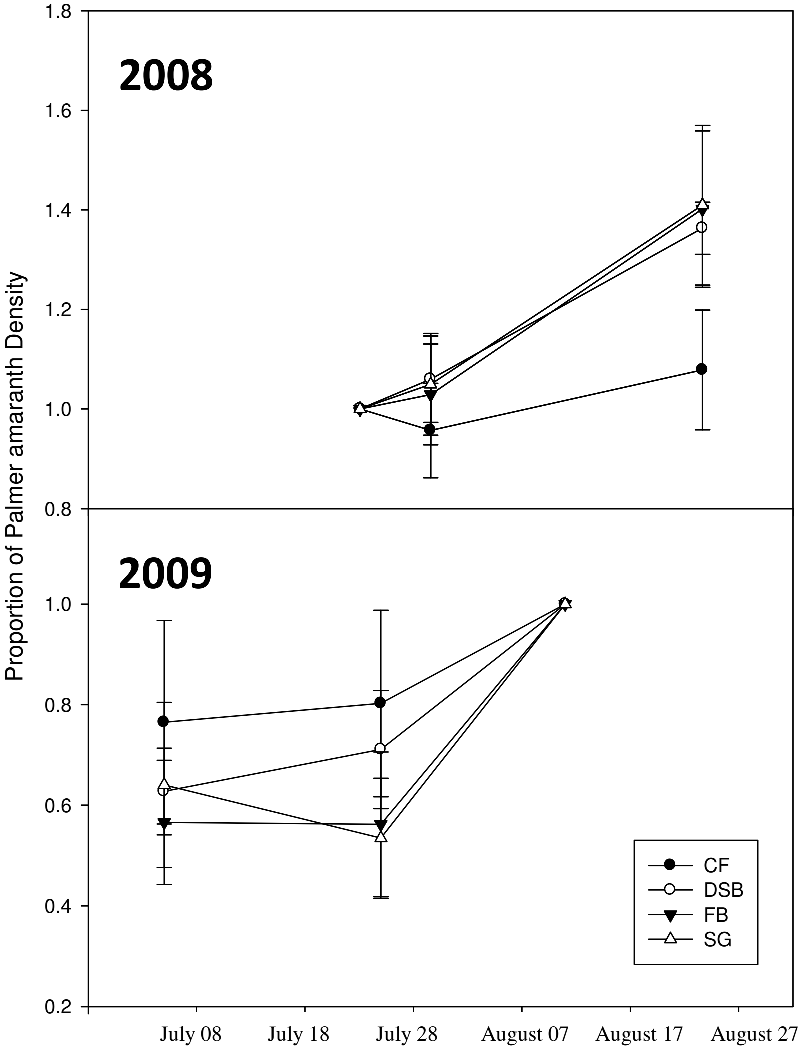

Figure 3.4 Palmer amaranth density (plants/m2) at the end of growing season in August with a burndown treatment or no treatment of glyphosate prior to cover crop planting in 2008 and 2009. Average values compared using a standard error bar.

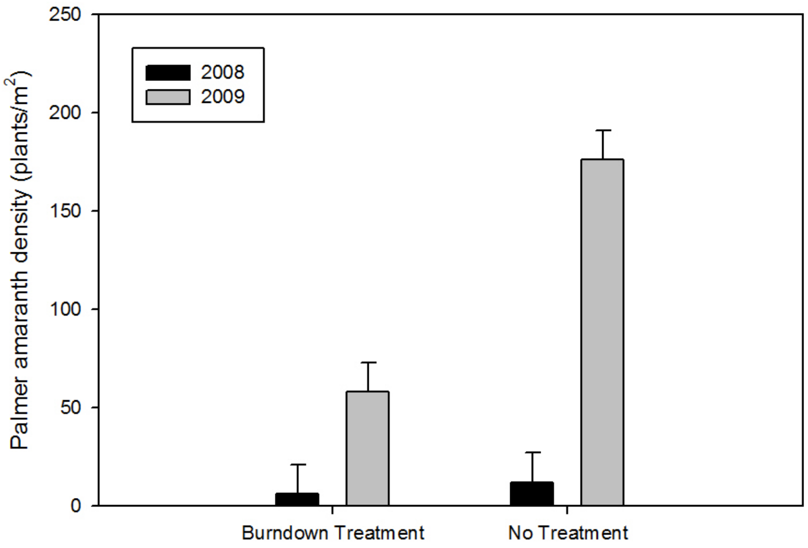

Figure 3.5 Proportional reduction of Palmer amaranth biomass relative to chemical fallow across cover crop biomass (g/m^2) for the 2009 growing season in plots that received a burndown application of glyphosate prior to cover crop planting. Points represent raw proportional reduction of Palmer amaranth biomass compared to fallow data and line was fit to data: Red =4411+0.004*CCbio, (R^2 = 0.18).

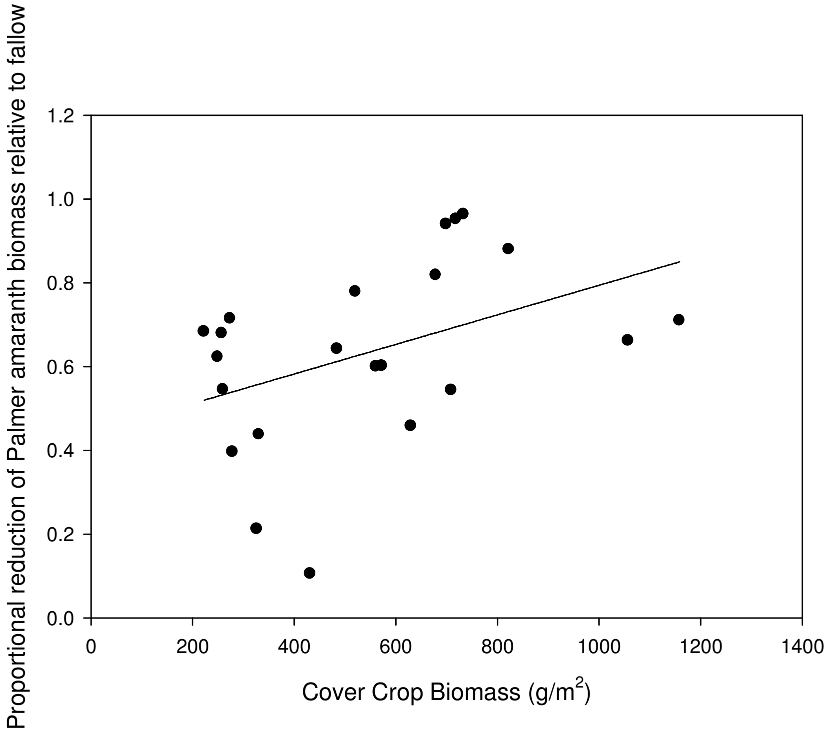

Figure 3.6 Palmer amaranth fecundity (x1000 seeds/plant) relative to plant biomass (g/plant). Points represent individual plant biomass and seed production and line was fitted to data: f=exp(0.0045*x) (R^2=0.77).

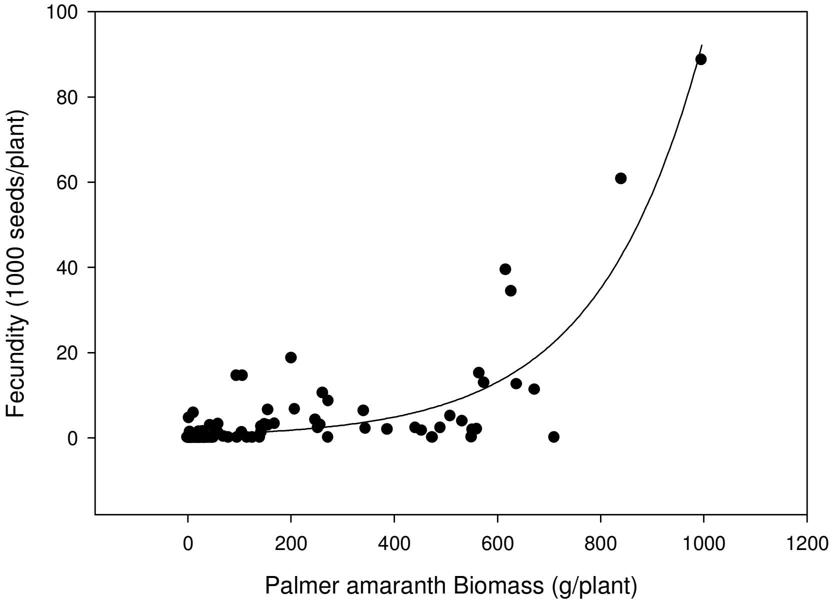

Figure 3.7 Palmer amaranth density (plants/m^2) in August in response to preemergence herbicide treatment in the grain sorghum phase of the rotation for 2008 and 2009. Average density values compared with a standard error bar.

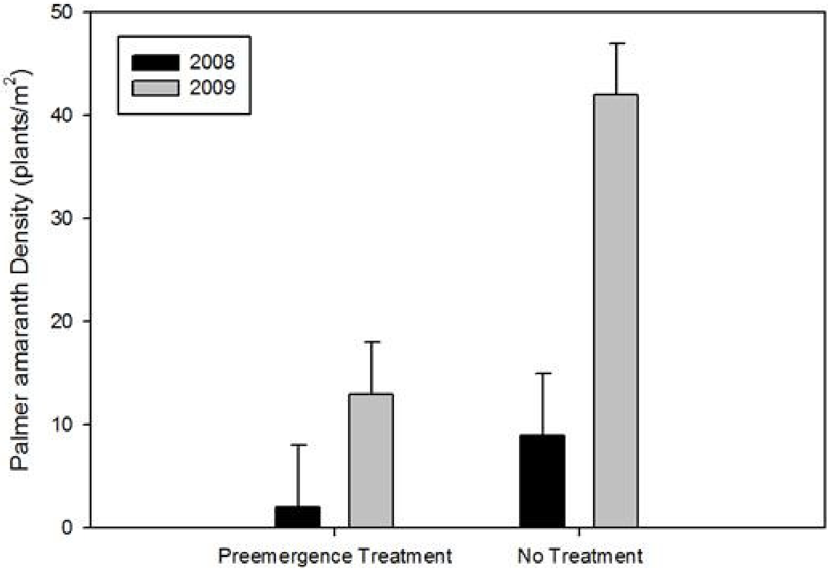

Figure 3.8 Palmer amaranth biomass (g/m2) in response to 0 and 134 kg N/ha application in the grain sorghum phase of the rotation for 2008 and 2009. Average biomass values compared with a standard error bar.

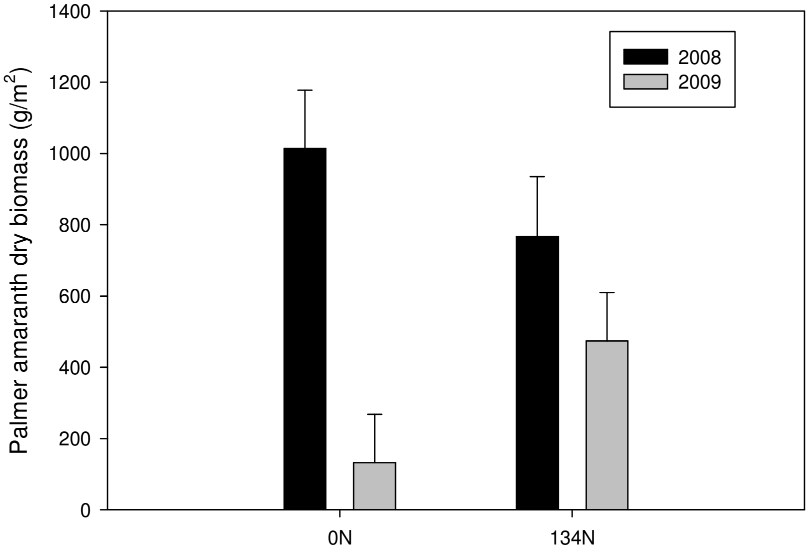

Table 3.1 Average monthly air temperature and total monthly precipitation for 30-year Normal (1971-2000), 2008, and 2009 at Manhattan, KS.

	Average Temperature (C)			Total Precipitation (mm)		
Month	Normal	2008	2009	Normal	2008	2009
March	7.33	5.29	7.01	60	59	80
April	13.03	10.47	11.83	82	52	138
May	18.42	17.38	17.99	126	121	12
June	23.67	23.24	23.66	131	304	207
July	26.44	25.72	23.12	110	129	128
August	25.58	23.8	22.87	87	117	135
Total				597	782	700

Table 3.2 Cover crop biomass (kg/ha) for 2008 and 2009 harvest by season. Values with the same letter within column and growing season are not significantly different according to pairwise comparison in PROC MIXED.

Harvest Season	Cover Crop	Cover Crop Biomass	
		2008	2009
		kg/ha	
Spring	Canola	446	68
	Austrian winter pea	1981	111
	Standard Error	514	558
Fall	Doublecrop soybean	1351	2754
	Forage soybean	4590	5491
	Sudangrass	8853	8231
	Standard Error	437	

Table 3.3 Palmer amaranth biomass (g/m^2) in response to cover crop and herbicide treatment in 2008 and 2009. Values with the same letter within column are not significantly different according to pairwise comparison in PROC MIXED.

	Palmer amaranth biomass			
	2008		2009	
Cover Crop	Untreated	Burndown	Untreated	Burndown
	---------- g/m^2 ----------			
Chemical Fallow	1233 a	119 a	428 a	128 a
Doublecrop soybean	1020 a	4.0 a	292 a	59 a
Forage soybean	1234 a	23 a	398 a	57 a
Sudangrass	261 b	0.004 a	239 a	17 a
Standard Error	135		141	

Table 3.4 Palmer amaranth density in the grain sorghum phase of the rotation on May 31, 2008 and June 1, 2009 as impacted by cover crop treatment. Values with the same letter within column are not significantly different according to pairwise comparison in PROC MIXED and an * denotes significant difference between a treatment across years.

	Palmer amaranth density		
Cover Crop	2008	2009	Between Year
	plants/m^2		
Chemical fallow	8 ab	8 a	NS
Doublecrop soybean	12 ab	23 a	*
Forage soybean	15 a	10 a	NS
Sudangrass	6 b	0.5 a	NS
Canola	15 a	7 a	NS
Austrian winter pea	3 b	28 a	*
Standard Error	9	9	

CHAPTER 4 - Palmer amaranth and downy brome response to soybean cover crop

Abstract

Palmer amaranth and downy brome flourish during the nine month fallow period after winter wheat harvest before planting a summer annual crop. Weed emergence and biomass accumulation could be minimized using cover crops during the fallow period. Field experiments were established at the Department of Agronomy North Farm in Manhattan, KS in 2008 and 2009 and at the Department of Agronomy Harvey County Experiment Field in Hesston, KS in 2008. Five soybean seeding rates (100, 225, 350, 475, and 600 thousand seed/ha) and a no-cover control were arranged in a randomized complete block design with four replications. Three termination methods were stripped across seeding rates and included killing freeze, herbicide application, and crop rolling. Palmer amaranth was seeded at 100 seed / 0.5 m^2 quadrats in July of each year in each seeding rate main plot. Downy brome was seeded at 250 seed / 0.5 m^2 quadrats in September or early October of each site year into each termination subplot. Soybean biomass production was greatest at Manhattan in 2008 and 2009 and the least in Hesston in 2008. Palmer amaranth emergence was greater in Hesston compared to both years in Manhattan but it was not different across soybean seeding rates. Presence of the late season soybean cover crop decreased Palmer amaranth biomass compared to the no-cover control at all locations. Total Palmer amaranth biomass was negatively affected by increasing soybean biomass at all locations. Downy brome emergence was less in the rolled termination method than in the killing freeze and herbicide application methods in Manhattan in 2008 but was not affected by termination methods in 2009. The presence of the forage soybean cover crop reduced Palmer amaranth biomass accumulation and the cover crop termination method influenced downy brome emergence.

