INFLUENCE OF WARM-SEASON COVER CROP ON NO-TILL WINTER WHEAT (*TRITICUM AESTIVUM* L.) PRODUCTION

By

CASEY JOHN ANDREWS

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Thesis Approved:

Jeffrey T. Edwards, Ph. D

Thesis Adviser

Chad B. Godsey, Ph. D

Kristopher L. Giles, Ph. D

Sheryl A. Tucker, Ph. D

Dean of the Graduate College

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ABSTRACT

Due to the adverse economic and ecological consequences of the conventional-till, monoculture winter wheat production system that dominates Oklahoma, producers are interested in no-till farming practices and diversifying their cropping systems through crop rotation and cover crops. In response to this interest, we evaluated cover crop biomass production and canopy closure, winter wheat nitrogen requirement, Hessian fly infestation pressure and final wheat grain yield response to warm-season cover crops in no-till, dual-purpose and grain-only wheat production systems. Experimental design was a split split-block with cover crop treatment (cowpea, soybean, guar, sorghum-sudangrass, pearl millet and fallow control) seeded following wheat harvest and chemically terminated approximately 45 days after seeding as whole plots. Sub plot treatment was winter wheat variety (Duster and Endurance) sown into the standing cover crop residue. Sub-sub plots were topdress nitrogen application (non-fertilized or nitrogen rate determined by sensor based nitrogen rate recommendation). During 2009 and 2010, sorghum-sudangrass, pearl millet, and cowpea provided quick biomass and canopy closure, making them well suited for weed suppression and soil erosion prevention. In both dual-purpose and grain-only production systems, wheat productivity following fallow was equal to or greater than wheat following cover crops in almost all categories. Wheat following legume cover crops, in most cases, had production levels equal to or greater than wheat following grass cover crops; however, cover crops had no effect on Hessian fly infestation. Differences in Hessian fly infestation between resistant (Duster) and susceptible (Endurance) wheat varieties were found. Grain yield was not affected by differences in Hessian fly infestation, as infestation pressure was below the economic injury threshold. The integration of cash crops may be a better solution than cover crops, as producers can achieve many of the same benefits associated with cropping system diversification as seen with cover crops as well as receive economic returns through cash crop production.

CHAPTER I

INTRODUCTION

In Oklahoma, monocrop hard red winter wheat (*Triticum aestivum* L.) is the dominant cropping system. Over 2.3 million hectares are sown to winter wheat annually, as the Oklahoma climate offers producers multiple uses for the crop. Traditionally, winter wheat is sown in the fall and allowed to overwinter before being harvested in the summer for grain. Taking advantage of Oklahoma's mild climate, wheat producers can produce enough biomass to graze cattle during the winter and have ready access to this biomass due to few snow-covered days. Wheat that is grazed during the winter and harvested for grain in the summer is known as dual-purpose wheat. Dual-purpose wheat has been agronomically and economically successful for Oklahoma producers; therefore, many producers have shifted production from more diversified cropping systems to strictly monoculture winter wheat. While this cropping system works well for many producers, the continuous production of only one crop can have adverse consequences economically and ecologically.

Negative effects of conventional-till, monoculture winter wheat production include the opportunity cost associated with a fallow period, soil erosion, nutrient leaching, and increased pest and weed problems. Monocrop systems often leave a fallow period where production is not taking place, thus limiting economic return to the producer. In order to alleviate these negative effects, producers have expressed interest incorporating no-till farming practices and diversification of their cropping systems through crop rotation and cover crops. The adoption of no-till practices has slowly gained interest in Oklahoma as farmers see the benefits ranging from reduced soil erosion and soil moisture conservation to reduction in time and machinery inputs. The reluctance to convert to no-till farming is associated with a lack of suitable alternative crops to fit current producers' production systems. The use of cover crops allows producers the ability to maintain their current production systems while adding an alternative crop to the short fallow period that may otherwise be too short to achieve a grain crop and be seeded back to wheat for that following year. Cover crops can reduce soil erosion, nitrogen leaching, and provide weed and pest suppression. Cover crops provide other benefits to the soil including enhanced nutrient cycling and greater water retention (Creamer and Baldwin, 1999; Clark, 2007). The implementation of crop rotation and cover crops into current cropping systems can provide both economic and ecological benefits.

The climate of a region plays a major role in the potential diversity of viable cropping systems. A major yield-limiting factor in the dryland cropping systems of western Oklahoma is precipitation, as annual precipitation for this region averages less than 880 mm. Water availability and soil nitrogen content are the main factors to consider when substituting a cover crop for fallow in a wheat rotation (McGuire et al., 1998). Nielsen and Vigil (2005) conducted a study in eastern Colorado to evaluate the effect of legume green fallow termination date on soil moisture and winter wheat yield. They concluded soil water content at wheat planting was reduced by 55 and 104 mm at early and late legume green-fallow termination dates as compared to the conventionally-tilled fallow plots. Nielsen and Vigil (2005) also found the average wheat yield was linearly correlated with the amount of soil moisture available at wheat planting. The negative effects of legume cover crops on fallow water storage can be offset by adequate seasonal precipitation (Danga et al., 2009). McGuire et al. (1998) found when adequate seasonal precipitation occurred, the yields of fertilized wheat after fallow and unfertilized wheat following a legume cover crop were similar.

Cover crops have the ability to enhance nutrient cycling in multiple ways. First, cover crops uptake essential nutrients needed for plant growth. This uptake traps surplus nutrients within the plant, thus preventing them from being lost from the root zone by leaching, runoff or erosion. Tonitto et al. (2006) found that in fertilizer-intensive cropping systems, non-legume cover crops reduced nitrate leaching 70% as compared to bare-fallow systems. They also found cover crop nitrogen uptake of post-harvest surplus inorganic nitrogen to range from 20 to 60 kg nitrogen ha^{-1}. Nutrient translocation from deeper subsoil to the soil surface is another advantage cover crops offer (Giese, 2009). Crops such as sorghum-sudangrass hybrids and cereal rye utilize fibrous root systems to penetrate deep into the soil for moisture and nutrients (Clark, 2007). Both grasses have the ability to produce large amounts of biomass quickly.

While most cover crops offer a means of nutrient recycling, some can actually add nutrients to the soil. Legume cover crops have the ability to fix atmospheric nitrogen through a symbiotic relationship between bacterium *(Rhizobium* spp.) found in the root nodules of these plants. The amount of nitrogen contributed to the soil by legume crops can range from 0 to 450 kg N_2 ha^{-1} per annum (Peoples and Craswell, 1995). Danga et al.

(2009) reports the amount of nitrogen contribution is dependent on the rate of symbiotic N_2-fixing activity, growth, and the nitrogen harvest index of the legume crops. The rate of N_2 fixation variation depends on the type of legume cultivar, method of measurement, presence of appropriate rhizobia, soil moisture, NO_3 levels, P nutrition, and soil acidity (Amanuel et al., 2000; Andrade et al., 2002; Beck, 1992; Doughton et al., 1993; Herridge et al., 1995). Chalk (1998) found grain legumes with high concentrations of nitrogen in biomass, low nitrogen harvest index, and high symbiotic dependence have the greatest potential to contribute positively to soil nitrogen levels.

The production of annual legume crops has been widely used to improve yields of cereals in rotations and contribute to the total pool of nitrogen in the soil (Herridge et al., 1995). The benefits obtained from the use of a legume in a crop rotation can be separated into the N effect and non-N effect (Bullock, 1992; Stevenson and Van Kessel, 1996). Many research studies have shown the yield increase in cereals following legumes is mainly due to the nitrogen contribution (Herridge et al., 1995; Lopez-Bellido et al., 2004; McGuire et al., 1998; Turpin et al., 2002). In years where soil moisture is not limited in California's Sacramento Valley, McGuire et al. (1998) found wheat yields following a winter legume cover crop were similar to those of fertilized wheat following fallow. Additionally, there were no grain yield differences in wheat following fallow that received 28 kg N ha^{-1} as compared to treatments receiving the higher nitrogen fertilizer rate of 112 kg N ha^{-1} (McGuire et al., 1998). A study conducted in southeastern Australia evaluating wheat yield and grain quality response after legume and cereal grain crops showed wheat yields increased following a legume or alternative cereal grain crop (Evans et al., 1991). Evans et al. (1991) also noted that lupins, peas and barley improved wheat yield 44, 32, and 4% as compared to a continuous wheat rotation. In the same study, grain nitrogen content was also increased 12% for both lupins and peas, while barley grain nitrogen content increased less than one percent.

The nutrients recycled by cover crops are not immediately available for uptake by the following crop. Mineralization, the process by which soil microbes break down chemical compounds in organic matter and convert it into plant available forms, must occur before nutrients can be utilized by the next crop. The rate by which organic residues are decomposed is influenced by air temperature, humidity, soil moisture, aeration, soil temperature, microbial biomass and nutrient status (Swift et al., 1979). In Montana, wheat yields in a spring wheat-fallow system were higher than in lentil green manure-spring wheat system during the first three cycles of the system due to a lower amount of nitrogen availability following lentils (Cochran and Kolberg, 2002). In order to optimize utilization of cover crop residues, it is essential to understand the decomposition and nutrient release dynamics of crop residues at different maturity stages (Danga et al., 2009). The period of maximum demand for the principal crop must be synchronized with the period of maximum nutrient release from decomposed organic residues to obtain optimal utilization (Myers et al., 1982). Palm (1995) found that organic residues released up to 80% of their nutrients during decomposition, but less than 20% was captured by crops.

