ENHANCING
SUSTAINABLE CROPPING SYSTEMS
THROUGH THE USE OF
COVER CROPS

By

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CHAPTER I

INTRODUCTION

In areas of western Oklahoma where precipitation (< 900 mm yr^{-1}) is the main limiting factor in dryland cropping systems, the use of cover crops has generally been viewed as unacceptable due to high temperatures, limited precipitation, and potential evapotranspiration. Cropping systems have switched from relatively diversified cropping system to a continuous winter wheat system. This requires heavy tillage and high fertilizer and pesticide inputs. Such farming practices may result in soil erosion, reduced soil organic matter, deteriorating soil structure, reduced water infiltration, increased compaction, weed infestations, and severe plant pathogen problems (Kandel, 2006).

The current general consensus of many producers in the western part of Oklahoma is that no suitable summer crops exist for their climate and no suitable alternative exists to replace winter wheat forage for cattle, so they are reluctant to crops other than winter wheat. Quality of winter wheat has continued to decline in this area because of increased weed and insect populations as a result of minimal crop rotation. Another aspect of limited crop rotation is that no-till systems have not become popular in this region because of possible grain yield reduction under no-till with continuous winter wheat. To ease transition into a no-till system, including cover crops into a simple crop rotation may be helpful. Cover crops could be relatively inexpensive and if legumes are used they may reduce N fertilizer costs for the following crop.

A cover crop is any living ground cover that is planted into or after a main crop and then commonly killed before the next crop is planted (Hartwig, Ammon, 2002). The next year's crop is planted into the cover crop usually by some no- or minimum tillage method. There is a potential economic value of using cover crops as green manures; they add N to the soil and the cost of the fertilizer saved is worth the value of the fixed N. The primary benefit of cover crops is the reduction of soil erosion caused by wind and water; this in turn eventually results in improved soil productivity. Soil is vulnerable to erosion when left fallow. A cover crop provides vegetative cover during the fallow period, in turn cushioning the force of falling raindrops that can detach soil particles and increase erosion. They also slow the rate of runoff, which improves moisture infiltration into the soil. Cover crops and green manures can be annual, biennial, or perennial herbaceous plants grown in a pure or mixed stand during all or part of the year. Hall et al. (1984) reported that when corn was planted into a birdsfoot trefoil or crownvetch living mulch on a 14 % slope, water runoff, soil loss and pesticide loss were reduced from 95 to greater than 99 % compared to conventional till corn.

Cover crops can fit well into many different cropping systems during periods of the year when no cash crop is being grown. In some areas even the simplest corn/soybean rotation can accommodate a rye cover crop following corn, which will scavenge residual N and provide ground cover in the fall and winter. When spring-killed as a no-till mulch, the rye provides a water-conserving mulch and suppresses early-season weeds for the following soybean crop (Sullivan, 2003).

CHAPTER II

REVIEW OF LITERATURE

Oklahoma is a large state with varying climatic regions throughout. Most farmers in the western part of the state feel that due to limited rainfall there are not many cropping options for a productive farming operation, especially those focused on cattle production. Western Oklahoma typically receives an average of 43 to 76 cm of rain per year (Mesonet, 2010). This drastically limits the number of crops that can be successfully grown in these areas. Finding alternative crops to enhance current cropping systems is needed in order to improve current systems.

No-Till Production

The most common crop management practice in the southern Great Plains is the monoculture winter wheat production system using conventional till. This requires multiple tillage operations just to control weeds. These intensive tilled systems are thought to be non-sustainable since excessive tillage results in poor soil structure, erosion, high reliance on pesticides, reduction in organic matter, etc. (Hartwig and Ammon, 2002; Kandel, 2006). However, a reliable alternative to conventional tillage is conversion to a no-till system. No-till farming can be defined as farming with little to no disturbance to the soil. Seeds are placed in a narrow row; residue is moved allowing a disk to cut into the soil providing a furrow for the seed and then residue is replaced back over the row. This means that the only soil disturbing activities are those related to planting, nutrient placement and residue conditioning. No-till farming has many potential benefits including the ability to reduce sheet and rill erosion, improve the soil organic matter content, reduce carbon dioxide losses from the soil as well as increase plant available moisture (NRCS, 2006).