Introduction

Intensification of a crop rotation by adding cover crops has demonstrated value in Kansas and the surrounding Great Plains. Shortening the fallow period by including a cover crop provides many benefits including reduced soil erosion, improved soil physical properties, addition of nutrients like nitrogen through fixation by leguminous crops, and suppression of weeds (Al-Khatib et al. 1997, Leikam et al. 2007, Teasdale et al. 2005, Troeh et al. 2004). Weed suppression can be a result of direct competition of the cover crop with the weed or through the crop's ability to alter the growing environment (Facelli and Picket 1991, Fisk et al. 2001). Cover crops can reduce soil moisture content, moderate soil temperatures, and intercept light entering though the canopy (Facelli and Picket 1991, Teasdale et al. 1991, Teasdale and Mohler 1993). These unique properties give cover crops the capability to affect weed emergence and growth.

Palmer amaranth and downy brome are competitive species. Palmer amaranth reduced yields in corn by 11 to 91% and in soybean by 17 to 68% depending on Palmer amaranth density (Klingaman and Oliver 1994, Massinga et al. 2001). Palmer amaranth also reduced grain sorghum yield by 9.1% for every kilogram of Palmer amaranth biomass produced (Moore et al. 2004). Downy brome competes with winter wheat and reduced yields up to 20% with 65 plants/m^2 (Stahlman and Miller 1990). The potential exists to reduce the emergence and growth of these weeds with the addition of a late season soybean cover crop after winter wheat harvest.

A full-season soybean crop reduced Palmer amaranth biomass up to 97% without the aid of chemical control (Monks and Oliver 1988). A cover crop alone could control weed species, yet control of weeds was correlated to cover crop final biomass (Barberi and Mazzoncini 2001). Arid climates with high temperatures have the potential to limit soybean biomass and therefore jeopardize control. It is important to test and optimize the growth and competition of soybeans after winter wheat in both arable and arid regions in Kansas.

The objectives of this study were to (1) monitor the response of Palmer amaranth emergence and growth to different soybean seeding rates after winter wheat harvest, (2) monitor the growing environment of Palmer amaranth by measuring light availability at the soil surface, and to (3) determine if soybean seeding rate and cover crop termination method affect downy brome emergence in the fall.

Materials and Methods

Field experiments were established at Department of Agronomy North Farm, Manhattan, KS on a Wymore silty clay loam soil in 2008 and 2009, and at the Department of Agronomy Harvey County Experiment Field, near Hesston, KS on a Ladysmith silty clay loam soil in 2008. Main plot treatments included six soybean seeding rates (0, 100, 225, 350, 475, and 600 thousand seeds / ha). Three cover crop termination methods were imposed: killing freeze, herbicide application, or crop rolling. Late-maturing, maturity group V soybean varieties were selected, with “Hutcheson” in 2008 and “KS5502N” in 2009. Soybeans were no-till drilled at 0.25-m row spacing into winter wheat stubble following a burndown application of glyphosate at 408 g ae/ha. Planting dates were June 30, 2008 and July 7, 2009 in Manhattan, and July 7, 2008 in Hesston. Main plots were 9.1 m by 4.6 m with the three termination method subplots stripped across main plots with dimensions of 3 m by 4.6 m.

Palmer amaranth quadrats were 0.375 m by 1.33 m and were sown into each main plot at 100 seed / 0.5 m^2 on the same day as cover crop planting at all three site-years. Downy brome quadrats were 0.375 m by 1.33 m and were seeded at 250 seed / 0.5 m^2 on September 28, 2008 and September 28, 2009 in Manhattan, and October 3, 2008 in Hesston into the termination subplots of each main plot.

In 2009 the Hesston site was not available and a site near Hutchinson, KS at the South Central Experiment Field was used as well as a location added near Ness City, KS with cooperator Tyler Rider. Above average temperatures and drought conditions at the time of cover crop planting and during the early growing season resulted in poor soybean emergence and growth at the Hutchinson and Ness City sites. Soybean populations were less than expected at both locations. No Palmer amaranth emergence was recorded at Ness City and both seeded and natural populations of Palmer amaranth overtook the Hutchinson location. Thus, both of these 2009 experiment locations were abandoned.

Weed emergence and density counts were monitored every two weeks during the growing season. Soybean canopy development was monitored at least once a month with a LiCor Li-2000 canopy analyzer. A reference reading was taken above the canopy to measure incoming irradiance and then five readings were taken below the canopy at every 0.5 m of row. The analyzer compares light interception from the above canopy reading to the five below canopy readings and calculates LAI and standard error. Readings were taken down the center of a single row in each main plot. The same row was measured throughout the season. To account for standing wheat stubble, measurements were also taken in the no-cover control for each replication as described above. These values were subtracted from the LAI readings for each seeding rate, replication, and date that measurements were taken.

Aboveground portions of Palmer amaranth and soybean within each quadrat were harvested on September 28, 2008 and October 5, 2009 at Manhattan and October 3, 2008 at Hesston. On the same dates aboveground biomass estimates of soybean main plots were obtained by harvesting four rows by 3.05 m. Samples were dried for 48 hours at 60 C to obtain biomass. The soybean cover crop was terminated on October 18, 2008 and October 19, 2009 at Manhattan and on October 28, 2008 at Hesston.

Soybean and Palmer amaranth quadrat biomass, Palmer amaranth quadrat density, soybean main plot biomass, LAI readings taken closest to harvest, and downy brome emergence in response to soybean seeding rate and termination method across site-years were analyzed using Proc Mixed in SAS v9.13. The Proc Mixed procedure computed both least-squared means and least-squared standard error at alpha = 0.05. The relationship of soybean main plot and quadrat biomass to seeding rate was analyzed by fitting the crop yield model described by Cousens (1985) in Sigma Plot 10.0:

$$\text{SBbio} = [(I*\text{rate})/(1+((I*\text{rate})/A))] \qquad \text{(Equation 4.1)}$$

where SBbio is soybean biomass in kg/ha for main plots and g/m^2 for quadrats, rate is the soybean seeding rate (x1000 seeds/ha), I is the slope of the line for soybean biomass as seeding rate approaches 0, and A is the maximum soybean biomass as the seeding rate approaches infinity. Palmer amaranth biomass in response to soybean seeding rate was modeled using linear regression:

$$\text{PA bio} = \text{Cbio} + \text{PAreduc}*\text{rate} \qquad \text{(Equation 4.2)}$$

where PA bio is Palmer amaranth biomass (g/m^2), rate is soybean seeding rate (x1000 seed/ha), Cbio is predicted Palmer amaranth biomass with no cover crop, and PAreduc is the slope, describing the rate at which soybean seeding rate reduces Palmer amaranth biomass. Change in LAI over the season for each soybean seeding rate was modeled using a quadratic equation:

$$\text{LAI} = y0 + \text{slope}*\text{rate} + \text{quad}*\text{rate}^2 \qquad \text{(Equation 4.3)}$$

where LAI is leaf area index recorded, rate is soybean seeding rate (x1000 seed/ha), y0 is the y intercept, slope is the linear parameter that determines increase in LAI over the season, and quad is the quadratic coefficient that determines the decrease in slope to the maximal point or how quickly maximum LAI is achieved. To determine if differences existed between soybean canopy development rate (LAI), by seeding rate, 95% confidence intervals were plotted for each site-year in Sigma Plot 10.0. From the point lower confidence intervals of one equation diverged from upper intervals of another seeding rate equation leaf area accumulation was deemed significantly different.

Weather data were compiled from the online Kansas State Weather Data Library (http://wdl.agron.ksu.edu) and 30-yr precipitation values were obtained from the High Plains Regional Climate Center Database (http://www.hprcc.unl.edu/). Data were not available for the 30-yr normal values at Hesston, KS so weather data was used from Newton, KS 10 km from the experiment site.

Results and Discussion

Weather patterns varied little between Manhattan and Hesston in 2008 with similar average monthly temperatures (Table 4.1). Temperatures in Manhattan in 2008 were similar to the 30-yr normal but in 2009 temperatures were below normal in every month except November. Average monthly temperatures at Hesston in 2008 were similar to the 30-yr normal except in September when the average temperature was 7 C below the 30-yr normal. Monthly precipitation during the planting month of July was similar across all three site-years. Timely precipitation on July 8, 2008 at Hesston ensured adequate moisture at planting. Significant precipitation at Manhattan soon after planting provided enough moisture for both soybean and Palmer amaranth emergence to occur in both years. Heavy precipitation in October 2008 at Hesston delayed cover crop termination.

Initial biomass accumulation by the late season soybean cover crops at low seeding rates was similar based on regression analysis with the yield model described in Cousens et al. (1985) (Figure 4.1 and Table 4.2). Maximum biomass accumulation at high seeding rates was similar across years at the Manhattan location and both were larger than Hesston in 2008 (Table 4.2). Least-squared mean estimates of soybean main plot biomass demonstrated that biomass production peaked at the 225,000 seeds/ha rate in Hesston 2008 and at the 350,000 seeds/ha rate in Manhattan 2008 and 2009 (Figure 4.1).

Leaf area index values for Hesston 2008 and Manhattan 2009 were analyzed separately because of differences in location and soybean varieties planted. Regression analysis of the Hesston data showed differences in LAI and mean separation showed differences in LAI values near soybean harvest. Analysis with 95% confidence intervals showed that LAI of the 225,000 to 600,000 seeds/ha seeding rates diverged from the 100,000 seeds/ha rate at 7 weeks after planting (WAP) (Figure 4.2). LAI values were similar for the 225,000 to 600,000 seeds/ha rates throughout the season. The linear and quadratic coefficients of Equation 4.3 for the 225,000 to 600,000 seeds/ha rates were not significantly different, but were different from the 100,000 seeds/ha rate (Table 4.3). This also corresponds to the peak in main plot soybean biomass being reached at the 250,000 seeds/ha rate. At Hesston LAI peaked at 11 WAP. Leaf area index decline was similar for all seeding rates after 15 WAP.

At Manhattan in 2009 LAI varied by seeding rate. The 100,000 and 225,000 seeds/ha rates had similar values (Figure 4.2, Table 4.3). All model parameters for Equation 4.3 fit to the seeding rates were equivalent and the upper and lower 95% confidence intervals of the 100,000 and 225,000 seeds/ha rate equations did not diverge. LAI values for the 350,000 to 600,000 seeds/ha rates were equivalent, however the 600,000 seeds/ha rate reached peak LAI two weeks before the 475,000 seeds/ha rate. At soybean biomass harvest LAI estimates were significantly different for all treatments except the 475,000 and 600,000 seeds/ha rates (Table 4.5). The divergence in LAI of the 100,000 and 225,000 seeds/ha rates may have resulted from infestation of bean pod mottle virus over the entire Manhattan site in 2009. The virus causes leaf chlorosis and necrosis of infected plants, which can limit LAI (Windham and Ross 1985).

Palmer amaranth density did not respond to soybean seeding rate but to site-year because both crop and weed species emerged at the same time at all locations. There was no cover crop canopy present to impact weed emergence. Palmer amaranth density averaged across all treatments at harvest was greatest at Hesston in 2008 with 21 plants/m^2 where a dense natural population supplemented seeded numbers. Emergence in Manhattan was less in 2008 with 3 plants/m^2 than in 2009 with 9 plants/m^2 with a standard error of 1 plant/m^2 across site-years. Norsworthy and Oliveira (2007) found that soybean crops did not impact common cocklebur (*Xanthium strumarium*) emergence until the V5 stage of development. The soybean crop reduced common cocklebur emergence by 84 and 94 %. In the current study had Palmer amaranth emerged after the soybean cover crop canopy had developed a decrease in emergence similar to that reported by Norsworthy and Oliveira (2007) may have been observed.

Palmer amaranth biomass in the no-cover control quadrats was similar in the Hesston 2008 and Manhattan 2009 site-years (Figure 4.3). The linear decrease in Palmer amaranth biomass as soybean seeding rate increased was similar across all three site-years (Table 4.4). Palmer amaranth biomass was decreased by the presence and increasing seeding rates of the soybean cover crop. Hesston had the greatest initial increase in soybean biomass as seeding rate increased in competition with Palmer amaranth (Figure 4.3 and Table 4.4). With weed competition, initial increase in soybean biomass was intermediate for Manhattan 2008 and lowest for Manhattan 2009 (Table 4.4). In both site years at Manhattan average soybean biomass at the 600,000 seeds/ha rate was greater than the 475,000 seeds/ha rate (Figure 4.3). Least-squared means for Palmer amaranth biomass were similar from the 350,000 to 600,000 seeds/ha rate (Figure 4.3). The response of soybean biomass indicates that higher seeding rates may be required to optimize soybean biomass competition with weed populations.

End of season soybean quadrat biomass was not a predictor of Palmer amaranth biomass harvested on the same day. However, soybean biomass increased to an optimum with soybean seeding rate as Palmer amaranth biomass decreased (Figure 4.3). This shows that greater soybean biomass may have played a role in Palmer amaranth biomass response.

Least-square means estimates of soybean main plot biomass correspond to estimates of Palmer amaranth biomass. In each site year where estimates of soybean main plot biomass were greatest (225,000, 350,000, and 350,000 seeds/ha for Hesston 08, Manhattan 08 and 09, respectively). Palmer amaranth biomass estimates were the lowest of the seeding rates (Figure 4.1 and Figure 4.3). The reduction of Palmer amaranth biomass by greater soybean biomass at higher seeding rates is supported by the findings of Barberi and Mazzoncini (2001) who reported a similar negative response of weed biomass to increasing cover crop biomass. Palmer amaranth biomass at harvest was highest for the no cover control and the 100,000 seeds/ha rate and lowest for the 225,000 to 600,000 seeds/ha rates (Figure 4.3). The negative response of Palmer amaranth biomass to the 225,000 to 600,000 seeds/ha rates suggests that faster developing soybean canopies that reach a higher LAI are more competitive than those of the 100,000 seeds/ha rate. At soybean harvest LAI estimates of the 100,000 seeds/ha rate was lower than the 225,000 to 600,000 seeds/ha rates (Table 4.5). Kruidhof et al. (2008) reported similar results showing that as the rate of light interception by *Brassica* and grass cover crops increased weed biomass decreased.

Downy brome emergence in response to termination method varied by site-year. Average emergence was the least at Hesston with 23 (SE 5) plants/m^2 and greatest at Manhattan with an average of 75 (SE 5) plants/m^2 emerging in 2008 and 70 (SE 5) plants/m^2 emerging in 2009. There was no soybean seeding rate effect on the emergence of downy brome for any site-year. At Hesston in 2008 termination treatments were carried out after initial downy brome emergence and no differences were observed in response to termination treatment (Table 4.6). Differences across years at Manhattan were observed even though termination treatments were applied on similar calendar dates of October 18, 2008 and October 19, 2009. In 2008 downy brome responded to the crop rolling treatment with a reduction in emergence compared to the freeze and glyphosate application treatments. In 2009 no differences in downy brome response was observed between all three treatments. Downy brome response to termination methods may have been confounded in the Hesston 2008 and Manhattan 2009 site-years by frost occurring before cover crop termination. The first killing freeze occurred on October 26, 2008 at Hesston and October 9, 2009 at Manhattan. Future research on the response of downy brome to termination methods should include an herbicide application after downy brome emergence because that is a common practice during fallow periods. Thill et al. (1979) found downy brome emergence was decreased with soil compaction. Research should monitor if the crop roller causes compaction, which may reduce downy brome emergence. All research should track downy brome into the following spring.

In this study planting at 225,000 seeds/ha in Hesston and 350,000 seeds/ha in Manhattan provided optimal canopy growth and high soybean biomass production. Replication of the study is needed to ensure these seeding rates are effective and to determine if higher seeding rates are needed in areas with high weed infestations.

References

Al-Khatib, K., C. Libbey, and R. Boydston. 1997. Weed suppression with *Brassica* green manure crops in green pea. Weed Science 45:439-445

Barberi, P. and M. Mazzoncini. 2001. Changes in weed community composition as influenced by cover crop and management system in continuous corn. Weed Science 49:491-499.

Cousens, R. 1985a. A simple model relating yield loss to weed density. Ann. App. Biol.107:239-252.

Facelli, J. and M. Picket. 1991. Plant litter: Light interception and effects on an old-field plant community. Ecology 72:1024-1031.

Fisk, J. W., O. Hesterman, A. Shrestha, J. J. Kells, R. R. Harwood, J. M. Squire, and C. C. Sheaffer. 2001. Weed suppression by annual legume cover crops in no-tillage corn. Agronomy Journal 93:319-325.

Kruidhof, H. M., L. Bastiaans, and M. J. Kropff. 2008. Ecological weed management by cover cropping: effects on weed growth in autumn and weed establishment in spring. Weed Research 48: 492-502.