The improvement of soil quality has been associated with the use of cover crops. Continuous crop production increases the amount of vegetative biomass, thereby increasing the amount of plant residues that soil microbes can decompose and convert to soil organic matter. As soil organic matter increases, water retention and soil tilth improve. In order to achieve desired soil quality results, the selection of the proper cover crop type is critical. Snapp et al. (2005) stated that, due to their ability to produce large amounts of biomass, cereal cover crops should be considered when soil organic levels must be increased rapidly. Cover crops with large taproots can reduce soil compaction that limits crop yield and water infiltration. Deep-rooted cover crops like alfalfa have the ability to increase the formation of macropores within the soil, thus increasing water percolation (Foltz et al., 1993). Increasing water infiltration allows more water to be stored within the soil, which improves yield in moisture-limited environments. Hoorman et al. (2009) showed that one pound of organic matter within the soil has the ability to hold eight to nine kg of water. They also demonstrated that continuously vegetated soils have the ability to retain 106 to 114 mm of water, while tilled, bare soils have the ability to hold 38 to 43 mm of water.

Well-established cover crop stands compete with weed species for resources needed for life such as space, nutrients, water and light. This competition can prevent the germination of weed seeds. Furthermore, even when weed seeds germinate they often exhaust stored energy before building the necessary structural capacity to break through the cover crop mulch layer. This is often termed the cover crop smother effect (Kobayashi et al., 2003). In addition to the smother effect, sorghum-sudangrass hybrid seedlings, shoots, leaves and roots secrete an allelopathic compound that has the ability to suppress many weeds (Clark, 2007).

Shifting from a monoculture to polyculture cropping systems breaks disease and pest cycles. Polycultures increase biological diversity and the population of natural predators which control pests. Cover crop treatments delayed the growth of mites and springtails in a broccoli crop, thus improving stand establishment (Wyland et al., 1998). Biological diversity also inhibits the survival of diseases because their specific host is removed from the environment. The use of cruciferous crops can reduce soil pathogen populations (Lewis and Papavizas, 1971; Subbarao et al., 1994). Cover crops can also act as a host to pathogens and insects (Dillard and Grogran, 1985; Creamer and Baldwin, 1999); therefore, cover crop selection can be critical in limiting the effects of pests and diseases within cropping systems.

One of the most destructive pests found in wheat growing regions is the Hessian fly (*Mayetiola destructor* (Say)). Females oviposit on the wheat leaves and the eggs will hatch within three to ten days depending on temperature. Following hatching, first instar larvae migrate from the leaf down between the leaf sheath and stem where they begin to find a suitable feeding site (Chapin, 2008; Alvey, 2009). This is critical, as second instar larvae lack creeping pads, which inhibit them from moving around the plant to find alternative feeding sites (Harris et. al, 2006). When first instar larvae begin feeding on the wheat plant, components within the saliva triggers a change in the signaling pathway, thus altering the development of the plant (Kosma et. al, 2010). Photoassimialtes are imported to the site of the puncture wound creating a nutritive tissue sink where the larvae feeds (Harris et. al, 2006). If infestation is high, these induced plant changes can cause stunting and death of tillers, lodging, prevents spike development, and reduce grain yield (Castle Del Conte et. al., 2005).

To reduce the impact of Hessian fly infestation, producers can use many different control methods. Use of resistant cultivars, crop rotation, seed treatments, delayed planting and conventional tillage are the more common control methods; however, these methods are not successful everywhere. In the southern United States, delaying planting may result in loss of forage production, thus limiting economic return through grazing stocker cattle. The use of resistant cultivars has been the most successful control method in this region (Royer et. al, 2009). This method utilizes the avoidance category for pest management, thus even though pests are present within a field, crop management practices deter significant pest population densities or crop damage (Peairs et. al., 2005). Kosma et. al. (2010) found larvae that initiated feeding on resistant cultivars were unable to compromise the cell walls around the feeding site, thus they were unable to derive nutrients needed from nutritive tissue sinks. Shukle et. al. (2010) observed larvae that fed upon resistant wheat cultivars showed signs of midgut microvilli disruption and eventually were absent, thus concluding the midgut is the target of plant resistance compounds.

As pests become more difficult to control and crops become better adapted for specific regions, more producers are interested in increasing crop diversity within their production system. This cultural control method may be extremely useful for Hessian fly control, as the Hessian fly is a specialist wheat pest with a narrow host range. By increasing crop diversity, the presence of an alternative crop may disrupt the ability of the pest to find its host crop or attract it away from the primary crop, thus limiting the pest's abundance on the host crop (Vandermeer, 1989; Peairs et. al., 2005). In New Zealand, a study was conducted to evaluate egg laying and larvae survival response of Hessian fly on cereal and non-cereal grasses. Harris et.al. (1996) found Hessian fly laid eggs and larvae survived feeding on both cereal and non-cereal (wild and prairie) grasses; however, wheat had the greatest amount of egg laying and larvae survival as compared to all other grasses. In addition, Hessian fly was more likely to lay eggs on host grasses that supported larval feeding as compared to host grasses that did not support larval feeding (Harris et.al., 1996). In North Carolina, no Hessian fly reproduction could be demonstrated on seven species of wild grasses (Zeiss et al., 1993). Chen et. al. (2009) reported Hessian fly adults laid approximately three times more eggs on wheat seedlings as compared to barley or rice seedlings. Newly hatched larvae survival was significantly decreased due to eggs not being laid on the abaxial leaf surface, thus hindering the larvae's ability to migrate to the leaf sheath. Larval growth was much slower in larvae that feed upon susceptible barley seedlings as compared to wheat seedlings under the same conditions (Chen et. al, 2009).

Many studies have evaluated the effect of cover crops on wheat yield; however, a literature review found no published research evaluating the effects of both grass and legume cover crops in a dual-purpose wheat production system compared to a grain-only wheat production system. Secondly, no published research has evaluated the impact of cover crops as a form of pest management on Hessian fly populations in wheat. The objectives of this experiment were to (i) determine hard red winter wheat grain yield response to production of warm-season cover crops during the summer fallow period, (ii) determine the effect of warm-season cover crops on wheat nitrogen requirement as predicted by Sensor Based Nitrogen Rate (SBNR) recommendation, and (iii) determine if warm-season cover crops inhibit Hessian fly infestation.

CHAPTER II

METHODOLOGY

Field Experiment

To evaluate the feasibility of cover crops in a no-till winter wheat production system, a study was established at Bornemann Farms, southeast of Union City, OK (35º22'39.83" N, 97º51'32.62" W, elevation 390 m), in 2009. The soil type was a Pond Creek silt loam (fine-silty, mixed, superactive, thermic Pachic Argiustolls). This rainfed site receives an average of 868 mm of precipitation annually. Prior to this experiment, this site was in a no-till wheat/canola rotation for three years and conventional-till monocrop wheat production prior to that.

Summer Cover Crops

The experiment was established directly following the harvest of wheat in 2009. Cover crops were sown directly into the standing wheat stubble 18 June 2009 and 22 June 2010 using appropriate planting densities for the region (Table 1). Five cover crops treatments were evaluated: cowpea (*Vigna unguiculata* L.), soybean (*Glycine max* L.), guar (*Cyamopsis tetragonoloba* L.), sorghum-sudangrass hybrid (*Sorghum bicolor* x *S. bicolor var. sudanese*), pearl millet (*Pennisetum glaucum* L.) and a fallow control. The individual cover crop plots measured 15.2 m long by 7.3 m wide. Cover crops were sown using a Great Plains no-till drill (Great Plains Mfg. Inc., Salina, KS) equipped with coulters and a row spacing of 19 cm. Legume cover crops were inoculated using the recommended strain of rhizobium bacteria just prior to planting. Vegetation in fallow treatments was chemically controlled as needed throughout the summer growing season with 1.12 kg ha^{-1} glyphosate.

Table 1. Cover crop cultivar and seeding density for the 2009 and 2010 summer growing seasons near Union City, OK.

Cover Crop	Cultivar	Seeding Density (kg ha^{-1})
Cowpea	Iron & Clay	30
Soybean	Forrest	40
Guar	Kinman	6
Sorghum-sudangrass	Sweet Sunny Sue	16
Pearl Millet	Hybrid Pearl-PP102M	21

Five sets of canopy closure readings were taken weekly each season starting 2 July 2009 and 6 July 2010 as weather permitted (Table 2). Canopy closure was measured using digital photography. Photographs were taken using a digital camera mounted on a monopod approximately one meter above biomass crop canopy. The digital photographs were batch analyzed using SigmaScan Pro (v. 5.0, Systat Software, Point Richmond, CA). This program was used to determine the number of green pixels in a photograph relative to the total pixels in the photograph similar to the procedure described by Purcell (2000).

Table 2. Date of canopy closure measurement for cover crops sown in 2009 and 2010 near Union City, OK.

	Canopy Closure Measurement Date				
Year	1	2	3	4	5
2009	2 July	10 July	16 July	27 July	6 August
2010	6 July	13 July	20 July	27 July	6 August

The cover crops in this study were chemically terminated at the early to mid-bloom stage of growth on 12 August 2009 and 11 August 2010 using 1.12 kg ha $^{-1}$ glyphosate. Termination date was established at early to mid-bloom developmental stage to avoid the onset of seed production. In order to obtain uniform spray coverage on the tall foliage, a bar was mounted ahead of the spray boom to restrict the crop canopy from obstructing the spray pattern. Prior to termination, two one-meter samples were clipped to determine biomass totals per plot. Biomass samples were dried for approximately 10 days at 50 ºC and weighed to estimate the total biomass produced per plot. Cover crop residue was allowed to stand undisturbed until wheat sowing.