According to Farahani et al. (1998), reduced till and no-till systems conserve more water early in the fallow period than conventional till systems and often have as much water stored by May of the fallow years as the conventional till systems have saved three to four months later. By not tilling the soil, root channels remain intact allowing for greater water infiltration. This may allow farmers to adopt more intensive cropping systems than a monoculture winter wheat system. Research has shown that winter wheat grain yields in a wheat – corn – fallow rotation, with less fallow time for the soil water content to recharge, are usually equal to those in a wheat-fallow rotation, in turn leading to a more profitable system (Halvorson et al., 1994; Dhuyvetter et al., 1996). In addition to increased profitability, several researchers have stated that converting to no-till and intensifying cropping sequences in the central Great Plains can contribute to an improved environment via decreasing wind erosion and atmospheric dust load (Fryrear, 1985; Papendick and Saxton, 1997). Prior to cultivation, research has found that in the Mississippi River Valley silt contents of surface horizons approached 90% (Seatz, 1959) with soil organic matter contents that ranged from 5 to 10% in some areas (Rhoton and Tyler, 1990). Today, because of heavy cultivation and erosion, soil organic matter contents have been decreased (Rhoton, 2000). Reduction in tillage as well as incorporating intensified cropping systems could potentially decrease erosion and increase soil organic matter content.

Perhaps the greatest benefit from reducing tillage is the effect of increasing soil organic carbon (Havlin et al., 1990; Campbell and Zentner, 1997; Havlin and Kissel, 1997; Rasmussen and Smiley, 1997; Peterson et al., 1998; Halvorson et al., 1999; Halvorson et al., 2002; West and Post, 2002). A study conducted by West and Post (2002) found that on average a change from conventional tillage to no-till can sequester 57+/- 14 g C M^{-2} yr^{-1}. This can in turn reduce the atmospheric carbon dioxide from emissions other than those that are agriculturally related by sequestering carbon in the soil. Halvorson et al., (2002) has found annual contributions of below ground residue C ranging from 1060 to 2031 kg C ha^{-1} corresponding to varying N rates.

Also, the increase in soil organic carbon (SOC) with N fertilization contributes to improved soil quality and productivity, and increased efficiency of C sequestration into the soil (Halvorson et al., 2002).

Cover Crops

Most farmers are reluctant to switch to no-till farming due to the idea that no suitable summer crop exists for their current cropping system and no alternative is comparable to using winter wheat as forage. The incorporation of a cover crop may enable reluctant producers to try no-till and still maintain one wheat crop per year by utilizing a summer cover crop; the fallow period is eliminated which can lead to decreased soil erosion, moderated soil temperatures, conserved or even increased soil-moisture storage and perhaps add N to the system if a legume is used. The value in adding N to the soil by using legumes suggests that the cost of fertilizer saved indicates the economic value of N fixation (Hartwig and Ammon, 2002; Sullivan, 2003).

There are multiple options for legume cover crops such as Austrian Winter Pea (*Pisum sativue subsp. arvense*), Cowpea (*Vigna sinensis* L.), and Sunn hemp (*Crotalaria juncea* L.). Austrian winter pea has the greatest potential as a green manure in the winter wheat- fallow or winter wheat – grain sorghum cropping system due to the addition of N provided, increased soil organic matter, reduced soil erosion, and greater field water-use efficiency (Sullivan, 2003). In Wyoming, Sooby et al., (1997) has found that conventional fallow lost 20 cm of soil water between May and September while the pea green manure crop used only 23 cm (Sooby et al., 1997). Austrian winter pea is easily grown; but the cover crop must first be inoculated with *Rhizobium legumino-sarium* to ensure symbiotic N fixation (Sooby et al., 1997). Austrian winter pea requires phosphorus and potassium levels similar to cereal grains and these plants express excellent winter hardiness and growth. Austrian winter pea is typically planted at a drilling depth of 1.3 to 2.5 cm. Wheat stubble holds snow in place and protects the peas from winterkill; a deep furrow drill can also ensure winter survival. Fall planting promotes greater spring growth, N fixation occurring in the fall, more time allotted to microbial symbiosis, reduced herbicide usage, and greater biomass accumulation. Also, placing these peas in a rotation may reduce the severity of soil borne diseases that attack winter wheat (Mahler and Auld, 1989). In the spring the peas, since such a high quality forage, can be used for grazing, hay, and as a green manure. Termination of the crop is important to conserve water if winter wheat is being planted. Dalrymple et al., 1993 stated that evaporation from the soil would be reduced when at least 2578 kg ha^{-1} of crop residue is left on the soil surface. This reduction in water evaporation is a necessity in areas where precipitation is limited as well as providing required water to following crops.