Klingaman, T.E. and L. R. Oliver. 1994. Palmer amaranth (*Amaranthus palmeri*) interference in soybean (*Glycine max*). Weed Science 42:523-527.

Leikam, D., R. E. Lamond, L. C. Banczkowski, J. S. Hickman, and D. A. Whitney. 2007. Using legumes in crop rotations Publication L-778 Cooperative Extension Service, Kansas State University, Manhattan, KS.

Massinga, R.A., R. S. Currie, M. J. Horak, and J. Boyer Jr. 2001. Interference of Palmer amaranth in corn. Weed Science 49:202-208.

Monks, D. W. and L. R. Oliver. 1988. Interactions between Soybean (*Glycine max*) cultivars and selected weeds. Weed Science 36:770-774.

Moore, J. W., D. S. Murray, and R. B. Westerman. 2004. Palmer amaranth (*Amaranthus palmeri*) effects on the harvest and yield of grain sorghum (*Sorghum bicolor*). Weed Technology 18:23-29.

Norsworthy, J. K. and M. J. Oliveira. 2007. Tillage and soybean canopy effects on common cocklebur (*Xanthium strumarium*) emergence. Weed Science 55:474-480.

Stahlman, P. W. and S. D. Miller. 1990. Downy brome (*Bromus tectorum)* interference and economic thresholds in wheat (*Triticum aestivum*). Weed Science 38:224-228.

Teasdale, J. R., C. E. Beste, and W. E. Potts. 1991. Response of weeds to tillage and cover crop residue. Weed Science 39:195-199.

Teasdale, J. R. and C. L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agronomy Journal 85:673-680.

Teasdale, J. R., P. Pillai, and R. T. Collins. 2005. Synergism between cover crop residue and herbicide activity on emergence and early growth of weeds. Weed Science 53:521-527.

Thill, D. C., R. D. Schirman, and A. P. Appleby. 1979. Influence of soil moisture, temperature, and compaction on the germination and emergence of downy brome (*Bromus tectorum*). Weed Science 27:625-630.

Troeh, F. R., J. A. Hobbs, and R. L. Donahue. 2004. Soil and water conservation for productivity and environmental protection. Fourth Edition. Pearson Education. Upper Saddle River, New Jersey.

Windham, M. T. and J. P. Ross. 1985. Phenotypic responses of six soybean cultivars to bean pod mottle virus infection. Ecology and Epidemiology 75: 305-309

Figures and Tables

Figure 4.1 Response of soybean main plot biomass across seeding rate at Manhattan, KS in 2008 and 2009 and Hesston, KS in 2008. Regression curves are fit to Equation 4.1 with the solid line representing Manhattan 2008, dashed-dotted line representing Manhattan 2009, and the dashed line representing Hesston. Points are least-squared means by seeding rate and site-year with least squared standard error with closed circles (Manhattan 2009), open diamonds (Manhattan 2009), and closed squares (Hesston 2008). Parameter estimates for Equation 1 are listed in Table 4.2.

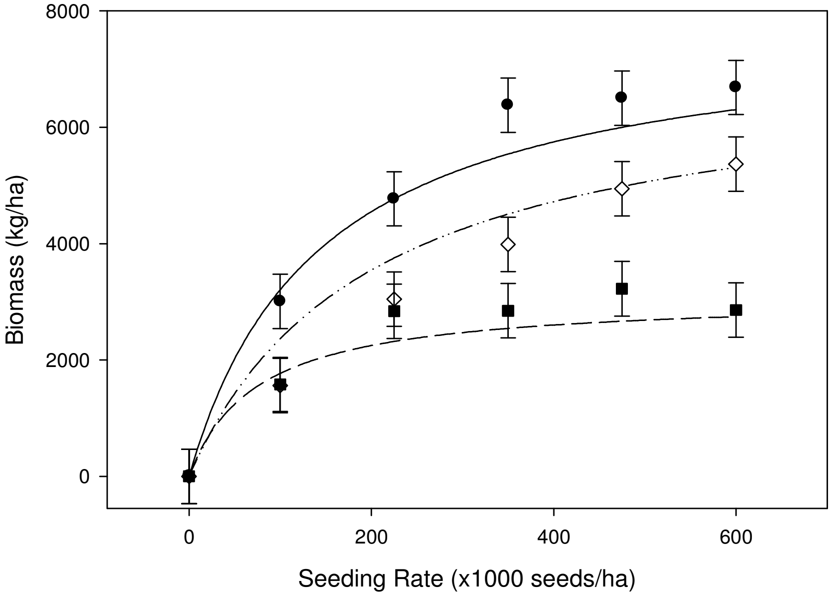

Figure 4.2 Soybean leaf area index (LAI) for each seeding rate (x1000 seeds/ha) over weeks after planting for Hesston 2008 and Manhattan 2009. Parameter estimates for Equation 4.3 listed in Table 4.3.

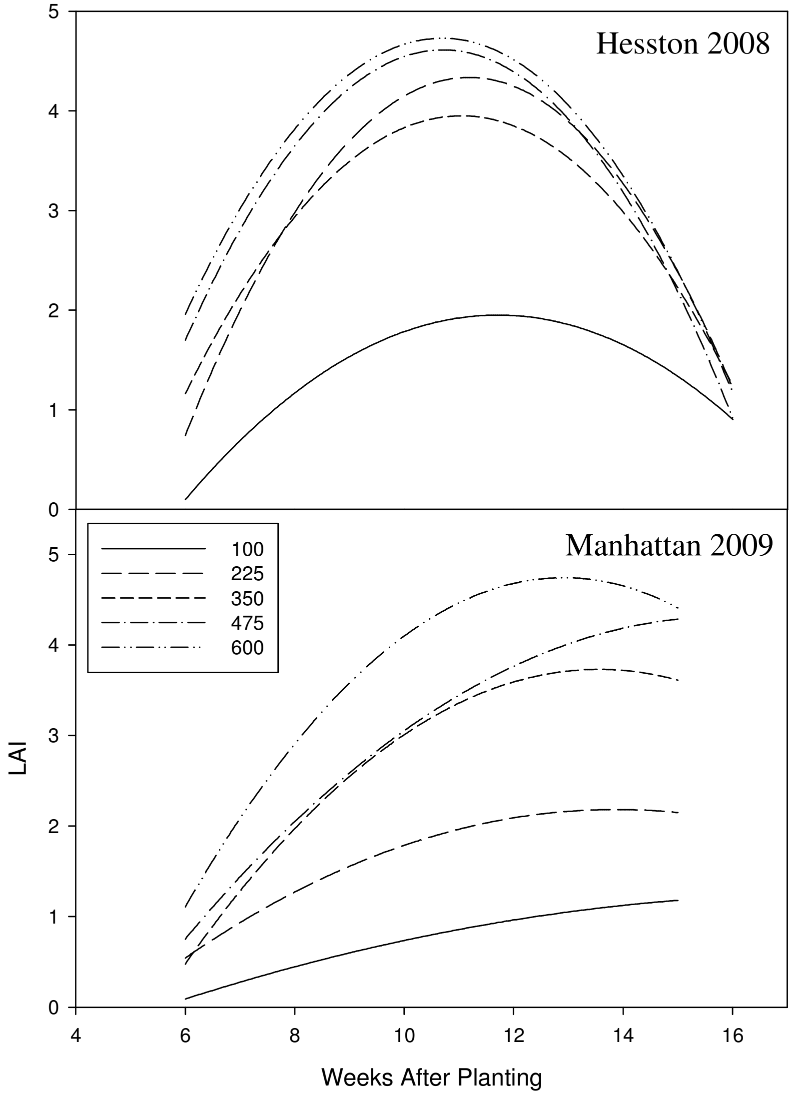

Figure 4.3 Response of soybean and Palmer amaranth biomass (g/m^2) to soybean seeding rate (x1000 seeds/ha). Regression of response of soybean (dashed line) plotted using Equation 4.1 and Regression of the response of Palmer amaranth (solid line) plotted using Equation 4.2. Points represent least-squared means of soybean (open diamond) and Palmer amaranth (closed circle) with least-squared standard errors computed for each seeding rate by site year. Parameter estimates listed in Table 4.4.

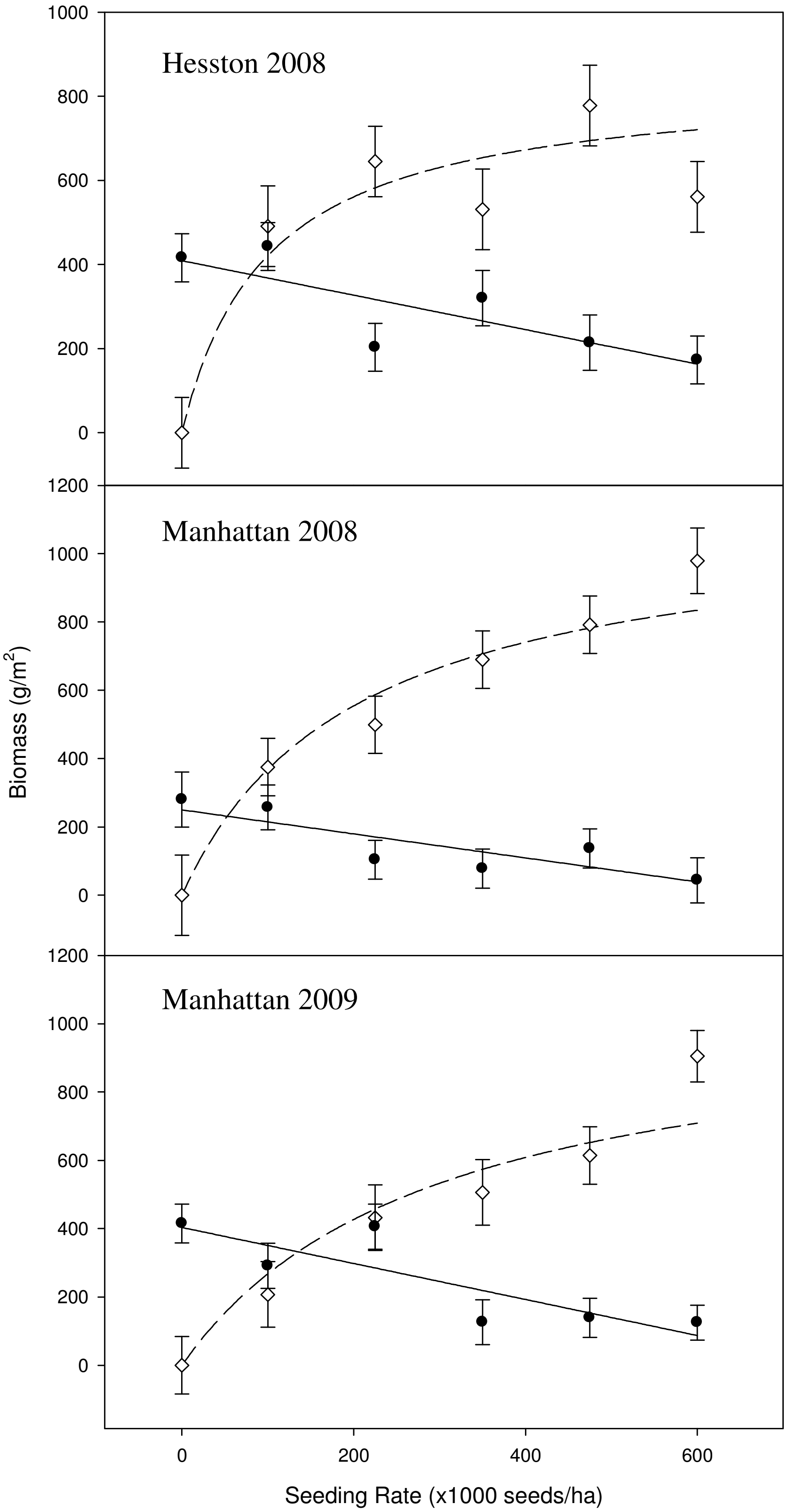
Hesston 2008
Manhattan 2008
Manhattan 2009
Biomass (g/m^2)
Seeding Rate (x1000 seeds/ha)
0
200
400
600
800
1000
1200
0
200
400
600

Table 4.1 Monthly average and 30 year normal temperature and precipitation data for the 2008 and 2009 growing season for Manhattan and Hesston, KS.

	Average Temperatures					Precipitation				
Month	Manhattan			Hesston		Manhattan			Hesston	
	2008	2009	30 yr Normal	2008	30 yr Normal	2008	2009	30 yr Normal	2008	30 yr Normal
	------------C------------					------------mm------------				
July	26	23	26	26	24	129	128	120	120	85
August	24	23	25	25	27	117	135	76	99	82
September	19	18	20	19	26	178	46	87	139	74
October	13	9	14	14	15	52	59	60	103	63
November	6	8	5	7	6	22	50	25	14	57
Totals						498	418	368	475	470

Table 4.2 Parameter estimates (±SE) and R^2 values for Equation 4.1 for Figure 4.1 soybean main plot biomass by site-year across seeding rates.

		Parameter Estimates		
Year	Site	Initial Slope	Asymptote	R^2
		kg/ha		
2008	Hesston	41.48 (14.46)	3084 (278)	0.85
	Manhattan	54.43 (15.61)	7810 (947)	0.85
2009	Manhattan	35.54 (8.87)	7069 (959)	0.87

Table 4.3 Parameter estimates (±SE) and R^2 values for LAI response to site year and seeding rate (Equation 4.3) in figure 4.2.

Site-Year	Seeding Rate (x1000 seeds/ha)	Parameter Estimates			R^2
		y0	slope	Quadratic	
Hesston 2008	100	-5.89 (1.91)	1.33 (0.39)	-0.06 (0.02)	0.52
	225	-12.41 (2.44)	3.00 (0.50)	-0.13 (0.02)	0.74
	350	-9.44 (2.36)	2.42 (0.48)	-0.11 (0.02)	0.66
	475	-10.48 (1.66)	2.82 (0.34)	-0.13 (0.02)	0.86
	600	-9.67 (1.85)	2.69 (0.38)	-0.13 (0.02)	0.82
Manhattan 2009	100	-1.37 (1.32)	0.29 (0.28)	-0.01 (0.01)	0.60
	225	-2.92 (1.30)	0.74 (0.27)	-0.03 (0.01)	0.79
	350	-6.75 (2.33)	1.55 (0.47)	-0.06 (0.02)	0.83
	475	-4.89 (1.50)	1.16 (0.32)	-0.04 (0.02)	0.93
	600	-7.96 (1.26)	1.97 (0.27)	-0.08 (0.01)	0.95

Table 4.4 Parameter estimates (±SE) and R2 values for soybean biomass response to site year over seeding rate (EQ 1) in competition with Palmer amaranth (Equation 4.2) and its response to site year over seeding rate Figure 4.3.

			Parameter Estimates		
Soybean	Year	Location	Initial Slope	Asymptote	R^2
	2008	Hesston	8.44 (3.55)	840 (112)	0.80
		Manhattan	5.51 (2.49)	1116 (287)	0.59
	2009	Manhattan	3.57 (1.26)	1058 (265)	0.78
Palmer Amaranth			Cbio	PAreduc	
	2008	Hesston	408.89 (38.42)	- 0.41 (0.11)	0.28
		Manhattan	249.76 (45.89)	-0.35 (0.13)	0.44
	2009	Manhattan	403.40 (52.09)	-0.53 (0.14)	0.43

Table 4.5 LAI (±SE) recorded at time of soybean main plot biomass harvest by site year and seeding rate.

Seeding Rate (x1000 seeds/ha)	Hesston 2008	Manhattan 2009
	--------------------LAI (m^2/m^2)-------------------	
100	2.18 (0.34)	1.07 (0.34)
225	4.23 (0.34)	2.04 (0.34)
350	3.95 (0.34)	3.50 (0.34)
475	4.12 (0.34)	4.17 (0.34)
600	4.29 (0.34)	4.30 (0.34)

Table 4.6 Mean downy brome emergence (±SE) in plants/m^2 by site year and termination method.

Termination Method	Downy Brome Emergence		
	Hesston	Manhattan	
	2008	2008	2009
	---------------------plants/m^2----------------------		
Freeze	30 (14)	84 (14)	67 (14)
Glyphosate	10 (14)	63 (14)	69 (14)
Rolling	30 (14)	43 (14)	76 (14)

Appendix A - Response of kochia and downy brome to cover cropping

Raw Data

This section of the appendix contains all of the raw data from the second chapter, *Response of kochia and downy brome to cover cropping*, that may be needed for further research. Data are arranged as they appeared in the chapter and are referenced to figures and tables in which they appeared.