Winter Wheat Establishment

Two separate wheat production systems (dual-purpose and grain-only) were evaluated in this study. In the dual-purpose, cattle were allowed to graze from late October until the first hollow stem growth stage. The grain-only system was fenced off from the rest of the field to prevent grazing. Within each production system, a split split-block experimental design was used to evaluate the effects of cover crops on pest management, nitrogen requirement and grain yield (Figure 1). Cover crop main plots were split by sowing half of each block to one of two hard red winter wheat varieties (Endurance and Duster) perpendicular to the row orientation of the cover crops. These wheat varieties were selected due to their adaptation to the area and dissimilar response to Hessian fly infestation, as Endurance is susceptible to Hessian fly while Duster expresses resistance.

Figure 1. Example of plot design within one replication. The main plot treatment was cover crop with wheat cultivar as the sub-plot and nitrogen treatment as the sub sub-plot. Plot design was replicated four times per production system.

Endurance	SBNR	NF	SBNR	NF	SBNR	NF	SBNR	NF	SBNR	NF	SBNR	NF
N-RICH STRIP												
Duster	SBNR	NF	SBNR	NF	SBNR	NF	SBNR	NF	SBNR	NF	SBNR	NF
	Fallow		Guar		Soybean		Cowpea		Pearl millet		Sorghum-sudangrass	

Abbreviations: SBNR, sensor based nitrogen rate; NF, non-fertilized.

Prior to seeding dual-purpose wheat, all plots were sprayed with 1.12 kg ha $^{-1}$ glyphosate to terminate any weeds prior to wheat emergence. The grain-only trial received an additional 1.12 kg ha^{-1} glyphosate treatment prior to seeding each year. Winter wheat was seeded using the same Great Plains no-till drill as previously mentioned and received an in-furrow application of 47 L ha^{-1} liquid ammonium phosphate (10-34-0). Seeding date and density are provided in Table 3. The ideal seeding date in this region for dual-purpose is mid-September and grain-only is early to mid-October. Seeding dates were adjusted from optimum seeding date due to excessive fall precipitation in 2009 and insufficient soil moisture in 2010. Seeding densities were determined using appropriate seeding densities for the region and production system.

Table 3. Winter wheat seeding date and densities for dual-purpose and grain-only systems for 2009 and 2010 near Union City, OK.

System	Year	Seeding Date	Seeding Density (kg ha^{-1})
Dual-purpose	2009-2010	29 September 2009	134
	2010-2011	20 September 2010	134
Grain-only	2009-2010	28 October 2009	100
	2010-2011	5 November 2010	100

Plots were routinely scouted throughout the growing season and pesticides were applied when warranted. In 2009, 0.018 kg ha^{-1} pyroxsulam was applied to the entire study 1 December 2009 to control winter annual grasses and broadleaf weeds. In 2010, 0.83 kg ha^{-1} pinoxaden and 0.56 kg ha^{-1} MCPA were applied 10 March 2011 for control of Italian ryegrass (*Lolium multiflorum*) and broadleaf weeds. On 6 December 2010, an additional 0.56 kg ha^{-1} chlorpyrifos was applied to the grain-only system to control a winter grain mite (*Penthaleus major*) infestation.

Nitrogen Management

The sub sub-plot treatments tested the effect of warm-season cover crops on wheat nitrogen requirement as predicted by Sensor Based Nitrogen Recommendation (SBNR) as compared to a non-fertilized treatment. A nitrogen-rich strip was applied, in the buffer areas between each variety subplot after sowing by applying 220 kg N ha^{-1}. This application rate ensured nitrogen would not limit plant growth during the growing season. Normalized difference vegetation index measurements for each plot and its corresponding nitrogen-rich strip were taken 15 March 2010 and 22 March 2011 using a handheld NDVI sensor. This comparison was used to determine the amount of nitrogen fertilizer needed by the SBNR plots. Top-dress nitrogen rate recommendations were made using the sensor based nitrogen rate calculator for winter wheat in the US Grain Belt (http://www.soiltesting.okstate.edu/SBNRC/SBNRC.php, verified 11/15/2011). All four replications per production system were combined to obtain a mean fertilizer recommendation. Fertilizer was applied in 17 kg N ha^{-1} increments and plots were fertilized at the 17 kg N ha^{-1} increment that was closest to the actual SBNR recommendation. Urea ammonium nitrate (UAN) solution (28-0-0) was the fertilizer source applied using a 3-m bicycle sprayer equipped with streamer nozzles. The sprayer was calibrated to deliver 34 kg N ha^{-1} fertilizer; therefore, plots requiring higher rates received multiple passes (Table 4). The 17 kg N ha^{-1} rate was obtained by using a 50/50 solution of UAN fertilizer and water.

Table 4. Top-dress nitrogen rates applied to winter wheat varieties within each cover crop treatment for 2010 and 2011 growing seasons near Union City, OK. Rate recommendations were made using the sensor based nitrogen rate calculator for winter wheat.

		Top-dress Nitrogen Rates			
		2010		2011	
System	Cover Crop	Duster	Endurance	Duster	Endurance
		------------------------kg N ha^{-1}--------------------			
Dual-purpose					
	Fallow	34	17	119	136
	Cowpea	51	34	119	153
	Soybean	51	51	119	119
	Guar	51	51	119	119
	Sorghum-sudangrass	51	68	136	153
	Pearl Millet	34	51	136	119
Grain-only					
	Fallow	17	51	0	0
	Cowpea	17	17	34	0
	Soybean	34	17	51	0
	Guar	17	17	51	0
	Sorghum-sudangrass	0	0	17	34
	Pearl Millet	17	17	34	17

Hessian Fly

Two Hessian fly samples one in late-fall (first generation) and the other in early-spring (second generation) were obtained from a single legume crop, single grass crop and the fallow control. The legume and grass cover crops were selected based on greatest canopy closure; therefore, samples were taken from the cowpea and sorghum-sudangrass plots. Five wheat samples were selected at random throughout the SBNR plots. Plants were excavated with roots intact using garden trowels and placed into one-gallon plastic freezer bags. Samples were trimmed to 20 cm, so the samples could be stored in zip-close plastic bags. All samples were transported to the laboratory and stored in a freezer until they could be dissected. Dissection of first generation samples consisted of pulling each leaf down to the base of the plant and inspecting for the presence of any larvae or pupae. Second generation samples were dissected by cutting the entire length of the stem open vertically and inspecting for the any larvae or pupae. The number of larvae, pupae and tillers per sample bag were recorded.

Insolation

At anthesis, a LI-191S line quantum sensor (Li-Cor, Lincoln, NE) was used to determine the fraction of photosynthetically active radiation interception by wheat crop canopy. This was calculated by measuring photosynthetically active radiation above and below the crop canopy in unobstructed light within one hour of solar noon. The sensor was placed parallel to the orientation of the wheat rows when measuring below canopy radiation. The radiation from the soil surface was subtracted from the radiation value above the crop canopy and divided by above canopy radiation values to quantify the fraction of photosynthetically active radiation reaching the soil surface. Fraction of photosynthetically active radiation intercepted by the plant canopy was calculated as one minus the fraction of light reaching the soil surface.

Harvest

Grain was harvested using a Wintersteiger small-plot combine (Wintersteiger Inc., Salt Lake City, UT) once moisture content of all plots was less than 13.5 percent. The center 2 m of each plot was harvested for a total harvested area of 10.6 m^2. Due to the straw piles left by the plot harvester, a rotary mower was used to distribute straw more evenly prior to planting cover crops.

Statistical Analysis

Cover crop biomass and canopy closure, Hessian fly infestation, nitrogen fertilizer recommendation, nitrogen fertilizer response index, insolation and wheat grain yield were analyzed using SAS software version 9.2 (SAS, Cary, NC). Analysis of variance was performed using PROC MIXED. Cover crop biomass and canopy closure were analyzed as randomized complete block experimental design. The remaining components were analyzed with appropriate comparisons using orthogonal contrasts in split block design with years and fertilizer treatments analyzed separately.

CHAPTER III

RESULTS AND DISCUSSION

1.1 Dual-Purpose Production System

1.1.1 Cover Crop Biomass and Canopy Closure

Guar was removed from the 2009 analysis due to poor stand establishment. There were no differences in total biomass between grass cover crops (sorghum-sudangrass and pearl millet) or between legume cover crops (cowpea and soybean) in 2009 (Figure 2). Grass cover crops yielded 6,250 kg ha^{-1} more biomass than legume cover crops. In 2010, sorghum-sudangrass yielded 3,430 and 5,630 kg ha^{-1} more biomass than pearl millet and the legume cover crops, respectively. Biomass production did not differ among legume cover crops in 2010, and overall cover crop biomass production was reduced by 41% in 2010 as compared to 2009.