Cowpea is another alternate cover crop. Cowpeas were originally fed to livestock as high quality hay because they do not cause bloat (Jost, 1998). Today they are an excellent crop rotation option. They require little to no fertilizer and can thrive on highly acid to neutral soils. They are short-day, warm weather plants, sensitive to cold and killed by frost (Duke, 1990) and germination occurs rapidly at soil temperatures above 18.3 degrees Celsius. Cowpeas are considered drought tolerant due to a tendency to form a deep taproot and can grow competitively in sandy soils. In Kansas, Jost (1998) found cowpeas to be a good fit in a winter wheat rotation. In the middle of September the peas were plowed down as a green manure and reseeded back to wheat. Without the use of fertilizer, the wheat grain yield increased an average of 270 kg ha^{-1} (Jost, 1998). When planting cowpeas, seeds should be planted at a depth similar to soybeans, typically around 2.5 to 3.8 cm; a seeding rate around 28 kg ha^{-1} is recommended for no-till drilling practices with a seed cost of $0.77/kg.

An alternative to winter legumes are adapted tropical legumes, such as sunn hemp, which produce higher biomass contents in temperate climates (Mansoer et al., 1997). Sunn hemp originated in India but has been grown in Brazil and Bangladesh as a soil-improving crop (USDA, 1999). Research has been conducted in the United States since the 1930s where sunn hemp was reported to be excellent for improving soil conditions (USDA, 1999). Seed production was limited to southern Texas due to the tropical climate but the USDA and the University of Hawaii Institute of Tropical

Agriculture and Human Resources released the cultivar ‘Tropic Sun’ sunn hemp in 1983 (USDA, 1999). When grown in the United States sunn hemp behaves as a summer annual and performs well on poor sandy soils with a pH of 5 to 7.5, can grown in droughty soil with low fertility and is also resistant to nematodes. Tropic Sun has been tested and is non-toxic to poultry and livestock (USDA, 1999). There is little potential for becoming a weed because sunn hemp does not consistently set seed north of 28 degrees N latitude. Sunn hemp is fast growing in a short growing season, 60 to 90 days, and can produce over 5604 kg of biomass and over 112 kg of N ha^{-1}. Sunn hemp could be used after small grains or other winter crops, such as canola. When drilling, plant 1.3 to 2.5 cm deep with a seeding rate of 34 to 56 kg ha^{-1} in 18 cm rows (USDA, 1999).

Nitrogen Contribution

Rotating legumes with non-legumes has its advantages, the legume will grow with little to no N input and there will also be a N credit for the following non-legume crop. One of the biggest obstacles with N contribution from cover crops is estimating or measuring the amount of N that a given cover crop will contribute to the following crops, especially in a no-till system. An estimated 10 to 20 percent of the annual N input to soils comes from symbiotic N fixation (Leikam et al., 2007).

Since 1945, the development of rather inexpensive inorganic fertilizers and the continuing widespread use of herbicides have caused a dramatic decline in the use of cover crops (Frye et al., 1985). N production from legumes is a key benefit of growing cover crops, especially with recent increase in N prices. Legume plants typically have higher N content in their stems, leaves, and root residues compared to grasses. This N is released by the breakdown of the plant residues and then becomes available to the subsequent crops. The amount of N available from legumes depends on the species of legume grown, the total biomass produced, and the percentage of N in the plant tissue (Sullivan, 2003). Using annual, winter annual, or perennial legumes to provide N may reduce N inputs without reducing crop grain yield. Holderbaum et al. (1990) showed that hairy vetch had the highest N content due to the high dry matter accumulation followed by bigflower vetch and crimson clover. Research also shows that by planting hairy vetch in the fall, allowing the cover crop to grow until cash crop planting time, the following spring yielded above ground dry matter ranging from 3.7 to 5.1 kg ha^{-1} and contained 130 to 209 kg N ha^{-1}(Holderbaum et al. 1990). As found by Hartwig (1986), a well-established stand of crown vetch contributed up to 50 kg N ha^{-1} to first year corn and contributed 22 to 44 kg ha^{-1} to second year corn. Nitrogen accumulations by leguminous cover crops typically range from 40 to 200 kg of N ha^{-1} (Hartwig, 1986).