Table A.1 Cover crop biomass, kochia biomass, and kochia density arranged by cover crop treatment, and planting and growing season. Data used to generate figures 2.1 to 2.8.

Plot	Planting Season	Growing Season	Cover Crop Treatment	Cover Crop Biomass	Kochia Biomass	Kochia Density	Reduction of Kochia Density Compared to Fallow	Reduction of Kochia Biomass Compared to Fallow
				-------g/m^2-------		plants/m^2		
130	Fall	2007-2008	f	0	14.2	225	0	0
206	Fall	2007-2008	f	0	8.4	175	0	0
306	Fall	2007-2008	f	0	13	253	0	0
423	Fall	2007-2008	f	0	6.5	228	0	0
121	Fall	2007-2008	v	152.2	2.06	80	0.6368	0.8046
215	Fall	2007-2008	v	128.4	1.88	145	0.3417	.
310	Fall	2007-2008	v	121.9	2.946	152	0.3099	0.7206
420	Fall	2007-2008	v	102.6	0.7993	53	0.7594	0.9242
124	Fall	2007-2008	vwt	317.5	0.0195	16	0.9274	0.9982
212	Fall	2007-2008	vwt	278.1	0.0851	40	0.8184	0.9919
313	Fall	2007-2008	vwt	323.4	0.0998	41	0.8138	0.9905
419	Fall	2007-2008	vwt	309.3	0.0747	28	0.8729	0.9929
123	Fall	2007-2008	wpf	111.1	1.0471	57	0.7412	.
213	Fall	2007-2008	wpf	106.6	0.4044	38	0.8275	0.9617
309	Fall	2007-2008	wpf	201.8	0.6418	59	0.7321	0.9391
418	Fall	2007-2008	wpf	131.6	0.795	60	0.7276	0.9246
126	Fall	2007-2008	wpwt	337.8	0.0161	8	0.9637	0.9985
210	Fall	2007-2008	wpwt	257.9	0.0208	18	0.9183	0.998
314	Fall	2007-2008	wpwt	388.9	0.0062	5	0.9773	0.9994
417	Fall	2007-2008	wpwt	.	0.0666	26	.	.

104	Fall	2007-2008	wt	202.1	0.4089	118	0.4642	0.9612
204	Fall	2007-2008	wt	234.2	0.0591	30	0.8638	0.9944
304	Fall	2007-2008	wt	150.5	0.0247	8	0.9637	0.9977
427	Fall	2007-2008	wt	106.9	0.0465	15	0.9319	0.9956
128	Spring	2007-2008	l	141.9	12.3	153		
208	Spring	2007-2008	l	164	33.8	178		
308	Spring	2007-2008	l	166.6	45.3	178		
424	Spring	2007-2008	l	172.1	9.4	150		
105	Spring	2007-2008	lst	92.1	54.8	283		
203	Spring	2007-2008	lst	143.8	15.9	275		
301	Spring	2007-2008	lst	234.9	87.5	81		
429	Spring	2007-2008	lst	270.7	29.5	115		
125	Spring	2007-2008	sp	52.7	16.2	200		
211	Spring	2007-2008	sp	65.6	41.2	135		
315	Spring	2007-2008	sp	100.8	61.4	88		
421	Spring	2007-2008	sp	126.8	24.4	91		
103	Spring	2007-2008	spst	199.2	17	147		
202	Spring	2007-2008	spst	203	22.9	143		
303	Spring	2007-2008	spst	264.5	45.6	93		
426	Spring	2007-2008	spst	316.9	32.7	154		
129	Spring	2007-2008	st	172.8	20.5	185		
207	Spring	2007-2008	st	222.9	17.7	209		
307	Spring	2007-2008	st	280.2	34.4	163		
425	Spring	2007-2008	st	374.8	25.2	147		
120	Fall	2008-2009	f	0	1.4	8	0	0
221	Fall	2008-2009	f	0	17.2	64	0	0
321	Fall	2008-2009	f	0	3.7	21	0	0
408	Fall	2008-2009	f	0	0.85	13	0	0
111	Fall	2008-2009	v	0	3	20	.	.
230	Fall	2008-2009	v	0	7.6	54	.	.
325	Fall	2008-2009	v	0	.	13	0.4816	0.4816
405	Fall	2008-2009	v	0	0.4	7	0.9309	0.9309
114	Fall	2008-2009	vwt	314.7	0.0042	1	0.9993	0.9993
227	Fall	2008-2009	vwt	207.8	0.033	4	0.9943	0.9943
328	Fall	2008-2009	vwt	362.4	0.0498	8	0.9914	0.9914
404	Fall	2008-2009	vwt	306.8	0.0201	5	0.9965	0.9965
113	Fall	2008-2009	wpf	4.3	2.3	8	0.6026	0.6026
228	Fall	2008-2009	wpf	9.8	8.1	50	.	.
324	Fall	2008-2009	wpf	6.7	0.2104	3	0.9636	0.9636
403	Fall	2008-2009	wpf	32.3	0.6	11	0.8963	0.8963
116	Fall	2008-2009	wpwt	405.2	0.329	7	0.9432	0.9432
225	Fall	2008-2009	wpwt	312.4	0.0342	6	0.9941	0.9941

329	Fall	2008-2009	wpwt	342.6	0.0237	3	0.9959	0.9959
402	Fall	2008-2009	wpwt	347.5	0.0327	8	0.9943	0.9943
109	Fall	2008-2009	wt	225.5	0.0056	1	0.999	0.999
219	Fall	2008-2009	wt	402.7	0.0331	10	0.9943	0.9943
319	Fall	2008-2009	wt	420.3	0.007	3	0.9988	0.9988
412	Fall	2008-2009	wt	123.8	0.08	4	0.9862	0.9862
118	Spring	2008-2009	l	36.2	105.2	49		
223	Spring	2008-2009	l	.	78.7	93		
323	Spring	2008-2009	l	51.3	6	15		
409	Spring	2008-2009	l	27.4	4.8	25		
110	Spring	2008-2009	lst	104.1	1.2	7		
218	Spring	2008-2009	lst	427.2	2.8	24		
316	Spring	2008-2009	lst	105.8	0.65	4		
414	Spring	2008-2009	lst	69.7	1	11		
115	Spring	2008-2009	sp	114.2	26.4	71		
226	Spring	2008-2009	sp	120.3	19.9	71		
330	Spring	2008-2009	sp	113	6.4	46		
406	Spring	2008-2009	sp	122.6	0.38	4		
108	Spring	2008-2009	spst	189.9	4.3	54		
217	Spring	2008-2009	spst	.	0.19	16		
318	Spring	2008-2009	spst	191	0.4	4		
411	Spring	2008-2009	spst	92.1	0.71	12		
119	Spring	2008-2009	st	73.4	36.7	51		
222	Spring	2008-2009	st	.	23.6	51		
322	Spring	2008-2009	st	95.7	3.4	9		
410	Spring	2008-2009	st	60.6	3.8	39		

Table A.2 Weed mortality to herbicide application in response to planting season, growing season, and cover crop treatment.

Plot	Planting Season	Growing Season	Cover Crop Treatment	Weed Mortality
				%
130	Fall	2007-2008	f	98.18182
206	Fall	2007-2008	f	98.21429
306	Fall	2007-2008	f	100
423	Fall	2007-2008	f	100
121	Fall	2007-2008	v	100
215	Fall	2007-2008	v	100
310	Fall	2007-2008	v	100
420	Fall	2007-2008	v	98.4375
124	Fall	2007-2008	vwt	100
212	Fall	2007-2008	vwt	100
313	Fall	2007-2008	vwt	100
419	Fall	2007-2008	vwt	100
123	Fall	2007-2008	wpf	85.71429
213	Fall	2007-2008	wpf	90
309	Fall	2007-2008	wpf	98.7013
418	Fall	2007-2008	wpf	72.22222
126	Fall	2007-2008	wpwt	100
210	Fall	2007-2008	wpwt	100
314	Fall	2007-2008	wpwt	100
417	Fall	2007-2008	wpwt	100
104	Fall	2007-2008	wt	100
204	Fall	2007-2008	wt	100
304	Fall	2007-2008	wt	100
427	Fall	2007-2008	wt	93.33333
128	Spring	2007-2008	l	99.42529
208	Spring	2007-2008	l	99
308	Spring	2007-2008	l	97.91667
424	Spring	2007-2008	l	99.35484
105	Spring	2007-2008	lst	95.45455
203	Spring	2007-2008	lst	100
301	Spring	2007-2008	lst	93.06931
429	Spring	2007-2008	lst	100
125	Spring	2007-2008	sp	98.93617
211	Spring	2007-2008	sp	100
315	Spring	2007-2008	sp	100
421	Spring	2007-2008	sp	100

103	Spring	2007-2008	spst	100
202	Spring	2007-2008	spst	100
303	Spring	2007-2008	spst	100
426	Spring	2007-2008	spst	98.33333
129	Spring	2007-2008	st	99.03846
207	Spring	2007-2008	st	100
307	Spring	2007-2008	st	98.97959
425	Spring	2007-2008	st	100
120	Fall	2008-2009	f	100
221	Fall	2008-2009	f	100
321	Fall	2008-2009	f	100
408	Fall	2008-2009	f	100
111	Fall	2008-2009	v	100
230	Fall	2008-2009	v	93.75
325	Fall	2008-2009	v	100
405	Fall	2008-2009	v	100
114	Fall	2008-2009	vwt	100
227	Fall	2008-2009	vwt	100
328	Fall	2008-2009	vwt	100
404	Fall	2008-2009	vwt	100
113	Fall	2008-2009	wpf	100
228	Fall	2008-2009	wpf	100
324	Fall	2008-2009	wpf	66.66667
403	Fall	2008-2009	wpf	100
116	Fall	2008-2009	wpwt	100
225	Fall	2008-2009	wpwt	100
329	Fall	2008-2009	wpwt	100
402	Fall	2008-2009	wpwt	100
109	Fall	2008-2009	wt	100
219	Fall	2008-2009	wt	100
319	Fall	2008-2009	wt	100
412	Fall	2008-2009	wt	100
118	Spring	2008-2009	l	25
223	Spring	2008-2009	l	66.66667
323	Spring	2008-2009	l	96.55172
409	Spring	2008-2009	l	92.45283
110	Spring	2008-2009	lst	73.33333
218	Spring	2008-2009	lst	42.10526
316	Spring	2008-2009	lst	88.88889
414	Spring	2008-2009	lst	85.10638
115	Spring	2008-2009	sp	50
226	Spring	2008-2009	sp	100

330	Spring	2008-2009	sp	79.16667
406	Spring	2008-2009	sp	100
108	Spring	2008-2009	spst	93.75
217	Spring	2008-2009	spst	100
318	Spring	2008-2009	spst	79.16667
411	Spring	2008-2009	spst	50
119	Spring	2008-2009	st	75
222	Spring	2008-2009	st	73.33333
322	Spring	2008-2009	st	100
410	Spring	2008-2009	st	80

Table A.3 Table A.5 Response of the proportion of downy brome biomass relative to total plot biomass to fall- and spring- sown cover crop and volunteer wheat biomass in the 2008-2009 growing season used in figure 2.9.

Plot	Season	Treatment	Cover Crop + Volunteer Wheat Biomass	Downy Brome Proportion of Total Plot Biomass
120	Fall	f	3	0.9507
221	Fall	f	6.3	0.8998
321	Fall	f	321.5	0.0716
408	Fall	f	59.7	0.2993
111	Fall	v	37.7	0.5474
230	Fall	v	206.4	0.2428
325	Fall	v	213.5	0.1611
405	Fall	v	0	1
114	Fall	vwt	296.2	0.1314
328	Fall	vwt	271.1	0.2101
404	Fall	vwt	87.8	0.2959
112	Fall	wl	47.9	0.5477
229	Fall	wl	227.7	0.1644
326	Fall	wl	22.8	0.5118
107	Fall	wlwt	254	0.3339
220	Fall	wlwt	183.1	0.3642
320	Fall	wlwt	116.8	0.2821
413	Fall	wlwt	62.7	0.1868
113	Fall	wpf	304.7	0.243
228	Fall	wpf	307.6	0.1345

324	Fall	wpf	15.1	0.7269
403	Fall	wpf	79.1	0.3626
116	Fall	wpwt	265.7	0.1917
225	Fall	wpwt	327.8	0.1027
329	Fall	wpwt	151.1	0.2001
402	Fall	wpwt	183.1	0.3064
109	Fall	wt	231.7	0.2038
219	Fall	wt	258.3	0.0956
319	Fall	wt	342.5	0.0731
412	Winter	wt	152	0.1269
118	Spring	l	73.7	0.648
223	Spring	l	33	0.8603
323	Spring	l	51.9	0.4401
409	Spring	l	40.8	0.2287
110	Spring	lst	71.6	0.7665
218	Spring	lst	74.4	0.6629
316	Spring	lst	40.3	0.2619
115	Spring	sp	68.6	0.6961
226	Spring	sp	117	0.4212
330	Spring	sp	58.5	0.375
406	Spring	sp	69	0.2273
108	Spring	spst	119.9	0.3309
217	Spring	spst	67.9	0.4537
318	Spring	spst	145.6	0.0129
411	Spring	spst	182.6	0.081
119	Spring	st	156.7	0.1381
222	Spring	st	95.5	0.424
322	Spring	st	28.8	0.5909
410	Spring	st	49.1	0.6137

SAS Code

This section of the appendix contains a representation of the SAS code used to derive least-squared means estimates, least-squared standard error, and pairwise comparisons for the response of cover crop biomass, kochia density, kochia biomass, and weed mortality to cover crop treatment, planting season, and growing season.

Table A.4 SAS Proc Mixed code for least-squared mean estimates, least-squared standard errors, and pairwise comparisons used in chapter 2

```
proc print data=kochia;

%macro mix1 (seas, y, covers);
title &covers;
proc mixed data = kochia covtest cl;
  where season =&seas;
  class block yr cover;
  model &y = yr|cover / ddfm= satterth outp = resd;
  random block;
  lsmeans yr|cover / cl;
  lsmeans cover/pdiff cl;
  lsmeans cover/pdiff adjust = simulate (report seed=4938378) cl;
  lsmeans yr|cover/pdiff cl;
  lsmeans yr|cover/pdiff adjust = simulate (report seed=4938378) cl;
proc print data = resd;
proc univariate data = resd normal plot;
  var resid;
proc sort data = kochia;
  by yr;
proc mixed data = kochia covtest cl;
  by yr;
  class block cover;
  model &y = cover/ ddfm = satterth outp = resdz;
  random block;
  lsmeans cover / cl;
proc print data = resdz;
proc univariate data = resdz normal plot;
  by yr;
  var resid;
%mend mix1;
%mix1 ('Winter', ccbio, 'winter cover biomass');
%mix1 ('Winter', kbio, 'winter kochia biomass');
%mix1 ('Winter', kden, 'winter kochia density');
%mix1 ('Spring', ccbio, 'spring cover biomass');
%mix1 ('Spring', kbio, 'spring kochia biomass');
%mix1 ('Spring', kden, 'spring kochia density');
run;
quit;
```

ANOVA Tables

This section of the appendix contains ANOVA tables generated by Proc Mixed testing for response of dependent variables to source variables.

Table A.5 Response of cover crop biomass to fall and spring planting season and growing season (2007-2008 and 2008-2009).

Source	DF Source	F-Test	P Value
Growing Season	1	0.73	0.3947
Planting Season	1	6.9	0.0107
Growing Season by Planting Season	1	3.96	0.0507

Table A.6 Response of fall-sown cover crop biomass to growing season (2007-2008 and 2008-2009) and cover crop treatments used in figure 2.1.

Source	DF Source	DF Dependent	F-Test	P Value
Growing Season	1	32	1.46	0.2354
Cover Crop	5	32	52.6	<.0001
Growing Season by Cover Crop	5	32	6.1	0.0004

Table A.7 Response of spring-sown cover crop biomass to growing season and cover crop treatment used in figure 2.1.

Source	DF Source	DF Dependent	F-Test	P Value
Growing Season	1	27	9.32	0.005
Cover Crop	4	27	2.94	0.0386
Growing Season by Cover Crop	4	27	2.57	0.0604

Table A.8 Response of kochia density to growing season and fall-sown cover crops used in figure 2.2.