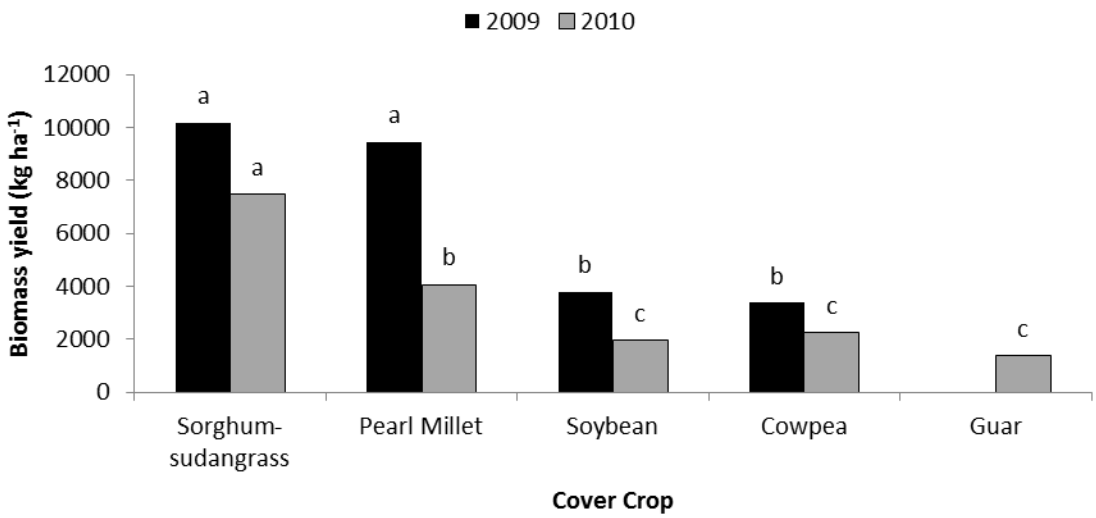

Figure 2. Mean cover crop biomass yield for summer 2009 and 2010 growing seasons near Union City, OK. Columns within year with the same letter are not significantly different (α=0.05).

In 2009, sorghum-sudangrass canopy closure was at least four times greater than any other cover crop at 14 and 22 days after seeding (DAS)(Figure 3; Table 5). Fallow and soybean treatments all failed to reach greater than 5% canopy closure by 28 days after seeding. At termination (49 DAS) in 2009, cowpea, sorghum-sudangrass, and pearl millet had achieved near full canopy closure. In 2010, a steady increase in canopy closure was seen in all cover crop treatments from days 14 to 28 (Figure 4: Table 5). Following day 28, grass cover crop growth rate significantly decreased while legume cover crop growth rate remained steady. At day 35, sorghum-sudangrass and pearl millet reached maximum canopy closure; however, maximum canopy closure of these treatments was 9 and 10% less than 2009. Sorghum-sudangrass and pearl millet canopy closure did not increase past 35 DAS but cowpea, and soybean did. Previous literature supports these findings as plant growth of cowpea, sorghum and millet are characterized by quick biomass production, thus making them well adapted for weed suppression and erosion control (Clark, 2007).

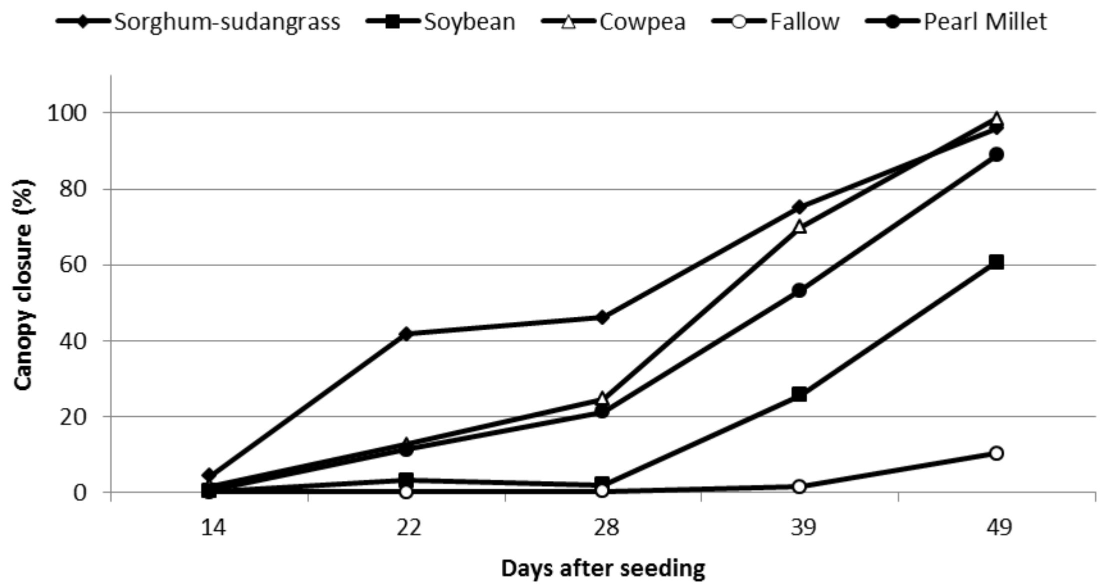

Figure 3. Mean percent canopy closure near Union City, OK during the 2009 summer growing season. Guar was removed from this comparison due to poor stand.

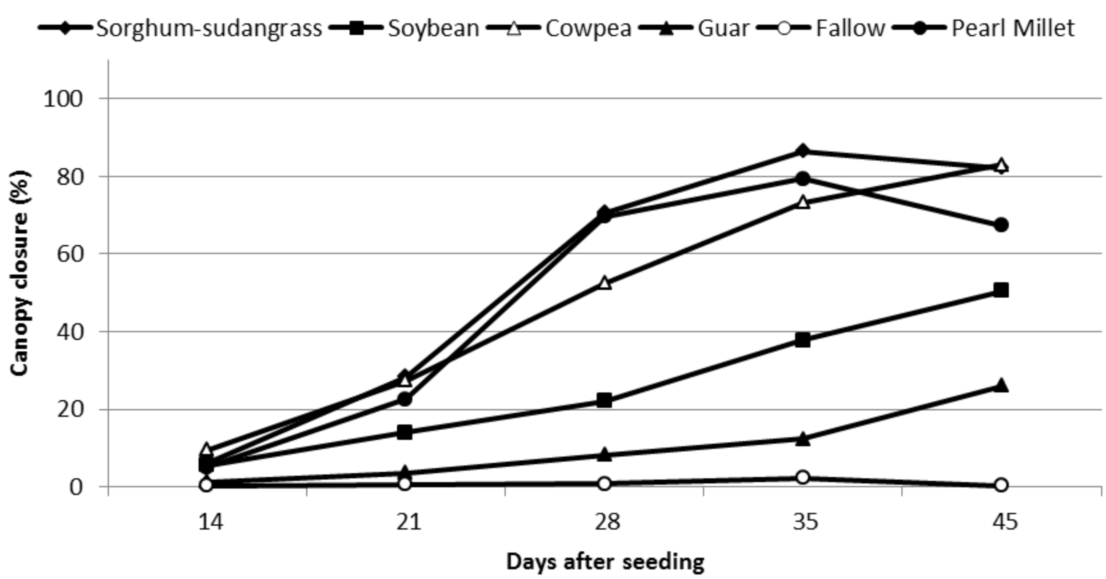

Figure 4. Mean percent canopy closure near Union City, OK during the 2010 summer growing season.

Table 5. Mean canopy closure among cover crops at various days after seeding (DAS) near Union City, OK throughout the 2009 and 2010 summer growing seasons. Values within a column with the same letter are not significantly different (α= 0.05).

Year	Cover Crop	14 DAS		22 DAS		28 DAS		39 DAS		49 DAS	
2009	Sorghum-sudangrass	4	a	42	a	46	a	75	a	96	a
	Cowpea	2	b	13	b	25	ab	70	a	99	a
	Pearl Millet	0	b	11	b	21	ab	53	a	89	a
	Soybean	0	b	3	b	2	b	26	b	61	b
	Guar	-†		-		-		-		-	
	Fallow	0	b	0	b	0	b	1	b	10	c
		14 DAS		21 DAS		28 DAS		35 DAS		45 DAS	
2010	Sorghum-sudangrass	6	ab	28	a	71	a	87	a	82	a
	Cowpea	10	a	27	a	52	a	73	b	83	a
	Pearl Millet	5	b	23	ab	70	a	79	ab	67	b
	Soybean	6	b	14	b	22	b	38	c	55	c
	Guar	1	c	4	c	8	b	12	d	26	d
	Fallow	0	c	1	c	1	b	2	d	0	e

† Guar was removed from comparison in 2009 due to poor stand establishment.

These somewhat contrasting results between years for biomass and canopy closure can be attributed to timely precipitation and utilization of residual nitrogen deep within the soil profile. While precipitation was initially below average in June 2009, timely rains throughout July and early-August provided adequate soil moisture to sustain vegetative growth. In 2010, timely precipitation following harvest allowed timely and rapid stand establishment among all cover crops; however, precipitation throughout the rest of the growing season was limited. Additionally in 2010, nitrogen deficiency might have also been a confounding factor as grass cover crops exhibited biomass color and growth differences between the whole plot and the location of the previous year's nitrogen-rich strip (Figure 5). This difference illustrates how the previous year's grass cover crop and wheat utilized much of the residual nitrogen from the subsoil and lack of plant residue incorporation may have slowed nitrogen mineralization, thus causing nutrient deficiency in the larger plot.

Figure 5. Differences in biomass color and growth within grass cover crops during the summer 2010 growing season near Union City, OK. Strip through the middle was the location of the previous year's nitrogen-rich strip for wheat while the remaining plot areas were designated for SBNR and non-fertilized nitrogen treatments. In SBNR treatments, nitrogen was applied at rates necessary to achieve predicted wheat yield potential for that particular growing season but no nitrogen was added to support cover crop growth.