When examining cover crops previously discussed, Austrian winter pea can accumulate 1681 kg ha^{-1} of above ground biomass when provided 56 kg ha^{-1} of soil N (Sooby et al., 1997). This grain yield level occurs by early June with fall seedlings and by the second to third week in July with spring seedlings with fall seedlings exceeding 3363 kg ha^{-1} of biomass dry matter by the end of June. This leaves an expected 90 kg ha^{-1} of N to subsequent crops.

Table 1. Mean winter survival and green manure or forage yield of Austrian winter pea varieties†.

Variety	Winter survival	Green manure/ forage yield
	%	kg dry matter ha^{-1}
Fenn	85	4205
Common	77	3691
Melrose	86	3098
Glacier	68	2496

† Fall planted during 1995 and 1996, Archer, Wyoming (Sooby, 1997)

Research in Kansas found that with June termination, approximately 34 kg ha^{-1} N fertilizer following the winter pea cover crop produced comparable sorghum grain yields to no cover crops with 100kg N ha^{-1} applied (Jost, 1998). Furthermore, the winter peas' N needs are met by residual soil N; allowing an extra month of growth increased total N contribution back into the soil by 28 kg ha^{-1}. The N that is stored in the organic matter to potentially be used in future years. In Idaho, the green manure of Austrian winter pea contributed 67to 90 kg N ha^{-1} of credits (Jost, 1998). Comparably, cowpea has been found to contribute 73 to 353 kg N ha^{-1} (Jost, 1998). Finally, Sunn hemp has the ability to accrue large amounts of biomass and N in a short period of time. Research conducted in Alabama found that biomass accumulation reached an average of 2,359 kg and 141 kg N ha^{-1} in 9 to 12 w over a two-year study. This compares with 4,816 kg ha^{-1} with hairy vetch (*Vicia villosa* L.) and 4,928 kg ha^{-1} with crimson clover (*Trifolium incarnatum* L.) (Mansoer et al. 1997). Mansoer also reported that 38 percent of the N in the biomass remained available for corn planted in mid-April, 16 w after the sunn hemp was mowed. Further research on 'Tropic Sunn' showed biomass production of 7,600 kg per ha^{-1} at first frost, approximately 14 w after planting (Balkcom and Reeves, 2004). Nitrogen fertilizer rates should be adjusted depending on legume and the following cash crop. Nitrogen credits can be applied but vary with legume cover crop; this will in turn result in significant cost saving on N fertilizer.

Research conducted by Halvorson (1999) on sunflowers found that the tillage by N interaction reflected the highest seed yields to occur in a no-till treatment with yields of 1638 kg ha^{-1} with a N application of 101 kg ha^{-1} and with a higher level of N present in the surface 15 cm after 10 crop years. Research by Classen and Raney (1985) show an overall increase in grain sorghum grain yields after incorporating a legume in rotation as well as applying various N rates (Table 2).

Table 2. Nitrogen rates and sorghum yield differences when including a legume in rotation.

Cornbelt Experiment Field, Brown County			North Central Experiment Field, Republic County		
N rate	Continuous Sorghum	Sorghum after soybeans	N rate	Continuous Sorghum	Sorghum after soybeans
kg ha^{-1}	Yield, kg ha^{-1}	(5 yr avg.)	kg ha^{-1}	Yield, kg ha^{-1}	(5 yr avg.)
0	2571	4954	0	2007	3198
45	3574	5644	56	2508	3261
90	4954	5518	112	2885	3637
135	5330	5581	224	3198	3700
224	5518	5581			

Source: M.M. Classen, R.J.Raney, Kansas Fertilizer Research Report of Progress, 1985

Conditions that support good N fixation include a good stand, optimum soil nutrient levels like calcium and phosphorus, soil pH usually around 6.0 to 8.0, good nodulation, and adequate soil moisture and aeration. Heer and Janke (2004) reported N contributions from Austrian Winter Peas ranging from 30 to 60 kg N ha^{-1}. Nitrogen contributions in a no-till system will no doubt be affected by lack of tillage operations. The portion of green-manure N available to a following crop is usually about 40% to 60% of the total amount contained in the legume. For example, a hairy vetch crop that accumulated 180 kg N ha^{-1} prior to plowing down will contribute approximately 90 kg N ha^{-1} to the succeeding grain or vegetable crop. Hoyt (1987) estimated that 40% of plant tissue N becomes available the first year following a cover crop that is chemically killed and used as a no-till mulch. He estimates that 60% of the tissue N is released when the cover crop is incorporated as a green manure rather than left on the surface as a mulch. Lesser amounts are available for the second or third crop following a legume, but increased grain yields are apparent for two to three growing seasons.