Source	DF	DF	F-Test	P Value
Growing Season	1	36	74.99	<.0001
Cover Crop	5	36	21.81	<.0001
Growing Season by Cover Crop	5	36	13.98	<.0001

Table A.9 Response of kochia biomass to growing season and fall-sown cover crops used in figure 2.4.

Source	DF Source	DF Dependent	F-Test	P Value
Growing Season	1	32.2	0.04	0.8362
Cover Crop	5	32.1	10.58	<.0001
Growing Season by Cover Crop	5	32.1	1.55	0.2024

Table A.10 Response of kochia density to growing season and spring-sown cover crops cited in chapter.

Source	DF Source	DF Dependent	F-Test	P Value
Growing Season	1	27	130.07	<.0001
Cover Crop	4	27	0.99	0.4279
Growing Season by Cover Crop	4	27	2.08	0.1111

Table A.11 Response of kochia biomass to growing season and spring-sown cover crops used in figure 2.6.

Source	DF Source	DF Dependent	F-Test	P Value
Growing Season	1	27	5.35	0.0286
Cover Crop	4	27	1.04	0.4048
Growing Season by Cover Crop	4	27	2.79	0.0464

Table A.12 Kochia mortality due to herbicide application in response to fall-sown cover crop treatment.

Source	DF Source	DF Dependent	F-Test	P Value
Growing Season	1	36	0.39	0.537
Cover Crop	5	36	4.12	0.0046
Growing Season by Cover Crop	5	36	0.26	0.9299

Table A.13 Kochia mortality to herbicide application in response to spring-sown cover crop treatment.

Source	DF Source	DF Dependent	F-Test	P Value
Growing Season	1	27	16.75	0.0003
Cover Crop	4	27	0.32	0.8631

Growing Season by Cover Crop	4	27	0.19	0.9424

Appendix B - Palmer amaranth response to cover crop and herbicide application in a soybean-winter wheat-fallow-grain sorghum rotation

Raw Data

This section of the appendix contains all of the raw data from the third chapter, *Palmer amaranth response to cover crop and herbicide application in a soybean-winter wheat-fallow-grain sorghum rotation*, that may be needed for further research. Data are arranged as they appeared in the chapter and are referenced to figures and tables in which they appeared.

Table B.1 Cover crop biomass arranged by harvest year and cover crop treatment. Data used to generate table 3.2.

Block	Harvest Year	Cover Crop	Biomass
			kg/ha
1	2008	DSB	1475
1	2008	DSB	1420
2	2008	DSB	1580
2	2008	DSB	1185
3	2008	DSB	1560
3	2008	DSB	1190
4	2008	DSB	1270
4	2008	DSB	1130
1	2008	FB	4537
1	2008	FB	5851
2	2008	FB	3983
2	2008	FB	3250
3	2008	FB	5906
3	2008	FB	4831
4	2008	FB	4502
4	2008	FB	3860
1	2008	SG	13175
1	2008	SG	9108
2	2008	SG	7158
2	2008	SG	9662
3	2008	SG	9997
3	2008	SG	7719

4	2008	SG	6084
4	2008	SG	7918
1	2008	WP	1963
1	2008	WP	2021
2	2008	WP	1377
2	2008	WP	1987
3	2008	WP	2244
3	2008	WP	1693
4	2008	WP	2119
4	2008	WP	2443
1	2008	CAN	32
2	2008	CAN	161
3	2008	CAN	61
4	2008	CAN	801
4	2008	CAN	869
1	2009	DSB	3270
1	2009	DSB	2790
2	2009	DSB	3310
2	2009	DSB	2500
3	2009	DSB	2605
3	2009	DSB	2230
4	2009	DSB	2745
4	2009	DSB	2580
1	2009	FB	7096
1	2009	FB	6305
2	2009	FB	4849
2	2009	FB	4322
3	2009	FB	5729
3	2009	FB	5615
4	2009	FB	4804
4	2009	FB	5213
1	2009	SG	11587
1	2009	SG	10578
2	2009	SG	7189
2	2009	SG	6996
3	2009	SG	8227
3	2009	SG	6791
4	2009	SG	7142
4	2009	SG	7337
1	2009	WP	112
2	2009	WP	109
3	2009	WP	109

4	2009	WP	112
1	2009	CAN	43
2	2009	CAN	75
3	2009	CAN	79
4	2009	CAN	77

Table B.2 Palmer amaranth density as of May 31 in 2008 and 2009, end of season density and biomass sorted by cover crop treatment, herbicide application (N is not sprayed, S is sprayed) and harvest year. Data used to generate Figure 3.4 and Table 3.3

Plot	Harvest Year	Herbicide Application	Cover Crop Treatment	Density on May 31	Palmer Amaranth Density	Palmer Amaranth Biomass
				plants/m^2		g/m^2
131	2008	N	SG	20	5	716.1152
134	2008	N	SG	20	2	0.031065
138	2008	N	AWP	0	N/A	N/A
139	2008	N	AWP	4	N/A	N/A
143	2008	N	CF	0	10	1806.985
145	2008	N	CF	7	11	2140.349
149	2008	N	DSB	12	29	1584.244
150	2008	N	DSB	5	10	1323.111
153	2008	N	FB	6	11	1717.499
154	2008	N	FB	5	9	1233.136
158	2008	N	CAN	2	N/A	N/A
160	2008	N	CAN	4	N/A	N/A
264	2008	N	AWP	13	N/A	N/A
265	2008	N	AWP	39	N/A	N/A
267	2008	N	CF	30	3	62.00948
270	2008	N	CF	7	17	2034.445
271	2008	N	SG	11	12	696.6854
273	2008	N	SG	7	15	602.2148
277	2008	N	CAN	12	N/A	N/A
280	2008	N	CAN	17	N/A	N/A
283	2008	N	DSB	2	9	429.232
284	2008	N	DSB	12	21	831.6327
289	2008	N	FB	5	25	1185.516
290	2008	N	FB	20	21	2107.573
333	2008	N	CF	6	14	1002.571
334	2008	N	CF	11	23	2070.77
337	2008	N	AWP	5	N/A	N/A
338	2008	N	AWP	1	N/A	N/A
341	2008	N	SG	5	10	10.94803
343	2008	N	SG	8	10	7.734854
348	2008	N	DSB	10	29	1255.048
350	2008	N	DSB	0	21	1370.919
352	2008	N	CAN	7	N/A	N/A

354	2008	N	CAN	7	N/A	N/A
356	2008	N	FB	12	5	1433.715
360	2008	N	FB	1	9	1585.217
461	2008	N	AWP	36	N/A	N/A
465	2008	N	AWP	5	N/A	N/A
466	2008	N	DSB	39	11	612.1467
468	2008	N	DSB	30	9	838.8724
473	2008	N	CF	15	8	750.4778
474	2008	N	CF	19	2	0
476	2008	N	SG	16	6	55.25908
478	2008	N	SG	1	4	1.297536
481	2008	N	FB	4	7	28.26376
485	2008	N	FB	8	11	585.1387
486	2008	N	CAN	25	N/A	N/A
488	2008	N	CAN	3	N/A	N/A
131	2008	S	SG	8	0	0
134	2008	S	SG	4	0	0
138	2008	S	AWP	1	N/A	N/A
139	2008	S	AWP	4	N/A	N/A
143	2008	S	CF	1	13	104.5349
145	2008	S	CF	14	14	264.8342
149	2008	S	DSB	9	9	16.23643
150	2008	S	DSB	4	3	1.338853
153	2008	S	FB	6	5	17.39573
154	2008	S	FB	10	24	126.0463
158	2008	S	CAN	4	N/A	N/A
160	2008	S	CAN	19	N/A	N/A
264	2008	S	AWP	8	N/A	N/A
265	2008	S	AWP	26	N/A	N/A
267	2008	S	CF	10	11	87.11682
270	2008	S	CF	14	8	131.2811
271	2008	S	SG	5	0	0
273	2008	S	SG	5	1	0.001125
277	2008	S	CAN	17	N/A	N/A
280	2008	S	CAN	3	N/A	N/A
283	2008	S	DSB	8	3	1.510693
284	2008	S	DSB	9	6	9.098092
289	2008	S	FB	11	1	0.187638
290	2008	S	FB	18	5	10.30313
333	2008	S	CF	7	4	116.6616
334	2008	S	CF	7	4	11.53233
337	2008	S	AWP	1	N/A	N/A

338	2008	S	AWP	4	N/A	N/A
341	2008	S	SG	8	0	0
343	2008	S	SG	12	0	0
348	2008	S	DSB	6	0	0.052294
350	2008	S	DSB	2	0	0.29943
352	2008	S	CAN	0	N/A	N/A
354	2008	S	CAN	4	N/A	N/A
356	2008	S	FB	18	18	10.30329
360	2008	S	FB	3	18	8.780258
461	2008	S	AWP	31	N/A	N/A
465	2008	S	AWP	26	N/A	N/A
466	2008	S	DSB	19	4	1.332727
468	2008	S	DSB	13	3	0.222989
473	2008	S	CF	12	12	224.8962
474	2008	S	CF	9	5	14.67786
476	2008	S	SG	6	1	0.025
478	2008	S	SG	1	1	0.002298
481	2008	S	FB	2	2	1.419415
485	2008	S	FB	0	5	12.15531
486	2008	S	CAN	47	N/A	N/A
488	2008	S	CAN	25	N/A	N/A
161	2009	N	FB	0	57	691.7006
162	2009	N	FB	16	26	863.9213
168	2009	N	SG	8	10	748.9505
170	2009	N	SG	50	40	365.8117
171	2009	N	DSB	12	36	505.1233
174	2009	N	DSB	5	115	249.0708
178	2009	N	CF	10	49	839.7577
179	2009	N	CF	40	252	515.6784
182	2009	N	CAN	0	N/A	N/A
183	2009	N	CAN	0	N/A	N/A
186	2009	N	AWP	1	N/A	N/A
189	2009	N	AWP	3	N/A	N/A
203	2009	N	DSB	3	202	372.1934
205	2009	N	DSB	0	454	268.3448
206	2009	N	CAN	3	N/A	N/A
210	2009	N	CAN	3	N/A	N/A
212	2009	N	AWP	5	N/A	N/A
215	2009	N	AWP	3	N/A	N/A
216	2009	N	FB	6	190	151.8522
218	2009	N	FB	7	76	251.0696
221	2009	N	SG	12	63	163.8143

225	2009	N	SG	0	26	235.8153
227	2009	N	CF	13	93	207.4165
230	2009	N	CF	2	106	590.1118
361	2009	N	AWP	73	N/A	N/A
363	2009	N	AWP	21	N/A	N/A
367	2009	N	DSB	135	215	201.2273
370	2009	N	DSB	11	40	264.2377
372	2009	N	FB	48	728	359.3012
375	2009	N	FB	10	398	278.3574
376	2009	N	CAN	8	N/A	N/A
380	2009	N	CAN	4	N/A	N/A
381	2009	N	SG	27	335	203.2262
383	2009	N	SG	23	252	158.0346
386	2009	N	CF	32	71	266.7597
388	2009	N	CF	56	223	270.9566
404	2009	N	CAN	0	N/A	N/A
405	2009	N	CAN	0	N/A	N/A
406	2009	N	CF	0	304	333.2381
408	2009	N	CF	4	63	403.1978
412	2009	N	DSB	10	478	255.2188
413	2009	N	DSB	15	86	219.3207
416	2009	N	SG	44	SPRAYED	.
418	2009	N	SG	3	80	92.50943
421	2009	N	AWP	126	N/A	N/A
425	2009	N	AWP	2	N/A	N/A
426	2009	N	FB	19	320	268.5719
429	2009	N	FB	3	117	321.1897
161	2009	S	FB	2	17	58.30194
162	2009	S	FB	1	21	69.20665
168	2009	S	SG	10	179	37.08555
170	2009	S	SG	0	92	43.17527
171	2009	S	DSB	0	58	100.586
174	2009	S	DSB	0	96	77.1105
178	2009	S	CF	1	18	204.6973
179	2009	S	CF	2	113	201.3944
182	2009	S	CAN	14	N/A	N/A
183	2009	S	CAN	2	N/A	N/A
186	2009	S	AWP	3	N/A	N/A
189	2009	S	AWP	1	N/A	N/A
203	2009	S	DSB	2	27	71.77962
205	2009	S	DSB	5	26	48.22002
206	2009	S	CAN	16	N/A	N/A

210	2009	S	CAN	0	N/A	N/A
212	2009	S	AWP	6	N/A	N/A
215	2009	S	AWP	4	N/A	N/A
216	2009	S	FB	23	12	45.76
218	2009	S	FB	0	141	114.2113
221	2009	S	SG	4	30	6.164946
225	2009	S	SG	1	35	7.739617
227	2009	S	CF	28	29	27.05449
230	2009	S	CF	1	11	.
361	2009	S	AWP	41	N/A	N/A
363	2009	S	AWP	2	N/A	N/A
367	2009	S	DSB	18	185	58.09158
370	2009	S	DSB	0	30	40.48238
372	2009	S	FB	248	140	50.94263
375	2009	S	FB	10	50	51.0952
376	2009	S	CAN	31	N/A	N/A
380	2009	S	CAN	3	N/A	N/A
381	2009	S	SG	86	115	15.40087
383	2009	S	SG	22	29	23.28288
386	2009	S	CF	12	99	137.8939
388	2009	S	CF	6	23	142.099
404	2009	S	CAN	2	N/A	N/A
405	2009	S	CAN	4	N/A	N/A
406	2009	S	CF	2	2	114.2174
408	2009	S	CF	2	41	73.08152
412	2009	S	DSB	12	32	36.50407
413	2009	S	DSB	0	82	40.97972
416	2009	S	SG	9	53	.
418	2009	S	SG	4	14	4.749621
421	2009	S	AWP	111	N/A	N/A
425	2009	S	AWP	7	N/A	N/A
426	2009	S	FB	9	.	.
429	2009	S	FB	0	10	28.29219

Table B.3 Proportional reduction of Palmer amaranth biomass compared to fallow sorted by harvest year and cover crop used to generate figure 3.5

Plot	Season	Harvest Year	Cover Crop	Proportion of Palmer Amaranth Biomass Compared to Fallow
149	Summer	2008	DSB	0.9002
150	Summer	2008	DSB	0.9899
283	Summer	2008	DSB	0.9853
284	Summer	2008	DSB	0.9285
348	Summer	2008	DSB	0.9989
350	Summer	2008	DSB	0.9979
466	Summer	2008	DSB	0.991
468	Summer	2008	DSB	0.9979
153	Summer	2008	FB	0.892
154	Summer	2008	FB	0.2081
289	Summer	2008	FB	0.9986
290	Summer	2008	FB	0.9227
356	Summer	2008	FB	0.8948
360	Summer	2008	FB	0.9377
481	Summer	2008	FB	0.9842
485	Summer	2008	FB	0.9298
131	Summer	2008	SG	1
134	Summer	2008	SG	1
271	Summer	2008	SG	1
273	Summer	2008	SG	0.9999
341	Summer	2008	SG	1
343	Summer	2008	SG	1
476	Summer	2008	SG	0.9999
478	Summer	2008	SG	0.9998
171	Summer	2009	DSB	0.4538
174	Summer	2009	DSB	0.4792
203	Summer	2009	DSB	0.3088
205	Summer	2009	DSB	0.4258
367	Summer	2009	DSB	0.4888
370	Summer	2009	DSB	0.6337
412	Summer	2009	DSB	0.6785
413	Summer	2009	DSB	0.6126
161	Summer	2009	FB	0.3869
162	Summer	2009	FB	0.3785

216	Summer	2009	FB	0.6248
218	Summer	2009	FB	0.1503
372	Summer	2009	FB	0.6187
375	Summer	2009	FB	0.6886
426	Summer	2009	FB	0.7395
168	Summer	2009	SG	0.7463
170	Summer	2009	SG	0.7736
221	Summer	2009	SG	0.9393
225	Summer	2009	SG	0.9347
381	Summer	2009	SG	0.9286
383	Summer	2009	SG	0.8608
416	Summer	2009	SG	0.8678
418	Summer	2009	SG	0.9636