1.1.2 Nitrogen Management

In 2010, pairwise contrasts among main effects revealed a significant difference for recommended nitrogen rates between cover crop and fallow, and recommended nitrogen rates for cover crop treatments were 26 kg N ha^{-1} greater than the fallow treatments (Table 6). Predicted yield response to the application of SBNR-recommended nitrogen rate was 27% greater in wheat following cover crops as compared to fallow treatments. Wheat following legume crops had 520 kg ha^{-1} greater predicted yield potential with nitrogen fertilizer than grass crops. Average predicted yield potential without nitrogen in wheat following cover crops was 680 kg ha^{-1} less than the fallow treatments, while wheat following a legume had 550 kg ha^{-1} greater predicted yield potential without nitrogen as compared to wheat following grass cover crops. Recommended nitrogen rate and predicted yield potential responses may be attributed to cover crop nitrogen uptake and mineralization, as not growing a cover crop made residual nitrogen more readily available for winter wheat uptake and utilization. Previous literature indicated residues on the soil surface decompose more slowly than incorporated residues, which limits the release and nitrogen availability to the following crop in no-till systems (Clark, 2007). Increased predicted yield potential in wheat following legume as compared to grass cover crops suggests reduced nitrogen immobilization by legume residue. Grass cover crops typically have high carbon to nitrogen ratios; therefore, microorganisms must use soil nitrogen to decompose residue rather than making it available for plant growth (Clark, 2007).

Mean nitrogen fertilizer recommendations increased across all treatments from 44 kg N ha^{-1} in 2010 to 125 kg N ha^{-1} in 2011 (Table 6). Response levels nearly doubled between years due to increased predicted yield potential with nitrogen and decreased predicted yield without nitrogen as compared to 2010. In 2011, there were no differences among treatments for SBNR recommendations, predicted yield potential with topdress nitrogen, or response index. Predicted yield potential without nitrogen in wheat following guar was 310 kg ha^{-1} greater than cowpea or soybean. Lack of differences during 2011 was caused by limited precipitation throughout the cover crop and wheat growing seasons. Limited soil moisture following grazing termination decreased wheat biomass regrowth; therefore, reducing visual differences among treatments.

Table 6. The influence of cover crops on response index (RI), SBNR fertilizer recommendations, and predicted yield potential with (YPN) or without (YP0) topdress nitrogen, and within wheat cultivars near Union City, OK for 2010 and 2011.

	RI		SBNR		YPN	YP0	YPN	YP0
Main Effect	2010	2011	2010	2011	2010		2011	
			--kg N ha^{-1}--		---kg ha^{-1}---		---kg ha^{-1}---	
Cover Crop								
Fallow	1.2	2.6	22	119	3,460	3,000	4,140	1,650
Cowpea	1.4	3.1	42	138	3,350	2,470	4,270	1,390
Soybean	1.4	2.6	53	117	3,820	2,720	3,990	1,540
Guar	-†	2.4	-	115	-	-	4,170	1,770
Sorghum-sudangrass	1.6	3.0	58	137	3,130	1,920	4,320	1,450
Pearl Millet	1.5	2.7	39	123	3,000	2,180	4,130	1,560
Cultivar								
Duster	1.4	2.7	43	119	3,330	2,430	4,040	1,550
Endurance	1.4	2.8	45	130	3,530	2,580	4,300	1,570
Contrasts								
Cover Crop vs. Fallow	*	NS‡	*	NS	NS	**	NS	NS
Legume vs. Grass	NS	NS	NS	NS	**	**	NS	NS
Cowpea & Soybean vs. Guar	-	NS	-	NS	-	-	NS	*
Cowpea vs. Soybean	NS	NS	NS	NS	NS	NS	NS	NS
Sorghum vs. Millet	NS	NS	NS	NS	NS	NS	NS	NS
Duster vs. Endurance	NS	NS	NS	NS	NS	NS	NS	NS

† Guar was removed from comparison in 2009 due to poor stand establishment.

‡ NS,*,** Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

The impact of cover crop incorporation into a cropping system may not always be immediate. Nielsen and Vigil (2005) showed an establishment period is required when cover crops are introduced to a cropping system. In this period, they found fallow contained greater available nitrogen. After the second year, no significant differences were observed in available nitrogen levels within non-fertilized legume plots and fertilized fallow plots; however, their work was in a grain-only production system.

Increased fertility demands needed for forage and grain production within a dual-purpose system may not be achieved from cover crop N contributions, thus supplemental fertilization may be warranted to achieve optimum yield goals.

1.1.3 Hessian fly

In 2010 and 2011, first generation Hessian fly infestation was inconsequential; therefore, only the second generation Hessian fly infestation levels were analyzed. In 2010, average cumulative immature Hessian fly per tiller were 0.07 and 0.26 in Duster and Endurance, respectively. In 2011, these values were 0 and 0.15 in Duster and Endurance, respectively. Buntin (1999) reported economic damage from Hessian fly infestation occurred at 0.4 to 1.0 immatures per stem; therefore, Hessian fly infestation pressure over both years and varieties probably had little impact on overall grain yield. Additionally, there were no differences among all other treatments. Increased infestation densities in the second generation may be attributed to population migrating in from neighboring fields during the spring. The presence of cover crop residue revealed no reduction in infestation pressure; however, the reduction of larval establishment in resistant wheat cultivars supports the findings of Kosma et. Al (2010) and Harris et. al. (2006). Results from additional research studies support low infestation pressures within the region. These relatively low values may be attributed to an increase in farmers planting well-adapted, Hessian fly resistant winter wheat varieties.

The influence of habitat fragmentation may have been another factor in the reduced levels of Hessian fly infestation pressure. Typically, fields devoted for wheat production in Oklahoma are relatively large in scale. The introduction of increased crop diversity through small-plot research may have altered the overall dynamics of the Hessian fly's ecosystem; therefore, hindering the ability of the pest to find a suitable host critical for survival and reproduction.

1.1.4 Insolation

In 2010, canopy closure measured at anthesis did not differ among cover crops within SBNR treatments (Table 7). Within non-fertilized treatments, wheat following sorghum-sudangrass had 7% greater canopy closure as compared to pearl millet. Additionally, Duster had 5% less canopy closure as compared to Endurance. In 2011, both the SBNR and non-fertilized fallow treatments intercepted twice as much solar radiation as the cover crop treatments. Within SBNR treatments, canopy closure was 5% greater in Duster as compared to Endurance. Mean canopy closure was 71% less in 2011 than 2010. Evans et. al (1991) reported median increases in wheat above ground biomass following lupin and pea to be 20 and 29%, respectively. Winter and Musick (1991) found leaf area index at anthesis and winter wheat grain yield to be positive correlated. Increased leaf area enhances delivery of photosynthate, thus increasing grain yield potential (MacKown and Rao, 1998). The reduced canopy closure in this study in 2011 is probably due to lack of soil moisture as well as lack of timely rains to incorporate topdress nitrogen. Differences in canopy closure among fallow and cover crop treatments in 2011 suggest fallow plots may have had greater soil moisture content reserves where cover crop plots were depleted during the summer growing season.

Table 7. Mean wheat percent canopy closure for SBNR and non-fertilized (NF) cover crop and cultivar treatments taken at anthesis near Union City, OK in 2010 and 2011.

	2010		2011	
Main Effect	SBNR	NF	SBNR	NF
	------------------------ %		---------------------	
Cover Crop				
Fallow	90	86	32	19
Cowpea	90	85	16	9
Soybean	87	82	12	8
Guar	-†	-	20	10
Sorghum-sudangrass	86	86	17	10
Pearl Millet	88	79	19	7
Cultivar				
Duster	86	82	16	9
Endurance	90	87	23	12
Contrasts				
Cover Crop vs. Fallow	NS‡	NS	**	**
Legume vs. Grass	NS	NS	NS	NS
Cowpea & Soybean vs. Guar	-	-	NS	NS
Cowpea vs. Soybean	NS	NS	NS	NS
Sorghum vs. Millet	NS	*	NS	NS
Duster vs. Endurance	NS	**	**	NS

† Guar was removed from comparison in 2009 due to poor stand establishment.

‡ NS,*,** Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

1.1.5 Winter Wheat Grain Yield

In 2010, there were no grain yield differences among cover crops within SBNR and non-fertilized treatments; however, grain yields for Endurance were 270 kg ha^{-1} greater than Duster within SBNR treatments (Table 8). Overall, grain yield was approximately 3,000 kg ha^{-1} less in 2011 than 2010. In 2011, SBNR wheat following cover crops yielded 300 kg ha^{-1} less than the fallow treatments, while wheat following a grass yielded 250 kg ha^{-1} more than legume treatments. Grain yield did not differ among non-fertilized treatments. During both years, application of topdress fertilizer increased final grain yield regardless of cover crop treatment. Evans and Herridge (1987) reported wheat grain yield response following a legume crop to range from 0 to greater than 100% as compared to after wheat. Evans et.al. (1991) also found non-legume crops enhance subsequent wheat grain yield; however, the response was less than wheat following legume crops. In many of these studies, conventional tillage practices were used, which made nitrogen more available for the next crop. Increased grain yield following fallow treatments are consistent with the findings of Nielsen and Vigil (2005) during the establishment years. The cost of decreased available water and nitrogen availability associated with cover crops in water-limited environments may be too much to justify subsequent potential grain yield reductions.

Table 8. Mean wheat grain yield for SBNR and non-fertilized (NF) cover crop and cultivar treatments near Union City, OK in 2010 and 2011.

	2010		2011	
Main Effect	SBNR	NF	SBNR	NF
Cover Crop				
Fallow	4,660	4,490	1,620	1,230
Cowpea	4,530	4,050	1,190	980
Soybean	4,400	3,820	1,090	1,010
Guar	-†	-	1,370	1,120
Sorghum-sudangrass	4,410	4,200	1,400	1,050
Pearl Millet	4,350	3,870	1,520	1,230
Cultivar				
Duster	4,340	4,000	1,400	1,140
Endurance	4,610	4,280	1,330	1,060
Contrasts				
Cover Crop vs. Fallow	NS‡	NS	*	NS
Legume vs. Grass	NS	NS	*	NS
Cowpea & Soybean vs. Guar	NS	NS	NS	NS
Cowpea vs. Soybean	NS	NS	NS	NS
Sorghum vs. Millet	NS	NS	NS	NS
Duster vs. Endurance	**	NS	NS	NS

† Guar was removed from comparison in 2009 due to poor stand establishment.