High nitrate levels due to leaching into groundwater from the crop root zone presents a loss of a resource required for crop production. Current environmental concerns favor emphasis on the development of strategies to reduce the need for commercial N fertilizer. Unused N can leach out of the soil during the fall, winter, and spring seasons when crops are not growing, in turn posing a threat to contamination of groundwater. Cover crops can reduce the chance of environmental pollution from excess N; legume or grass cover crops planted after the main crop to capture excess nitrates is one approach (Hartwig, 2002). The cover crop needs to be adapted to cool season conditions to be effective. Hairy vetch lowered the potential for NO_3 leaching during the spring (Hoyt, 1987).

In addition to providing ground cover and, in the case of a legume, fixing N, cover crops also help suppress weeds and reduce insect pests and diseases. Winter annuals, cover crops, or living mulches can help control escape weeds and may hinder the incursion of new weeds that might otherwise become a problem in no-till corn. By planting a cover crop, available water, nutrients, and light are occupied. This shades the soil and helps prevent weeds from germinating and establishing themselves. Allelopathic plants can also be used. These plants inhibit or slow the growth of other nearby plants by releasing natural toxins known as allelochemicals. Cover crop plants that exhibit allelopathy include the small grains like rye, ryegrasses, and subterranean clover. A study by Else and Ilnicki (1989) stated that a sub-terraneanan clover provided nearly perfect weed control both with and without a corn crop. Teasdale (1988) reported that hairy vetch residue suppressed pigweed, foxtail, and velvetleaf as well as suggesting that maximum weed suppression by hairy vetch residue occurs shortly after cover crop death.

Dyck (1995) found that dry matter accumulation of lambsquarter was 72% lower following plots planted with crimson clover as a cover crop than just supplying sweet corn with N. The lambsquarter remained suppressed throughout the growing season and was 39% lower at final harvest.

Organic Matter and Soil Structure

A major benefit obtained from green manures is the addition of organic matter to the soil. The addition of organic matter to the soil increases soil tilth and productivity. In no-till crop production, the organic matter becomes concentrated at the soil surface, which greatly improves soil tilth (Hartwig, 2002). During the breakdown of organic matter by microorganisms, compounds are formed that are resistant to decomposition—such as gums, waxes, and resins. These compounds—and the mycelia, mucus, and slime produced by the microorganisms—help bind together soil particles as granules, or aggregates and larger aggregates into peds (Godsey). A well-aggregated soil tills easily, is well aerated, and has a high water infiltration rate. These factors also eases crop emergence and promotes root growth. Increased levels of organic matter also influence soil humus. Humus—the substance that results as the end product of the decay of plant and animal materials in the soil—provides a wide range of benefits to crop production (Hartwig, 2002; Kandel, 2006).

GreenSeeker^{TM} Technology

Low N use efficiency is widespread in agronomic production today. This is in part due to soil N supply and crop demand, spatial variation within the field and uniform N application, and temporal variability and the influence of weather on mid-season N needs (Solari, 2008). Remote sensing is now available to address some of these issues.

The ratio of near infrared to red reflectance relative to leaf area index was first used in remote sensing; Rouse et al. (1974) later proposed the Normalized Difference Vegetative Index, or NDVI, where NDVI = (Near InfaRed-Red)/(NIR+Red), and this index is currently used (Solari, 2008). Raun et al. (2002) and Mullen et al. (2003) demonstrated that canopy assessments using the GreenSeeker™ (Trimble Navigation Limited Inc., Sunnyvale, CA) active sensor, which generates its own source of modulated light in the red (~650 nm) and NIR (~770 nm) bands to calculate NDVI, could be used to direct variable rate N application to wheat and improve fertilizer NUE. Raun also found that by topdressing winter wheat based on in-season NDVI readings plant NUE increased. Research by Oklahoma State University found a benefit of $16-$38/acre when using the GreenSeeker™ for topdressing winter wheat. These readings can assist in determining in-season N application and can explain the 83% variability in measured grain yield (Raun et al., 2001, in Osborne 2007). The use of the GreenSeeker™ can also be a useful tool in determining N contribution from legumes. In season readings of cash crops following legume cover crops can indicate the N contribution by the cover crops, especially when little or no additional N is needed.