Table B.4 Weed mortality to preemergence glyphosate application

Plot	Year	Cover Crop	Weed Mortality
			%
143	2008	CF	5.5
145	2008	CF	-0.53333
267	2008	CF	-0.58824
270	2008	CF	-0.39394
333	2008	CF	0.733333
334	2008	CF	-0.18519
473	2008	CF	10
474	2008	CF	4
149	2008	DSB	-0.84848
150	2008	DSB	0.142857
283	2008	DSB	0.923077
284	2008	DSB	-0.35294
348	2008	DSB	-0.65517
350	2008	DSB	-0.42308
466	2008	DSB	-0.625
468	2008	DSB	0.2
153	2008	FB	-0.2
154	2008	FB	-0.72727
289	2008	FB	-0.45455
290	2008	FB	-0.52174
356	2008	FB	-0.36364
360	2008	FB	-0.4375
481	2008	FB	0.25
485	2008	FB	-0.75
131	2008	SG	3
134	2008	SG	1.25
271	2008	SG	-0.04762
273	2008	SG	1.285714
341	2008	SG	-0.07692
343	2008	SG	0.875
476	2008	SG	1.5
478	2008	SG	18
178	2009	CF	-0.44186
179	2009	CF	-0.73394
227	2009	CF	0.424242
230	2009	CF	-0.3
386	2009	CF	-0.64063

388	2009	CF	-0.77642
406	2009	CF	-0.64688
408	2009	CF	0.416667
171	2009	DSB	0
174	2009	DSB	-0.7983
203	2009	DSB	-0.25641
205	2009	DSB	-0.34975
367	2009	DSB	-0.76957
370	2009	DSB	-0.55682
412	2009	DSB	-0.73059
413	2009	DSB	-0.44737
161	2009	FB	-0.33333
162	2009	FB	-0.42105
216	2009	FB	-0.62222
218	2009	FB	-0.23148
372	2009	FB	-0.79534
375	2009	FB	-0.56
426	2009	FB	-0.2625
429	2009	FB	-0.84158
168	2009	SG	0.272727
170	2009	SG	-0.46809
221	2009	SG	-0.75595
225	2009	SG	-0.36585
381	2009	SG	-0.67069
383	2009	SG	-0.91171
416	2009	SG	-0.87799
418	2009	SG	-0.61905

Table B.5 Weed mortality to wheat harvest and cover crop planting

Plot	Year	Cover Crop	Weed Mortality
			%
158	2008	CAN	0.368421
160	2008	CAN	-0.71429
277	2008	CAN	0.517241
280	2008	CAN	0
352	2008	CAN	-5
354	2008	CAN	-0.5
476	2008	CAN	.
478	2008	CAN	0
143	2008	CF	-3
145	2008	CF	0.2
267	2008	CF	0.882353
270	2008	CF	0.151515
333	2008	CF	-0.13333
334	2008	CF	0.111111
473	2008	CF	-6
474	2008	CF	#DIV/0!
149	2008	DSB	0.606061
150	2008	DSB	0
283	2008	DSB	0.461538
284	2008	DSB	-0.17647
348	2008	DSB	0.103448
350	2008	DSB	0.153846
466	2008	DSB	-0.375
468	2008	DSB	0.6
153	2008	FB	0.5
154	2008	FB	0.272727
289	2008	FB	-0.13636
290	2008	FB	0.521739
356	2008	FB	0.090909
360	2008	FB	0.0625
481	2008	FB	0.25
485	2008	FB	-2
131	2008	SG	-1.66667
134	2008	SG	0.25
271	2008	SG	0.428571
273	2008	SG	0.214286
341	2008	SG	0.461538

343	2008	SG	-0.125
476	2008	SG	-0.25
478	2008	SG	0
138	2008	WP	-3
139	2008	WP	-3.5
264	2008	WP	-0.42857
265	2008	WP	0.179487
337	2008	WP	0.2
338	2008	WP	-0.36364
461	2008	WP	-0.25
465	2008	WP	-0.1875
182	2009	CAN	0.036145
183	2009	CAN	0.5
206	2009	CAN	0.80137
210	2009	CAN	0.34375
361	2009	CAN	0.818966
363	2009	CAN	0.145833
404	2009	CAN	0.166667
405	2009	CAN	0.986111
178	2009	CF	0.465116
179	2009	CF	0.756881
227	2009	CF	-0.31818
230	2009	CF	0.375
386	2009	CF	0.630208
388	2009	CF	0.800813
406	2009	CF	0.04375
408	2009	CF	-0.29167
171	2009	DSB	-0.3
174	2009	DSB	0.690341
203	2009	DSB	0.288462
205	2009	DSB	0.332512
367	2009	DSB	0.780435
370	2009	DSB	0.409091
412	2009	DSB	0.762557
413	2009	DSB	0.5
161	2009	FB	0.222222
162	2009	FB	0.210526
216	2009	FB	0.638889
218	2009	FB	0.435185
372	2009	FB	0.806988
375	2009	FB	0.97
426	2009	FB	0.2

429	2009	FB	0.826733
168	2009	SG	0.454545
170	2009	SG	0.297872
221	2009	SG	0.869048
225	2009	SG	0.317073
381	2009	SG	0.643505
383	2009	SG	0.896353
416	2009	SG	0.889952
418	2009	SG	0.587302
186	2009	WP	0.5
189	2009	WP	0.536585
212	2009	WP	.
215	2009	WP	0.555556
361	2009	WP	0.719397
363	2009	WP	0.673575
421	2009	WP	0.904676
425	2009	WP	0.5

Table B.6 Palmer amaranth fecundity as a response to individual plant biomass sorted by plant ID which is comprised of plot number and plant number used in figure 3.6.

Plant ID	Plant Biomass	Fecundity
	g/plant	seeds (x1000)/plant
131b1	474.4	0
131b2	711.1	0
138a1	32.9	5.00E-03
138a3	32.1	0.028
138a4	34	0
138b3	27.1	0
138b4	638	12.499
139a1	115.8	0
139a3	126	0
139a4	20.3	0
139b1	673.1	11.199
143a3	50.3	0
143b4	345	2.066
145a1	42.2	0
145a2	31.3	0
145b4	247.9	4.12
149a1	19.5	0
149a4	1.1	0
149b3	4.4	0.061
149b4	840.8	60.648
150b1	550.7	0.0476
150b2	453.7	1.604
153b3	106.8	14.487
153b4	262.3	10.433
154a1	23.8	0
154a2	4.5	0
154b2	996.2	88.56
158a1	201.7	18.618
158a2	40.4	0
158b3	13.9	0
158b4	4.9	0
160a1	11.7	5.741
264a1	23.6	0
264b1	156.1	2.867
264b3	565.7	15.059
265a1	27.1	0.347

265a3	5.3	0
265b1	560.8	1.982
265b3	253	2.288
267a1	272.6	0.019
267a3	17.5	0
267a4	35.7	0
270a1	20.9	0
270a2	26.7	0
270b3	169	3.177
270b4	21	0
271b2	94.9	14.473
277b3	509.2	5.018
277b4	29.6	1.405
280a1	32.1	0
283b4	341.4	6.259
284b1	59.5	3.119
284b2	4.9	1.276
289a1	8.4	0
289a2	37.8	0
290a1	143	2.535
333a2	9.4	0.9
333b3	2.9	4.597
334a3	96.3	0
334b3	79.6	0
334b4	149.7	3.081
337b1	575	12.798
337b2	143	1.207
338b1	35.7	0.205
338b2	156.1	6.452
338b4	3.2	0
341b3	3.1	0
343b2	23.8	0
350b3	18.9	0.42
350b4	52.8	1.511
352b4	627.5	34.265
354b1	532.6	3.797
356a3	441.6	2.257
360a1	7.4	0
360a2	105.5	1.227
461a2	12.1	0
461a3	9.2	0
461b3	207.8	6.625

465a1	69.9	0.224
465a3	22.2	1.334
465b3	273.1	8.578
465b4	9.6	0
466a2	3.1	0
466a4	4.9	0
466b1	257.2	2.938
466b2	23.5	0.094
468b3	552.2	1.811
468b4	1.6	0
473a1	46.1	3.00E-03
473a2	14.1	0
473b3	1.4	0.159
473b4	2	0
474a1	32.3	0
474b2	0.2	0
481b1	44.1	2.847
481b2	387.4	1.871
485a1	5.8	0
485a2	3.6	0
485b3	27.8	0.071
485b4	490.3	2.248
486a1	59.8	1.083
486a2	616.9	39.335
486b1	140.2	0.024
488a1	16.1	0
488b1	22.7	4.00E-03
488b2	47.7	3.00E-03

Table B.7 Initial Palmer amaranth emergence in the grain sorghum phase on May 31, 2008 and May 18, 2009

Plot	Year	Previous Cover Crop	Previous Herbicide Treatment	Palmer Amaranth Density
				plants/m^2
126	2008	CAN	None	9
127	2008	CAN	None	4
256	2008	CAN	None	23
257	2008	CAN	None	4
317	2008	CAN	None	3
319	2008	CAN	None	9
447	2008	CAN	None	36
450	2008	CAN	None	17
108	2008	CF	None	5
109	2008	CF	None	8
247	2008	CF	None	10
248	2008	CF	None	4
324	2008	CF	None	1
325	2008	CF	None	8
454	2008	CF	None	6
455	2008	CF	None	31
112	2008	DSB	None	0
115	2008	DSB	None	8
252	2008	DSB	None	2
255	2008	DSB	None	22
301	2008	DSB	None	7
305	2008	DSB	None	9
458	2008	DSB	None	10
459	2008	DSB	None	16
117	2008	FB	None	5
120	2008	FB	None	11
237	2008	FB	None	16
240	2008	FB	None	16
327	2008	FB	None	7
329	2008	FB	None	11
441	2008	FB	None	35
444	2008	FB	None	41
101	2008	SG	None	9
104	2008	SG	None	7

256	2008	SG	None	3
257	2008	SG	None	11
306	2008	SG	None	6
309	2008	SG	None	4
436	2008	SG	None	1
438	2008	SG	None	6
123	2008	WP	None	6
125	2008	WP	None	1
242	2008	WP	None	0
244	2008	WP	None	0
312	2008	WP	None	1
313	2008	WP	None	0
431	2008	WP	None	0
434	2008	WP	None	9
126	2008	CAN	None	8
127	2008	CAN	None	5
256	2008	CAN	None	39
257	2008	CAN	None	5
317	2008	CAN	None	21
319	2008	CAN	None	9
447	2008	CAN	None	25
450	2008	CAN	None	26
108	2008	CF	None	2
109	2008	CF	None	4
247	2008	CF	None	13
248	2008	CF	None	3
324	2008	CF	None	6
325	2008	CF	None	4
454	2008	CF	None	21
455	2008	CF	None	9
112	2008	DSB	None	8
115	2008	DSB	None	10
252	2008	DSB	None	5
255	2008	DSB	None	37
301	2008	DSB	None	3
305	2008	DSB	None	1
458	2008	DSB	None	14
459	2008	DSB	None	37
117	2008	FB	None	9
120	2008	FB	None	13
237	2008	FB	None	2
240	2008	FB	None	15

327	2008	FB	None	28
329	2008	FB	None	9
441	2008	FB	None	11
444	2008	FB	None	16
101	2008	SG	None	11
104	2008	SG	None	3
256	2008	SG	None	5
257	2008	SG	None	2
306	2008	SG	None	0
309	2008	SG	None	1
436	2008	SG	None	21
438	2008	SG	None	3
123	2008	WP	None	4
125	2008	WP	None	1
242	2008	WP	None	0
244	2008	WP	None	1
312	2008	WP	None	0
313	2008	WP	None	5
431	2008	WP	None	12
434	2008	WP	None	9
158	2009	CAN	Not Sprayed	9
160	2009	CAN	Not Sprayed	1
277	2009	CAN	Not Sprayed	0
280	2009	CAN	Not Sprayed	27
352	2009	CAN	Not Sprayed	39
354	2009	CAN	Not Sprayed	30
486	2009	CAN	Not Sprayed	4
488	2009	CAN	Not Sprayed	0
143	2009	CF	Not Sprayed	9
145	2009	CF	Not Sprayed	0
267	2009	CF	Not Sprayed	0
270	2009	CF	Not Sprayed	2
333	2009	CF	Not Sprayed	85
334	2009	CF	Not Sprayed	13
473	2009	CF	Not Sprayed	2
474	2009	CF	Not Sprayed	1
149	2009	DSB	Not Sprayed	47
150	2009	DSB	Not Sprayed	13
283	2009	DSB	Not Sprayed	77
284	2009	DSB	Not Sprayed	237
348	2009	DSB	Not Sprayed	18
350	2009	DSB	Not Sprayed	5

466	2009	DSB	Not Sprayed	34
468	2009	DSB	Not Sprayed	70
153	2009	FB	Not Sprayed	3
154	2009	FB	Not Sprayed	22
289	2009	FB	Not Sprayed	58
290	2009	FB	Not Sprayed	24
356	2009	FB	Not Sprayed	316
360	2009	FB	Not Sprayed	11
481	2009	FB	Not Sprayed	1
485	2009	FB	Not Sprayed	3
131	2009	SG	Not Sprayed	0
134	2009	SG	Not Sprayed	0
271	2009	SG	Not Sprayed	0
273	2009	SG	Not Sprayed	0
341	2009	SG	Not Sprayed	3
343	2009	SG	Not Sprayed	2
476	2009	SG	Not Sprayed	0
478	2009	SG	Not Sprayed	0
138	2009	WP	Not Sprayed	32
139	2009	WP	Not Sprayed	71
264	2009	WP	Not Sprayed	93
265	2009	WP	Not Sprayed	12
337	2009	WP	Not Sprayed	5
338	2009	WP	Not Sprayed	32
461	2009	WP	Not Sprayed	30
465	2009	WP	Not Sprayed	3
158	2009	CAN	Sprayed	0
160	2009	CAN	Sprayed	3
277	2009	CAN	Sprayed	2
280	2009	CAN	Sprayed	1
352	2009	CAN	Sprayed	0
354	2009	CAN	Sprayed	1
486	2009	CAN	Sprayed	0
488	2009	CAN	Sprayed	0
143	2009	CF	Sprayed	0
145	2009	CF	Sprayed	1
267	2009	CF	Sprayed	0
270	2009	CF	Sprayed	1
333	2009	CF	Sprayed	3
334	2009	CF	Sprayed	11
473	2009	CF	Sprayed	0
474	2009	CF	Sprayed	0

149	2009	DSB	Sprayed	0
150	2009	DSB	Sprayed	3
283	2009	DSB	Sprayed	19
284	2009	DSB	Sprayed	12
348	2009	DSB	Sprayed	3
350	2009	DSB	Sprayed	1
466	2009	DSB	Sprayed	2
468	2009	DSB	Sprayed	13
153	2009	FB	Sprayed	0
154	2009	FB	Sprayed	3
289	2009	FB	Sprayed	103
290	2009	FB	Sprayed	6
356	2009	FB	Sprayed	117
360	2009	FB	Sprayed	0
481	2009	FB	Sprayed	2
485	2009	FB	Sprayed	1
131	2009	SG	Sprayed	0
134	2009	SG	Sprayed	1
271	2009	SG	Sprayed	0
273	2009	SG	Sprayed	0
341	2009	SG	Sprayed	0
343	2009	SG	Sprayed	0
476	2009	SG	Sprayed	1
478	2009	SG	Sprayed	1
138	2009	WP	Sprayed	2
139	2009	WP	Sprayed	0
264	2009	WP	Sprayed	48
265	2009	WP	Sprayed	7
337	2009	WP	Sprayed	8
338	2009	WP	Sprayed	5
461	2009	WP	Sprayed	78
465	2009	WP	Sprayed	484

Table B.8 Weed mortality to preemergence applications of Bicep II Magnum in 2008 and Bicep II Magnum + Roundup Powermax in 2009 in the grain sorghum phase.