‡ NS,*,** Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

CHAPTER IV

RESULTS AND DISCUSSION

2.1 Grain-only Production System

2.1.1 Cover Crop Biomass and Canopy Closure

Guar was removed from the 2009 analysis due to poor stand establishment. Total biomass production was equivalent between sorghum-sudangrass and pearl millet in 2009 (Figure 6). Additionally, there were no differences in total biomass production between pearl millet and soybean as well as between soybean and cowpea. In 2010, sorghum-sudangrass and pearl millet produced equivalent total biomass. Biomass production did not differ among pearl millet, soybean, cowpea, and guar. Overall cover crop biomass production was 56% less in 2010 as compared to 2009.

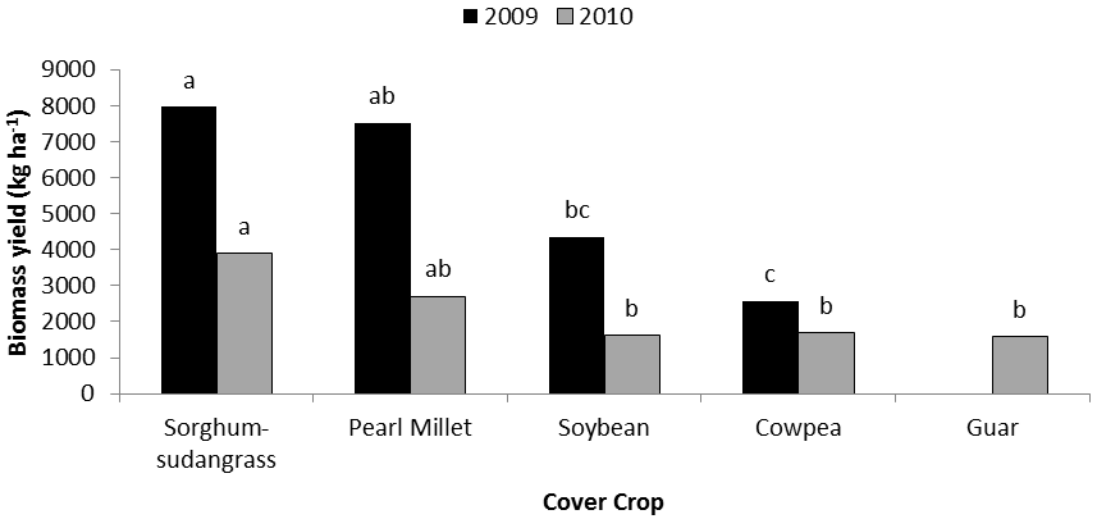

Figure 6. Mean cover crop biomass yield for summer 2009 and 2010 growing seasons near Union City, OK. Columns within year with the same letter are not significantly

In 2009, canopy closure of sorghum-sudangrass was at least two times greater than any other cover crop at 14, 22 and 28 days after seeding (DAS) and reached a maximum canopy closure of 95% (Figure 7; Table 9). Fallow and soybean failed to reach greater than 5% canopy closure by 28 days after seeding. At termination (49 DAS), sorghum-sudangrass, cowpea and pearl millet had achieved near full canopy closure. In 2010, adequate soil moisture early within the growing season allowed all cover crops to increase canopy closure from 14 to 28 DAS (Figure 8; Table 9). Following day 28, all cover crops continued to increase canopy closure; however, grass cover crop closure rate was slowed while legume cover crop growth rate remained steady. At day 35, sorghum-sudangrass, pearl millet, and cowpea reached maximum canopy closure; however, maximum canopy closure of these treatments was 22, 38, and 21% less than 2009. Canopy closure of sorghum-sudangrass, pearl millet, and cowpea did not increase past 35 DAS but soybean and guar did. Clark (2007) states characteristics such as quick biomass production and canopy closure adapt well for weed suppression and erosion control in cowpea, sorghum and millet crops.

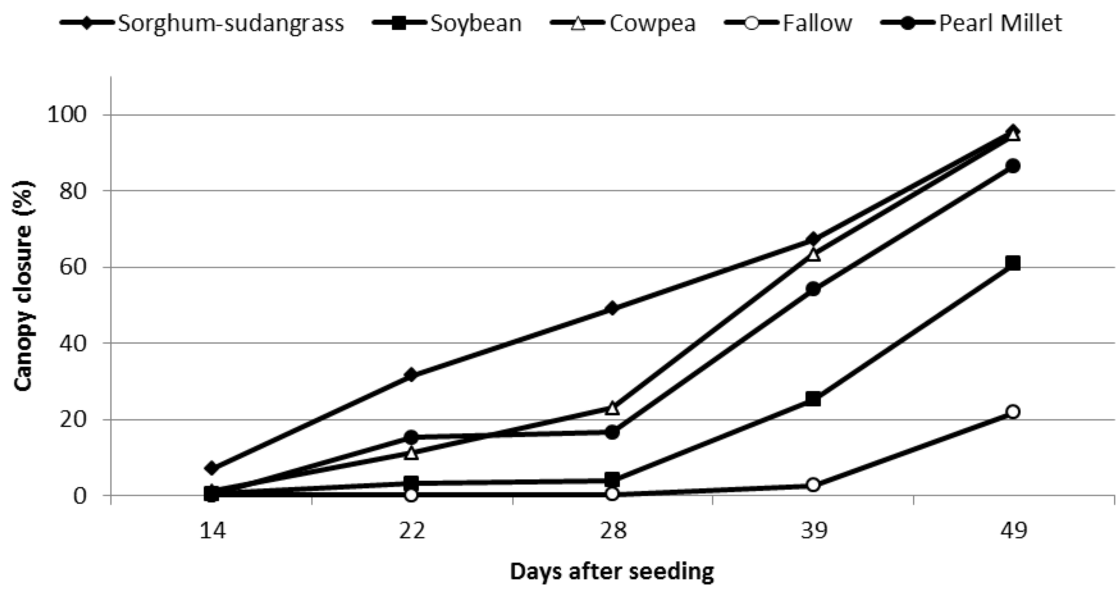

Figure 7. Mean percent cover crop canopy closure near Union City, OK during the 2009 summer growing season. Guar was removed from this comparison due to poor stand establishment.

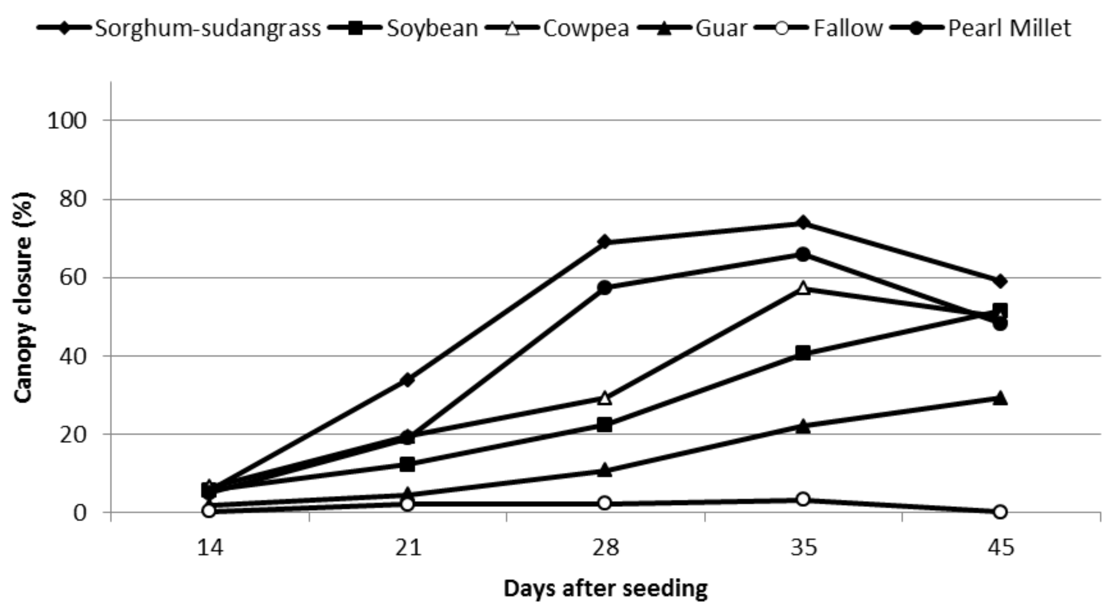

Figure 8. Mean percent cover crop canopy closure near Union City, OK during the 2010 summer growing season.

Table 9. Mean canopy closure among cover crops at various days after seeding (DAS) near Union City, OK throughout the 2009 and 2010 summer growing seasons. Values within a column with the same letter are not significantly different (α= 0.05).

Year	Cover Crop	14 DAS		22 DAS		28 DAS		39 DAS		49 DAS	
2009	Sorghum-sudangrass	7	a	32	a	49	a	67	a	96	a
	Cowpea	1	b	11	bc	23	b	63	a	95	a
	Pearl Millet	0	b	15	b	17	b	54	a	87	a
	Soybean	0	b	3	bc	4	c	25	b	61	b
	Guar	-†		-		-		-		-	
	Fallow	0	b	0	c	0	c	3	c	22	c
		14 DAS		21 DAS		28 DAS		35 DAS		45 DAS	
2010	Sorghum-sudangrass	6	a	34	a	69	a	74	a	59	a
	Cowpea	7	a	19	b	29	c	57	b	50	a
	Pearl Millet	5	a	19	b	57	b	66	ab	48	a
	Soybean	6	a	12	c	22	c	40	c	52	a
	Guar	2	b	4	d	11	d	22	d	29	b
	Fallow	0	b	2	d	2	d	3	e	0	c

† Guar was removed from comparison in 2009 due to poor stand establishment.

Lack of timely precipitation and utilization of residual nitrogen deep within the soil profile can be attributed to these somewhat contrasting results between years for both biomass and canopy closure. While precipitation was initially below average in June 2009, timely rains throughout July and early August provided adequate soil moisture to sustain growth. In 2010, timely precipitation following harvest allowed timely and rapid stand establishment among all cover crops; however, precipitation throughout the rest of the growing season was limited. Additionally in 2010, nitrogen deficiency might have also been a confounding factor as grass cover crops exhibited biomass color and growth differences between the whole plot and the location of the previous year's N-rich strip (Figure 9). This difference illustrates how the previous year's grass cover crop and wheat utilized much of the residual nitrogen from the subsoil. The lack of plant residue incorporation may have slowed the nitrogen mineralization, which caused nutrient deficiency.

Figure 9. Differences in biomass color and growth within grass cover crops during the summer 2010 growing season near Union City, OK. Strip through the middle was the location of the previous year's nitrogen-rich strip for wheat while the remaining plot areas were designated for SBNR and non-fertilized nitrogen treatments. In SBNR treatments, nitrogen was applied at rates necessary to achieve predicted yield potential for that particular growing season but no nitrogen was added to support cover crop growth.

2.1.2 Nitrogen Management

In 2010, pairwise contrasts among main effects revealed no differences for SBNR recommended nitrogen rates or the predicted yield response to the application of the SBNR recommended nitrogen rates (Table 10). Predicted grain yield potential with nitrogen fertilizer in wheat following fallow was 820 kg ha^{-1} greater than cover crop treatments. Wheat following legume cover crops had 1,190 kg ha^{-1} greater predicted yield potential with nitrogen and 1,330 kg ha^{-1} greater predicted yield potential without nitrogen as compared to grass crops. Additionally, predicted yield potential with and without nitrogen in Duster was 700 and 860 kg ha^{-1} greater than Endurance. Recommended nitrogen rate and predicted yield potential responses may be attributed to cover crop nitrogen uptake and nitrogen mineralization. Not growing a cover crop made residual nitrogen more readily available for winter wheat uptake and utilization. Previous literature indicated residues on the soil surface decompose more slowly than incorporated residues found in conventional tillage, thus limiting the release and nitrogen availability to the following crop (Clark, 2007). Increased predicted yield potential in wheat following legume cover crops may be attributed to reduced nitrogen immobilization within legumes as compared to grass cover crops. Grass cover crops typically have high carbon to nitrogen ratios; therefore, microorganisms must use soil nitrogen to decompose residue rather than making it more readily available for plant growth.

Average nitrogen fertilizer recommendation and response levels remained relatively consistent between 2010 and 2011. In 2011, predicted yield response to the application of SBNR recommended nitrogen rates did not differ among all treatments. There were no differences in recommended fertilizer rates among cover crop main effects; however, SBNR recommendations for Duster were 10 kg N ha^{-1} greater than Endurance. Additionally, wheat following grass cover crops had 1,070 kg ha^{-1} less predicted yield potential with nitrogen and 1,310 kg ha^{-1} less predicted yield potential without nitrogen as compared to legume crops. Lack of differences during 2011 was probably due to limited precipitation throughout the cover crop and wheat growing seasons.

Table 10. The influence of cover crops on response index (RI), SBNR fertilizer recommendations, and predicted yield potential with (YPN) or without (YP0) topdress nitrogen, and within wheat cultivars near Union City, OK for 2010 and 2011.

	RI		SBNR		YPN	YP0	YPN	YP0
Main Effect	2010	2011	2010	2011	2010		2011	
			--kg N ha^{-1}--		---kg ha^{-1}---		---kg ha^{-1}---	
Cover Crop								
Fallow	1.3	1.0	33	0	4,280	3,590	3,800	3,800
Cowpea	1.1	1.1	14	12	3,840	3,550	4,860	4,620
Soybean	1.2	1.3	27	13	4,180	3,620	4,470	4,190
Guar	-†	1.2	-	12	-	-	4,020	3,770
Sorghum-sudangrass	1.0	1.3	3	11	2,420	2,360	2,900	2,670
Pearl Millet	1.2	1.1	19	12	3,080	2,680	3,340	3,090
Cultivar								
Duster	1.1	1.2	14	15	3,950	3,660	4,020	3,700
Endurance	1.2	1.2	21	5	3,250	2,800	3,780	3,680
Contrasts								
Cover Crop vs. Fallow	NS‡	NS	NS	NS	**	NS	NS	NS
Legume vs. Grass	NS	NS	NS	NS	**	**	**	**
Cowpea & Soybean vs. Guar	NS	NS	NS	NS	NS	NS	NS	NS
Cowpea vs. Soybean	NS	NS	NS	NS	NS	NS	NS	NS
Sorghum vs. Millet	NS	NS	NS	NS	NS	NS	NS	NS
Duster vs. Endurance	NS	NS	NS	*	*	*	NS	NS

† Guar was removed from comparison in 2009 due to poor stand establishment.

‡ NS,*,** Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

Overall, predicted yield potential with nitrogen was greater than without nitrogen during both years; therefore, incorporating cover crops into a cropping system may not always show immediate impacts. Nielsen and Vigil (2005) showed an establishment period takes place when cover crops are introduced to a cropping system. In this period, they found fallow contained more available nitrogen. After the second year, no significant differences were observed in available nitrogen levels within non-fertilized legume plots and fertilized fallow plots. While these results are consistent with predicted yield potential in 2010, the remaining predicted yield potentials showed no significant differences between wheat following cover crops and fallow, which may be attributed to more nitrogen availability rather than soil moisture. During both years, wheat following a legume crop had increased predicted yield potential with and without nitrogen. Delays in planting over both years may have influenced the impact of nitrogen. Early season growth was limited; therefore, allowing soil nitrogen to be utilized as wheat came out of dormancy.

2.1.3 Hessian fly

In 2010 and 2011, first-generation Hessian fly infestation was inconsequential; therefore, only the second-generation infestation levels were analyzed. In 2010, average cumulative immature Hessian fly per tiller were 0.01 and 0.11 in Duster and Endurance, respectively. In 2011, these values were 0 and 0.09 in Duster and Endurance, respectively. Buntin (1999) reported economic damage from Hessian fly infestation occurred at 0.4 to 1.0 immatures per stem; therefore, Hessian fly infestation pressure over both years and varieties had little impact on overall grain yield. Additionally, there were no differences among all cover crop treatments. Increased infestation densities in the second generation may be attributed to population migrating in from neighboring fields during the spring. The presence of cover crop residue had no effect on ovipoistion; however, the reduction of larval establishment in resistant wheat cultivars supports the findings of Kosma et. al (2010) and Harris et. al. (2006). Results from additional research studies support low infestation pressures within the region. These relatively low values may be attributed to an increase in farmers planting well-adapted, Hessian fly resistant winter wheat varieties.

The influence of habitat fragmentation may have been another factor in the reduced levels of Hessian fly infestation pressure. Typically, fields devoted for wheat production in Oklahoma are relatively large in scale. The introduction of increased crop diversity through small-plot research may have altered the overall dynamics of the Hessian fly's ecosystem; therefore, hindering the ability of the pest to find a suitable host critical for survival and reproduction.

2.1.4 Insolation

In 2010, canopy closure in wheat following cover crops was 12 and 10% less as compared to wheat following fallow in both the SBNR and non-fertilized treatments, respectively (Table 11). Wheat following legume crops had an 18% increase in canopy closure as compared to grass crops in both SBNR and non-fertilized treatments. Within both SBNR and non-fertilized treatments, wheat following sorghum-sudangrass provided the least amount of canopy closure and was 16 and 13% less canopy closure as compared to pearl millet. In 2011, wheat following a legume crop had 9 and 11% greater canopy closure as compared to wheat following a grass crop in the SBNR and non-fertilized treatments, respectively. Additionally, canopy closure in Duster was 10% greater than Endurance within SBNR treatments. Canopy closure did not differ among all other cover crop treatments. Canopy closure was 7% less in 2011 than 2010. Evans et. al (1991) reported median increases in wheat aboveground biomass following lupin and pea to be 20 and 29%, respectively. Winter and Musick (1991) found leaf area index at anthesis and grain winter wheat grain yield to be positively correlated. Increased leaf area enhances delivery of photosynthate, thus increasing grain yield potential (MacKown and Rao, 1998). The reductions found in this experiment were attributable to the lack of soil moisture as well as lack of timely rains to incorporate topdress nitrogen. Differences among legume and grass treatments in 2011 suggest legume plots had greater available soil nitrogen, whereas uptake of residual nitrogen from grass crops during the summer growing season limited wheat biomass production. Lack of substantial precipitation never allowed topdress nitrogen to be incorporated into the soil for plant uptake.

Table 11. Mean wheat canopy closure for SBNR and non-fertilized (NF) cover crop and cultivar treatments taken at anthesis near Union City, OK in 2010 and 2011.