Plot	Harvest Year	Cover Crop	Weed Mortality
			%
126	2008	CAN	1
127	2008	CAN	0.8
256	2008	CAN	0.846154
257	2008	CAN	0.6
317	2008	CAN	0.952381
319	2008	CAN	0.666667
447	2008	CAN	0.96
450	2008	CAN	1
108	2008	CF	1
109	2008	CF	0.75
247	2008	CF	0.769231
248	2008	CF	1
324	2008	CF	1
325	2008	CF	1
454	2008	CF	0.952381
455	2008	CF	0.888889
112	2008	DSB	0.625
115	2008	DSB	0.8
252	2008	DSB	0.2
255	2008	DSB	0.837838
301	2008	DSB	-0.66667
305	2008	DSB	1
458	2008	DSB	0.357143
459	2008	DSB	1
117	2008	FB	1
120	2008	FB	0.769231
237	2008	FB	0.5
240	2008	FB	1
327	2008	FB	0.857143
329	2008	FB	1
441	2008	FB	0.909091
444	2008	FB	1
101	2008	SG	1
104	2008	SG	0.666667
256	2008	SG	0.8

257	2008	SG	1
306	2008	SG	.
309	2008	SG	1
436	2008	SG	0.952381
438	2008	SG	1
123	2008	WP	0.75
125	2008	WP	1
242	2008	WP	.
244	2008	WP	1
312	2008	WP	.
313	2008	WP	1
431	2008	WP	0.916667
434	2008	WP	1
158	2009	CAN	.
160	2009	CAN	1
277	2009	CAN	1
280	2009	CAN	1
352	2009	CAN	.
354	2009	CAN	1
486	2009	CAN	.
488	2009	CAN	.
143	2009	CF	.
145	2009	CF	1
267	2009	CF	.
270	2009	CF	1
333	2009	CF	1
334	2009	CF	1
473	2009	CF	.
474	2009	CF	.
149	2009	DSB	.
150	2009	DSB	1
283	2009	DSB	1
284	2009	DSB	1
348	2009	DSB	1
350	2009	DSB	1
466	2009	DSB	1
468	2009	DSB	1
153	2009	FB	.
154	2009	FB	1
289	2009	FB	1
290	2009	FB	1
356	2009	FB	1

360	2009	FB	.
481	2009	FB	1
485	2009	FB	1
131	2009	SG	.
134	2009	SG	1
271	2009	SG	.
273	2009	SG	.
341	2009	SG	.
343	2009	SG	.
476	2009	SG	1
478	2009	SG	1
138	2009	WP	1
139	2009	WP	.
264	2009	WP	1
265	2009	WP	1
337	2009	WP	1
338	2009	WP	1
461	2009	WP	1
465	2009	WP	1

Table B.9 End of season Palmer amaranth density and biomass in the grain sorghum phase

Plot	Nitrogen Rate	Year	Herbicide Application	Cover Crop	Palmer Amaranth Density	Palmer Amaranth Biomass
	kg/ha				plants/m^2	g/m^2
101	134	2008	Not Sprayed	SG	14	17.65
101	134	2008	Sprayed	SG	3	.
104	0	2008	Not Sprayed	SG	14	1642.53
104	0	2008	Sprayed	SG	1	33.56179
108	134	2008	Not Sprayed	CF	15	49.425
108	134	2008	Sprayed	CF	1	.
109	0	2008	Not Sprayed	CF	24	1177.093
109	0	2008	Sprayed	CF	1	.
112	134	2008	Not Sprayed	DSB	9	2404.323
112	134	2008	Sprayed	DSB	3	.
115	0	2008	Not Sprayed	DSB	16	.
115	0	2008	Sprayed	DSB	2	597.8308
117	134	2008	Not Sprayed	FB	3	.
117	134	2008	Sprayed	FB	1	0.00125
120	0	2008	Not Sprayed	FB	1	736.9297
120	0	2008	Sprayed	FB	6	67.425
123	0	2008	Not Sprayed	WP	7	.
123	0	2008	Sprayed	WP	1	649.05
125	134	2008	Not Sprayed	WP	7	1704.557
125	134	2008	Sprayed	WP	0	0
126	134	2008	Not Sprayed	CAN	14	749.1184
126	134	2008	Sprayed	CAN	1	79.05
127	0	2008	Not Sprayed	CAN	11	.
127	0	2008	Sprayed	CAN	2	.
231	134	2008	Not Sprayed	CAN	14	.
231	134	2008	Sprayed	CAN	4	1883.243
235	0	2008	Not Sprayed	CAN	19	1913.08
235	0	2008	Sprayed	CAN	3	1157.651
237	0	2008	Not Sprayed	FB	32	3194.627
237	0	2008	Sprayed	FB	0	518.4292
240	134	2008	Not Sprayed	FB	19	1164.018
240	134	2008	Sprayed	FB	3	2208.961
242	0	2008	Not Sprayed	WP	2	171.5967
242	0	2008	Sprayed	WP	3	.
244	134	2008	Not Sprayed	WP	4	778.1696
244	134	2008	Sprayed	WP	1	143.9005

247	0	2008	Not Sprayed	CF	10	1483.619
247	0	2008	Sprayed	CF	3	2465.096
248	134	2008	Not Sprayed	CF	2	566.0444
248	134	2008	Sprayed	CF	1	305.4
252	0	2008	Not Sprayed	DSB	8	.
252	0	2008	Sprayed	DSB	4	1467.941
255	134	2008	Not Sprayed	DSB	3	1345.376
255	134	2008	Sprayed	DSB	3	0
256	134	2008	Not Sprayed	SG	14	.
256	134	2008	Sprayed	SG	1	618.55
257	0	2008	Not Sprayed	SG	4	.
257	0	2008	Sprayed	SG	0	0
301	134	2008	Not Sprayed	DSB	12	.
301	134	2008	Sprayed	DSB	0	0
305	0	2008	Not Sprayed	DSB	12	.
305	0	2008	Sprayed	DSB	0	0
306	0	2008	Not Sprayed	SG	5	.
306	0	2008	Sprayed	SG	0	0
309	134	2008	Not Sprayed	SG	5	119.0792
309	134	2008	Sprayed	SG	0	0
312	0	2008	Not Sprayed	WP	4	833.4435
312	0	2008	Sprayed	WP	0	0
313	134	2008	Not Sprayed	WP	7	0
313	134	2008	Sprayed	WP	0	0
317	0	2008	Not Sprayed	CAN	4	.
317	0	2008	Sprayed	CAN	2	954.6302
319	134	2008	Not Sprayed	CAN	11	450.6375
319	134	2008	Sprayed	CAN	0	0
324	134	2008	Not Sprayed	CF	1	210.225
324	134	2008	Sprayed	CF	0	0
325	0	2008	Not Sprayed	CF	4	9.05
325	0	2008	Sprayed	CF	0	0
327	0	2008	Not Sprayed	FB	2	279.625
327	0	2008	Sprayed	FB	1	1369.47
329	134	2008	Not Sprayed	FB	9	0
329	134	2008	Sprayed	FB	0	0
131	0	2009	Not Sprayed	SG	4	43.89788
131	0	2009	Sprayed	SG	0	0
134	134	2009	Not Sprayed	SG	3	48.65686
134	134	2009	Sprayed	SG	0	0
138	134	2009	Not Sprayed	WP	39	730.8763
138	134	2009	Sprayed	WP	6	58.10992

139	0	2009	Not Sprayed	WP	100	252.1858
139	0	2009	Sprayed	WP	1	0.095
143	134	2009	Not Sprayed	CF	53	292.6063
143	134	2009	Sprayed	CF	0	0
145	0	2009	Not Sprayed	CF	86	351.7737
145	0	2009	Sprayed	CF	1	0
149	134	2009	Not Sprayed	DSB	29	773.4433
149	134	2009	Sprayed	DSB	1	0.01
150	0	2009	Not Sprayed	DSB	14	269.2762
150	0	2009	Sprayed	DSB	3	10.09306
153	134	2009	Not Sprayed	FB	10	459.5909
153	134	2009	Sprayed	FB	6	152.8102
154	0	2009	Not Sprayed	FB	32	645.7854
154	0	2009	Sprayed	FB	4	0.338571
158	134	2009	Not Sprayed	CAN	59	446.3049
158	134	2009	Sprayed	CAN	3	0.164286
160	0	2009	Not Sprayed	CAN	264	492.9228
160	0	2009	Sprayed	CAN	13	3.471087
264	134	2009	Not Sprayed	WP	44	1723.651
264	134	2009	Sprayed	WP	65	166.3966
265	0	2009	Not Sprayed	WP	23	182.894
265	0	2009	Sprayed	WP	23	45.40686
267	134	2009	Not Sprayed	CF	5	17.41902
267	134	2009	Sprayed	CF	0	0
270	0	2009	Not Sprayed	CF	23	92.97447
270	0	2009	Sprayed	CF	2	0.040625
271	134	2009	Not Sprayed	SG	11	477.5603
271	134	2009	Sprayed	SG	0	0
273	0	2009	Not Sprayed	SG	2	13.19726
273	0	2009	Sprayed	SG	0	0
277	134	2009	Not Sprayed	CAN	31	1388.925
277	134	2009	Sprayed	CAN	2	0.04
280	0	2009	Not Sprayed	CAN	84	329.0424
280	0	2009	Sprayed	CAN	1	0.0675
283	0	2009	Not Sprayed	DSB	29	348.221
283	0	2009	Sprayed	DSB	5	0.2125
284	134	2009	Not Sprayed	DSB	60	1971.829
284	134	2009	Sprayed	DSB	0	0
289	0	2009	Not Sprayed	SG	13	123.2255
289	0	2009	Sprayed	SG	36	23.12574
290	134	2009	Not Sprayed	SG	24	1886.472
290	134	2009	Sprayed	SG	5	78.29521

333	0	2009	Not Sprayed	CF	18	349.1008
333	0	2009	Sprayed	CF	3	0.145833
334	134	2009	Not Sprayed	CF	11	1506.459
334	134	2009	Sprayed	CF	8	6.237031
337	0	2009	Not Sprayed	WP	10	399.0381
337	0	2009	Sprayed	WP	10	34.9299
338	134	2009	Not Sprayed	WP	27	1856.091
338	134	2009	Sprayed	WP	4	0.224
341	134	2009	Not Sprayed	SG	26	667.1357
341	134	2009	Sprayed	SG	0	0
343	0	2009	Not Sprayed	SG	8	68.69726
343	0	2009	Sprayed	SG	0	0
348	134	2009	Not Sprayed	DSB	55	194.9159
348	134	2009	Sprayed	DSB	15	80.90976
350	0	2009	Not Sprayed	DSB	25	64.36999
350	0	2009	Sprayed	DSB	5	0.24375
352	134	2009	Not Sprayed	CAN	24	933.2607
352	134	2009	Sprayed	CAN	10	6.248397
354	0	2009	Not Sprayed	CAN	17	465.4337
354	0	2009	Sprayed	CAN	2	0.028
356	134	2009	Not Sprayed	FB	126	105.0385
356	134	2009	Sprayed	FB	67	.
360	0	2009	Not Sprayed	FB	35	156.0882
360	0	2009	Sprayed	FB	10	2.354282
461	134	2009	Not Sprayed	WP	40	235.8543
461	134	2009	Sprayed	WP	282	335.6589
465	0	2009	Not Sprayed	WP	161	135.7886
465	0	2009	Sprayed	WP	28	74.88992
466	134	2009	Not Sprayed	DSB	115	1757.952
466	134	2009	Sprayed	DSB	4	43.49101
468	0	2009	Not Sprayed	DSB	33	274.5147
468	0	2009	Sprayed	DSB	19	9.823813
473	0	2009	Not Sprayed	CF	8	181.9704
473	0	2009	Sprayed	CF	2	0.035
474	134	2009	Not Sprayed	CF	14	173.4549
474	134	2009	Sprayed	CF	2	0.026917
476	134	2009	Not Sprayed	SG	35	615.4812
476	134	2009	Sprayed	SG	1	0.2075
478	0	2009	Not Sprayed	SG	3	1.149167
478	0	2009	Sprayed	SG	0	0
481	134	2009	Not Sprayed	FB	4	209.3592
481	134	2009	Sprayed	FB	2	29.1173

485	0	2009	Not Sprayed	FB	48	238.1067
485	0	2009	Sprayed	FB	14	23.1828
486	134	2009	Not Sprayed	WP	0	0
486	134	2009	Sprayed	WP	2	0.01875
488	0	2009	Not Sprayed	WP	0	0
488	0	2009	Sprayed	WP	0	0

SAS Code

This section of the appendix contains a representation of the SAS code used to derive least-squared means estimates, least-squared standard error, and pairwise comparisons for the response of cover crop biomass, Palmer density, Palmer biomass, and weed mortality to cover crop treatment, harvest and planting operations, and herbicide application.

Table B.10 SAS Proc Mixed code for least-squared mean estimates, least-squared standard errors, and pairwise comparisons used in chapter 3

```
data dryccpa;
input block year $ herb $ cover $ bio;
cards;

proc print data = dryccpa;
proc mixed;
class block year herb cover;
model bio = year|herb|cover / ddfm = satterth outp = resd;
random block block*herb;
lsmeans year|herb|cover / cl;
lsmeans year|herb|cover / cl;
  lsmeans year|herb|cover/pdiff cl;
  lsmeans year|herb|cover/pdiff adjust = simulate (report seed=4938378) cl;
  proc print data = resd;
proc univariate data = resd normal plot;
  var resid;
run;
```

ANOVA Tables

This section of the appendix contains ANOVA tables generated by Proc Mixed testing for response of dependent variables to source variables.

Table B.11 Cover crop biomass production by year and cover crop

Source	DF Source	DF Variable	F-Test	P Value
year	1	56	0.21	0.647
cover	4	56	163.01	<.0001
year*cover	4	56	5.81	0.0006

Table B.12 Initial emergence of Palmer amaranth on May 31, 2008 and May 31, 2009

Source	DF Source	DF Variable	F-Test	P Value
year	1	187	3.28	0.0719

Table B.13 Palmer amaranth mortality to glyphosate burndown application prior to cover crop planting

Source	DF Source	DF Variable	F-Test	P Value
year	1	53	7.66	0.0078
cover	3	53	2.21	0.098
year*cover	3	53	2.14	0.1059

Table B.14 Palmer amaranth mortality to harvest and planting operations

Source	DF Source	DF Variable	F-Test	P Value
year	1	78	20.45	<.0001
cover	5	78	1.24	0.2993
year*cover	5	78	0.99	0.4297

Table B.15 Palmer amaranth end of season density response to burndown application, year, and summer cover crops

Source	DF Source	DF Variable	F-Test	P Value
spray	1	110	15.59	0.0001
yr	1	110	47.5	<.0001
spray*yr	1	110	12.48	0.0006
cover	3	110	0.96	0.4156
spray*cover	3	110	0.81	0.4916
yr*cover	3	110	0.71	0.5486
spray*yr*cover	3	110	0.85	0.4677

Table B.16 Palmer amaranth end of season biomass response to year, burndown application, and summer cover crops

Source	DF Source	DF Variable	F-Test	P Value
year	1	102	30.43	<.0001
herb	1	2.97	21.32	0.0195
year*herb	1	102	36.82	<.0001
cover	3	102	8.6	<.0001
year*cover	3	102	3.31	0.0232
herb*cover	3	102	5.19	0.0022
year*herb*cover	3	102	3.53	0.0174

Table B.17 Initial Palmer amaranth emergence in the grain sorghum phase as a response to year, previous seasons cover crop, and previous seasons burndown application

Source	DF Source	DF Variable	F-Test	P Value
year	1	162	5.14	0.0247
cover	5	162	1.97	0.0851
year*cover	5	162	2.21	0.0457
herb	1	6	0.43	0.5356
year*herb	1	162	0.73	0.3951
cover*herb	5	162	1.03	0.4028
year*cover*herb	5	162	1.08	0.3741

Table B.18 Palmer amaranth mortality to Bicep II Magnum application in 2008 and Bicep II + Roundup Powermax in 2009 in the grain sorghum phase

Source	DF Source	DF Variable	F-Test	P Value
year	1	61	10.18	0.0022
cover	5	61	2.05	0.0841
year*cover	5	61	2.05	0.0841

Table B.19 Palmer amaranth end of season density response to year, nitrogen rate, Bicep II application, and previous year's cover crop in the grain sorghum phase

Source	DF Source	DF Variable	F-Test	P Value
year	1	120	16.96	<.0001
nrate	1	120	0	0.9673
year*nrate	1	120	0.01	0.9375
herb	1	120	11.55	0.0009
year*herb	1	120	4.2	0.0425
nrate*herb	1	120	1.26	0.2641
year*nrate*herb	1	120	0.83	0.3653
cover	5	120	1.22	0.3042
year*cover	5	120	1.26	0.2851
nrate*cover	5	120	0.68	0.6401
year*nrate*cover	5	120	0.71	0.6175
herb*cover	5	120	1.06	0.3847
year*herb*cover	5	120	0.84	0.5244
nrate*herb*cover	5	120	0.99	0.4278
year*nrate*herb*cover	5	120	1.18	0.3219

Table B.20 Palmer amaranth end of season biomass response to year, nitrogen rate, Bicep II application, and previous year's cover crop in the grain sorghum phase

Source	DF Source	DF Variable	F-Test	P Value
year	1	101	22.76	<.0001
nrate	1	98.5	0.11	0.7401
year*nrate	1	98.8	5.36	0.0227
herb	1	98.7	31.18	<.0001
year*herb	1	98.5	0.3	0.5856
nrate*herb	1	98.7	1.21	0.2742
year*nrate*herb	1	99	1.47	0.228
cover	5	99	2.53	0.0334
year*cover	5	99.4	1.81	0.1175
nrate*cover	5	98.5	2.17	0.063
year*nrate*cover	5	98.5	1.58	0.172
herb*cover	5	98.7	0.28	0.9213
year*herb*cover	5	98.8	0.86	0.5111
nrate*herb*cover	5	98.5	0.85	0.5145
year*nrate*herb*cover	4	98.5	0.72	0.582

Appendix C - Palmer amaranth and downy brome response to soybean cover crop

Raw Data

This section of the appendix contains all of the raw data from the third chapter, *Palmer amaranth and downy brome response to soybean cover crop* that may be needed for further research. Data are arranged as they appeared in the chapter and are referenced to figures and tables in which they appeared.

Table C.1 Soybean wholeplot, subplot biomass and Palmer amaranth subplot biomass and density by site-year and plot used to generate table. 4.3

Site-Year	Plot	Seeding Rate	Wholeplot Soybean Biomass	Subplot Soybean Biomass	Palmer Amaranth Biomass	Palmer Amaranth Density
			kg/ha	g/m^2	g/m^2	plants/m^2
Manhattan 2008	104	0	0	0	470.6	3
Manhattan 2008	206	0	0	0	.	7
Manhattan 2008	301	0	0	0	.	0
Manhattan 2008	403	0	0	0	91.2	2
Manhattan 2008	101	100	2623.253	232.6	283.6	8
Manhattan 2008	203	100	3720.489	264.2	274.6	7
Manhattan 2008	302	100	3010.254	868.6	437.2	2
Manhattan 2008	404	100	1596.38	135.2	32.4	2
Manhattan 2008	102	225	4562.657	344.4	152	3
Manhattan 2008	201	225	4381.616	487	52	5
Manhattan 2008	304	225	5702.405	812.2	127.4	2
Manhattan 2008	401	225	3356.21	352.8	83.4	2
Manhattan 2008	103	350	5334.46	437.8	99.4	5
Manhattan 2008	104	350	6775.454	923.6	14.8	3
Manhattan 2008	303	350	6541.64	452.2	92	4
Manhattan 2008	406	350	5794.757	977.6	106.8	3
Manhattan 2008	105	475	5217.92	877.2	78.8	1
Manhattan 2008	205	475	7959.912	561.6	190	4
Manhattan 2008	306	475	5160.017	917.2	221.4	6
Manhattan 2008	402	475	6592.947	812.4	57.8	3
Manhattan 2008	106	600	6712.419	888.6	45	0

Manhattan 2008	206	600	7116.279	1116.4	19.2	1
Manhattan 2008	305	600	7810.389	933.2	.	1
Manhattan 2008	405	600	4028.331	.	67	4
Manhattan 2009	104	0	0	0	597.6	14
Manhattan 2009	206	0	0	0	238.2	9
Manhattan 2009	301	0	0	0	481.8	12
Manhattan 2009	403	0	0	0	345.4	10
Manhattan 2009	101	100	680.3523	114.4	376	2
Manhattan 2009	203	100	2191.1	147.2	135.2	3
Manhattan 2009	302	100	2501.798	.	361.2	4
Manhattan 2009	404	100	2602.023	360	.	0
Manhattan 2009	102	225	4358.912	382.4	488	8
Manhattan 2009	201	225	2831.952	.	125.8	9
Manhattan 2009	304	225	4208.575	591.8	.	10
Manhattan 2009	401	225	2503.272	321.2	605	24
Manhattan 2009	103	350	3194.531	549	41	3
Manhattan 2009	104	350	4590.315	.	.	0
Manhattan 2009	303	350	4945.525	628.6	198.8	6
Manhattan 2009	406	350	4939.629	339.8	138.2	2
Manhattan 2009	105	475	5300.735	706.8	71.2	20
Manhattan 2009	205	475	5044.276	689.8	62.48	4
Manhattan 2009	306	475	5670.684	390.4	216.4	12
Manhattan 2009	402	475	5480.55	669	207.4	10
Manhattan 2009	106	600	4372.177	772.8	87.8	28
Manhattan 2009	206	600	5417.173	858.6	162.6	19
Manhattan 2009	305	600	6328.043	775	20.4	2
Manhattan 2009	405	600	7069.415	1058.6	176.6	10
Hesston 2008	104	0	0	0	559.8	26
Hesston 2008	206	0	0	0	203.6	8
Hesston 2008	301	0	0	0	327.4	30
Hesston 2008	403	0	0	0	573.8	40
Hesston 2008	101	100	1310.527	475.4	484.4	22
Hesston 2008	203	100	1001.952	424	418	18
Hesston 2008	302	100	2064.74	.	.	30
Hesston 2008	404	100	1075.248	574.2	425.6	30
Hesston 2008	102	225	3184.698	794	229.2	26
Hesston 2008	201	225	3087.214	770.8	199.4	16
Hesston 2008	304	225	2573.412	589.2	137.2	30
Hesston 2008	401	225	1635.96	424.2	247.2	12
Hesston 2008	103	350	2752.253	462	251.8	22
Hesston 2008	104	350	2732.463	687	.	20
Hesston 2008	303	350	2826.282	.	370	24

Hesston 2008	406	350	2214.996	445.4	338.8	18
Hesston 2008	105	475	3071.089	.	231.6	20
Hesston 2008	205	475	3084.283	840.2	254.8	14
Hesston 2008	306	475	3027.845	742	154.6	20
Hesston 2008	402	475	2847.538	751	.	12
Hesston 2008	106	600	2926.697	589	130.6	14
Hesston 2008	206	600	2771.31	483	126	20
Hesston 2008	305	600	2438.548	687.4	240.6	28
Hesston 2008	405	600	2439.281	485.2	194.6	14

Table C.2 LAI response to soybean seeding rate used in figure 4.2

		Soybean Seeding Rate (x1000 seeds/ha)				
	WAP	100	225	350	475	600
Hesston 2008				LAI m^2/m^2		
	6	0.37	1.84	1.83	2.34	3.2
	6	0.33	0.65	1.74	2.17	1.85
	6	0.74	1.44	1.69	2.02	2.29
	6	0.27	0.44	1	1.21	1.55
	8	0.76	2.69	3.1	3.24	3.73
	8	-0.38	1.25	1.77	3.35	3.27
	8	1.15	3.81	2.71	3.44	3.48
	8	0.83	1.71	1.33	2.89	2.95
	13	1.8	4.2	4.02	3.45	3.57
	13	3	4.98	4.84	5.14	4.94
	13	2.31	3.77	3.18	3.98	4.07
	13	2.07	4.49	4.22	4.37	5.04
	16	1.41	1.15	1.68	1.26	1.1
	16	0.33	1.13	0.98	0.87	1.14
	16	0.8	1.3	0.37	0.68	0.56
	16	0.3	0.48	0.99	0.3	1.27
Manhattan 2009						
	6	0.19	0.62	0.62	0.69	1.01
	6	0.15	0.5	0.53	1.01	1.73
	6	0.11	0.77	0.58	0.36	0.87
	6	-0.09	0.28	0.17	0.95	0.81
	11	1.17	1.11	2.26	2.86	4.2
	11	1.02	2.5	3.37	2.87	4.28
	11	0.5	2.21	4.3	4.25	4.64
	11	0.74	2.04	3.5	3.8	4.74
	15	0.32	2.35	2.66	3.89	3.68
	15	1.16	1.99	4.6	4.81	4.52
	15	1.26	2.55	4.19	4.37	4.87
	15	1.98	1.7	2.99	4.07	4.56

Table C.3 LAI at soybean harvest for Hesston 2008 and Manhattan 2009 used to generate table 4.5

Plot	Site-Year	Seeding Rate	LAI
		x1000 seeds/ha	m^2/m^2
101	Hesston 2008	100	1.8
203	Hesston 2008	100	3
302	Hesston 2008	100	2.31
404	Hesston 2008	100	2.07
102	Hesston 2008	225	4.2
201	Hesston 2008	225	4.98
304	Hesston 2008	225	3.77
401	Hesston 2008	225	4.49
103	Hesston 2008	350	4.02
104	Hesston 2008	350	4.84
303	Hesston 2008	350	3.18
406	Hesston 2008	350	4.22
105	Hesston 2008	475	3.45
205	Hesston 2008	475	5.14
306	Hesston 2008	475	3.98
402	Hesston 2008	475	4.37
106	Hesston 2008	600	3.57
206	Hesston 2008	600	4.94
305	Hesston 2008	600	4.07
405	Hesston 2008	600	5.04
101	Manhattan 2009	100	0.32
203	Manhattan 2009	100	1.16
302	Manhattan 2009	100	1.26
404	Manhattan 2009	100	1.98
102	Manhattan 2009	225	2.35
201	Manhattan 2009	225	1.99
304	Manhattan 2009	225	2.55
401	Manhattan 2009	225	1.7
103	Manhattan 2009	350	2.66
104	Manhattan 2009	350	4.6
303	Manhattan 2009	350	4.19
406	Manhattan 2009	350	2.99
105	Manhattan 2009	475	3.89
205	Manhattan 2009	475	4.81
306	Manhattan 2009	475	4.37
402	Manhattan 2009	475	4.07
106	Manhattan 2009	600	3.68

206	Manhattan 2009	600	4.52
305	Manhattan 2009	600	4.87
405	Manhattan 2009	600	4.56

Table C.4 Downy brome density response to soybean seeding rate and soybean termination method arranged by plot and site year used to generate table 4.6

Plot	Site-year	Seeding Rate	Downy brome density		
			plants/m2		
			Roll	Freeze	Spray
104	Manhattan 2008	0	112	112	14
206	Manhattan 2008	0	148	148	136
301	Manhattan 2008	0	28	28	54
403	Manhattan 2008	0	62	78	100
101	Manhattan 2008	100	2	152	0
203	Manhattan 2008	100	80	272	70
302	Manhattan 2008	100	0	0	0
404	Manhattan 2008	100	0	78	44
102	Manhattan 2008	225	10	50	66
201	Manhattan 2008	225	24	242	154
304	Manhattan 2008	225	2	4	10
401	Manhattan 2008	225	2	188	96
103	Manhattan 2008	350	62	0	14
104	Manhattan 2008	350	0	92	46
303	Manhattan 2008	350	0	0	60
406	Manhattan 2008	350	88	0	132
105	Manhattan 2008	475	90	160	108
205	Manhattan 2008	475	88	0	0
306	Manhattan 2008	475	82	88	124
402	Manhattan 2008	475	26	156	0
106	Manhattan 2008	600	108	122	124
206	Manhattan 2008	600	2	6	0
305	Manhattan 2008	600	6	46	4
405	Manhattan 2008	600	0	0	146
104	Manhattan 2009	0	42	52	82
206	Manhattan 2009	0	14	28	24
301	Manhattan 2009	0	52	58	142
403	Manhattan 2009	0	46	88	58
101	Manhattan 2009	100	12	24	52
203	Manhattan 2009	100	40	72	144
302	Manhattan 2009	100	114	254	174
404	Manhattan 2009	100	48	50	62
102	Manhattan 2009	225	90	86	120
201	Manhattan 2009	225	86	72	28

304	Manhattan 2009	225	40	40	58
401	Manhattan 2009	225	136	94	82
103	Manhattan 2009	350	66	50	56
104	Manhattan 2009	350	42	18	10
303	Manhattan 2009	350	86	54	58
406	Manhattan 2009	350	28	24	66
105	Manhattan 2009	475	150	56	46
205	Manhattan 2009	475	124	12	6
306	Manhattan 2009	475	18	18	26
402	Manhattan 2009	475	208	168	102
106	Manhattan 2009	600	22	0	12
206	Manhattan 2009	600	162	.	106
305	Manhattan 2009	600	32	38	18
405	Manhattan 2009	600	168	228	74
104	Hesston 2008	0	36	56	0
206	Hesston 2008	0	7	38	0
301	Hesston 2008	0	6	31	0
403	Hesston 2008	0	40	47	0
101	Hesston 2008	100	57	43	0
203	Hesston 2008	100	42	22	0
302	Hesston 2008	100	55	68	0
404	Hesston 2008	100	56	67	0
102	Hesston 2008	225	29	45	0
201	Hesston 2008	225	39	56	0
304	Hesston 2008	225	47	32	0
401	Hesston 2008	225	5	11	0
103	Hesston 2008	350	50	39	0
104	Hesston 2008	350	25	68	0
303	Hesston 2008	350	22	24	0
406	Hesston 2008	350	42	4	0
105	Hesston 2008	475	14	51	0
205	Hesston 2008	475	1	12	0
306	Hesston 2008	475	17	32	0
402	Hesston 2008	475	35	43	0
106	Hesston 2008	600	16	31	0
206	Hesston 2008	600	13	29	0
305	Hesston 2008	600	45	28	0
405	Hesston 2008	600	27	62	0

SAS Code

This section of the appendix contains a representation of the SAS code used to derive least-squared means estimates, least-squared standard error, and pairwise comparisons for the response of soybean biomass, Palmer amaranth density, Palmer amaranth biomass, and downy brome density to soybean seeding rate and termination method

Table C.5 SAS code used to determine responses of soybean biomass, Palmer amaranth density and biomass, LAI at harvest, and downy brome response to soybean seeding rate and termination method

```
options ls = 75;
options ps = 48;
data wholeplotsb;
input loc block sr bio;
cards;
proc print;
proc mixed;
class sr loc;
model bio = sr|loc / outp = resd;
random block block*sr block*loc;
lsmeans sr|loc / cl;
  lsmeans sr|loc / cl;
  lsmeans sr|loc /pdiff cl;
  lsmeans sr|loc /pdiff adjust = simulate (report seed=4938378) cl;
  lsmeans sr|loc / pdiff cl;
proc print data = resd;
proc univariate data = resd normal plot;
  var resid;
run;
```

ANOVA Tables

This section of the appendix contains ANOVA tables generated by Proc Mixed testing for response of dependent variables to source variables.

Table C.6 Soybean whole plot biomass response to seeding rate

Source	DF Source	DF Variable	F-Test	P Value
rate	5	46	77.7	<.0001
Site	2	46	14.72	<.0001
rate*site	10	46	4.39	0.0002

.

Table C.7 LAI at soybean whole plot harvest response to site-year and seeding rate

Source	DF Source	DF Variable	F-Test	P Value
site	1	24	14.61	0.0008
rate	4	24	24.57	<.0001
site*rate	4	24	4.68	0.0062

Table C.8 Soybean biomass response to weed competition and soybean seeding rate

Source	DF Source	DF Variable	F-Test	P Value
rate	5	38	30.05	<.0001
site	2	38	2.35	0.1094
rate*site	10	38	2.26	0.034

Table C.9 Palmer amaranth density response to soybean seeding rate

Source	DF Source	DF Variable	F-Test	P Value
rate	5	46	0.77	0.5728
site	2	46	59.46	<.0001
rate*site	10	46	2.07	0.0469

Table C.10 Palmer amaranth biomass response to soybean seeding rate

Source	DF Source	DF Variable	F-Test	P Value
rate	5	38	7.73	<.0001
site	2	38	8.35	0.001
rate*site	10	38	1.45	0.1958

Table C.11 Downy brome response to soybean seeding rate and termination method

Source	DF Source	DF Variable	F-Test	P Value
rate	5	151	1.1	0.3633
year	2	151	4.71	0.0104
rate*year	10	151	0.89	0.5474
term	2	151	1.8	0.1686
rate*term	10	151	1.07	0.3876
year*term	4	151	2.08	0.0865
rate*year*term	20	151	1.23	0.2349