	2010		2011	
Main Effect	SBNR	NF	SBNR	NF
	------------------------ %	---------------------		
Cover Crop				
Fallow	65	67	44	37
Cowpea	57	67	45	42
Soybean	66	64	43	45
Guar	-†	-	48	39
Sorghum-sudangrass	36	41	33	30
Pearl Millet	52	54	39	33
Cultivar				
Duster	56	61	37	37
Endurance	55	56	47	39
Contrasts				
Cover Crop vs. Fallow	*	*	NS‡	NS
Legume vs. Grass	**	**	**	**
Cowpea & Soybean vs. Guar	-	-	NS	NS
Cowpea vs. Soybean	NS	NS	NS	NS
Sorghum vs. Millet	*	*	NS	NS
Duster vs. Endurance	NS	NS	**	NS

† Guar was removed from comparison in 2009 due to poor stand establishment.

‡ NS,*,** Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

2.1.5 Winter Wheat Grain Yield

In 2010, there were significant differences among all SBNR treatments with the exception of cowpea and soybean vs. guar (Table 12). Grain yields for wheat following fallow were 470 and 420 kg ha^{-1} greater than wheat following cover crops in SBNR and non-fertilized treatments, respectively. Wheat after a grass crop yielded 700 kg ha^{-1} less as compared to legume crops. Both wheat following soybean and pearl millet were the highest-yielding legume and grass crop treatments with each producing approximately 500 kg ha^{-1} more grain than the next closest legume and grass cover crop. Within the non-fertilized treatments, wheat following legumes produced 650 kg ha^{-1} more grain as compared to grass crop treatments. Additionally, Endurance yielded 220 kg ha^{-1} less grain as compared to Duster. In 2011, Grain yield in wheat following grasses yielded 370 kg ha^{-1} less than legumes in both SBNR and non-fertilized treatments, respectively. Wheat after pearl millet produced 425 kg ha^{-1} more grain as compared to sorghum-sudangrass in both the SBNR and non-fertilized treatments.

Even though wheat was planted past the optimum window during both years, differences in yield between 2010 and 2011 can be attributed to soil moisture and nitrogen availability. In 2010, soil moisture was a not limiting factor therefore wheat yields in 2010 were 1,040 kg ha^{-1} as compared to 2011 where soil moisture was greatly limited. Additionally, wheat following legumes yielded higher during both years and nitrogen treatments as compared to following grass cover crops. These results are consistent with yield potential predictions and canopy closure measurements made earlier in the growing season. Additionally, the overall application of topdress nitrogen fertilizer increased final grain yield.

Table 12. Mean wheat grain yield for SBNR and non-fertilized (NF) cover crop and cultivar near Union City, OK in 2010 and 2011.

	2010		2011	
Main Effect	SBNR	NF	SBNR	NF
Cover Crop				
Fallow	3,360	3,240	1,950	1,890
Cowpea	2,990	3,140	2,180	2,100
Soybean	3,500	3,160	2,090	2,060
Guar	-†	-	2,010	1,960
Sorghum-sudangrass	2,310	2,320	1,510	1,460
Pearl Millet	2,780	2,680	1,940	1,880
Cultivar				
Duster	3,020	3,020	1,980	1,930
Endurance	3,000	2,800	1,910	1,850
Contrasts				
Cover Crop vs. Fallow	**	*	NS‡	NS
Legume vs. Grass	**	**	**	**
Cowpea & Soybean vs. Guar	-	-	NS	NS
Cowpea vs. Soybean	*	NS	NS	NS
Sorghum vs. Millet	*	NS	**	**
Duster vs. Endurance	NS	*	NS	NS

† Guar was removed from comparison in 2009 due to poor stand establishment.

‡ NS,*,** Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

CHAPTER V

CONCLUSION

In Oklahoma, over 2.3 million hectares of hard red winter wheat are sown annually, as the Oklahoma climate offers producers multiple uses for the crop. While this cropping system has been successful for many producers, the continuous production of only one crop can have adverse consequences economically and ecologically. Negative effects of the conventional-till, monoculture winter wheat production system used in much of Oklahoma include the opportunity cost associated with a fallow period, soil erosion, nutrient leaching and increased pest and weed problems. As a result of these consequences, producers are becoming interested in incorporating no-till farming and diversification of their cropping systems through crop rotation and cover crops. The climate of this region plays a major role in the diversity of cropping systems as western Oklahoma's annual precipitation averages less than 880 mm. While the diversification of cropping systems is possible in Oklahoma, it may not always be feasible for the producer.

The incorporation of cover crops into Oklahoma cropping systems is primarily to provide soil erosion protection and enhancement of nutrient cycling. During both the summer of 2009 and 2010, sorghum-sudangrass, pearl millet, and cowpea provided quick biomass and canopy closure; therefore, making them well suited for weed suppression and soil erosion prevention. Additionally, the continuous production of biomass throughout the year could increase soil quality through increased soil organic matter levels as well as increased water infiltration.

While the incorporation of cover crops has the ability to enhance many soil qualities, this enhancement may come at the cost of reduced soil moisture and nitrogen availability in the short-term. In both dual-purpose and grain-only production systems, wheat productivity following fallow was equal to or greater than wheat following cover crops in almost all categories. Wheat following legume cover crops, in most cases, had production levels equal to or greater than wheat following grass cover crops. In order to optimize production, supplemental nitrogen may be warranted prior to wheat seeding into cover crop residue in order to avoid limiting early growth and development; therefore, allowing cover crop residues more time to break down and more readily available for late growth stages. This is even more critical in dual-purpose production systems as these systems require higher amounts of nitrogen in order to meet both fall forage and grain production goals.

For producers interested in using cover crops as a method of pest management, results from this study revealed no evidence of cover crops having any effect on Hessian fly infestation. The only differences in Hessian fly infestation were between resistant (Duster) and susceptible (Endurance) wheat varieties. Even though there were significant differences in infestation numbers between varieties, grain yield was not affected as infestation pressure was below the economic injury threshold.

The viability of producers incorporating cover crops into their current production systems is dependent on economic benefits through reduced inputs or increased yield production. The results of this study revealed little evidence to support economic benefit; however, this may be attributed to the duration of the study. Previous research suggests that there is an establishment period initially with the incorporation of cover crops into a no-till production system as crop residues are not incorporated into the soil through tillage. The integration of cash crops may be a better solution as producers can achieve many of the same benefits associated with cropping system diversification as seen with cover crops as well as receive economic returns through cash crop production.

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VITA

Casey John Andrews

Candidate for the Degree of

Master of Science

Thesis: INFLUENCE OF WARM-SEASON COVER CROP ON NO-TILL WINTER WHEAT (*TRITICUM AESTIVUM* L.) PRODUCTION

Major Field: Plant and Soil Sciences

Biographical:

Education:

Graduated from Weld Central High School, Keenesburg, Colo. in May 2004.

Completed the requirements for Associate of Science in Agriculture at Northeastern Junior College, Sterling, Colo. in May 2006.

Completed the requirements for the Bachelor of Science in Plant and Soil Sciences at Oklahoma State University Stillwater, Okla. in May 2009.

Completed the requirements for the Master of Science in Plant and Soil Sciences at Oklahoma State University, Stillwater, Okla. in December, 2011.

Experience:

Employed by USDA-ARS as a student employee for sorghum research (2007-2009).

Employed by Oklahoma State University, Department of Plant and Soil Sciences, as a graduate research assistant (2009-present).

Professional Memberships:

American Society of Agronomy - (2007-Present)
Crop Science Society of America - (2007-Present)
Soil Science Society of America – (2007-Present)

Name: Casey John Andrews Date of Degree: December, 2011

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: INFLUENCE OF WARM-SEASON COVER CROP ON NO-TILL WINTER WHEAT (*TRITICUM AESTIVUM* L.) PRODUCTION

Pages in Study: 48 Candidate for the Degree of Master of Science

Major Field: Plant and Soil Sciences

Scope and Method of Study:

Due to the adverse economic and ecological consequences of the conventional-till, monoculture winter wheat production system that dominates Oklahoma, producers are interested in no-till farming practices and diversifying their cropping systems through crop rotation and cover crops. In response to this interest, we evaluated cover crop biomass production and canopy closure, winter wheat nitrogen requirement, Hessian fly infestation pressure and final wheat grain yield response to warm-season cover crops in no-till, dual-purpose and grain-only wheat production systems. Experimental design was a split split-block with cover crop treatment (cowpea, soybean, guar, sorghum-sudangrass, pearl millet and fallow control) seeded following wheat harvest and chemically terminated approximately 45 days after seeding as whole plots. Sub plot treatment was winter wheat variety (Duster and Endurance) sown into the standing cover crop residue. Sub-sub plots were topdress nitrogen application (non-fertilized or nitrogen rate determined by sensor based nitrogen rate recommendation).

Findings and Conclusions:

During 2009 and 2010, sorghum-sudangrass, pearl millet, and cowpea provided quick biomass and canopy closure, making them well suited for weed suppression and soil erosion prevention. In both dual-purpose and grain-only production systems, wheat productivity following fallow was equal to or greater than wheat following cover crops in almost all categories. Wheat following legume cover crops, in most cases, had production levels equal to or greater than wheat following grass cover crops; however, cover crops had no effect on Hessian fly infestation. Differences in Hessian fly infestation between resistant (Duster) and susceptible (Endurance) wheat varieties were found. Grain yield was not affected by differences in Hessian fly infestation, as infestation pressure was below the economic injury threshold. The integration of cash crops may be a better solution than cover crops, as producers can achieve many of the same benefits associated with cropping system diversification as seen with cover crops as well as receive economic returns through cash crop production.

ADVISER'S APPROVAL: Dr. Jeff Edwards