Limitations of Cover Crops

The recognized benefits of green manuring and cover cropping—soil cover, improved soil structure, N from legumes—need to be evaluated in terms of cash returns to the farm as well as the long-term value of sustained soil health. For the immediate growing season, seed and establishment costs need to be weighed against reduced N fertilizer requirements and the effect on cash crop yields. Water consumption by green manure crops is a concern and is pronounced in areas with less than 76 cm of precipitation per year. Still, even in the fallow regions of the Great Plains and Pacific Northwest, several native and adapted legumes (such as black medic) seem to have potential for replacing cultivation or herbicides in summer fallow (Godsey). There is always additional management required when cover crops of any sort are added to a rotation. Turning green manures under or suppressing cover crops requires additional time, knowledge and expense, compared to having no cover crop at all. Insect communities associated with cover crops work to the farmer's advantage in some crops and create a disadvantage in others. For example, certain living mulches may enhance the biological control of insect pests but may serve as a host to non-beneficial pests.

Objectives

The objectives of this experiment were to (i) evaluate the possibility of an intensified cropping system compared to the current winter wheat-fallow system, (ii) evaluate the effect and possible benefits of selected cover crops when included into current Oklahoma cropping systems and (iii) determine the feasibility of using the GreenSeeker^{TM} optical sensor for determining in season N applications in a cropping system.

CHAPTER III

METHODOLOGY

Field Experiment

To evaluate the feasibility of using cover crops in a successful crop rotation, an on-going field study was established in Garfield County near Lahoma, Oklahoma (36° 23’41.38” N; 98° 03’ 04.32’ W) using crops and crop rotations suitable for the region (Table 3). Precipitation information for all growing seasons is given in Figure 1.

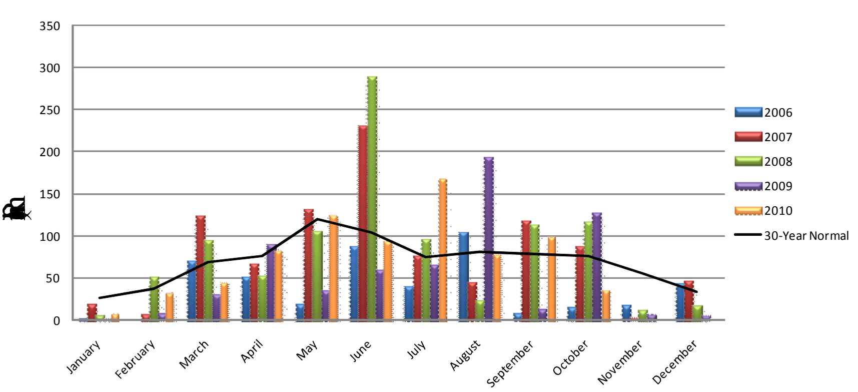


Figure 1. Monthly rainfall accumulation from 2006-2010 for Lahoma, OK (Mesonet, 2010).

The experiment was initiated in October 2006. Prior to establishment of this experiment, soybean had been planted by the farmer over the entire field.

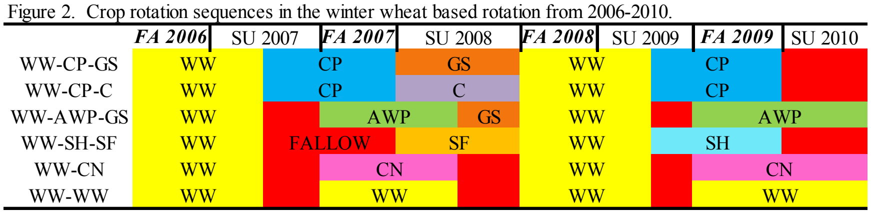
There were two separate studies, one winter wheat based rotation (wheat 2 out of 3 years) and one grain sorghum based rotation (grain sorghum 2 out of 3 years) (Table 3). Either winter wheat or grain sorghum was always found in rotation. Figures 2 and 3 give the sequence timeline of crops planted in rotation for the winter wheat and grain sorghum based rotations.

Table 3. Garfield County Crop Rotation Sequence.

Wheat (2 out of 3 years) Rotation		Grain Sorghum (2 out of 3 years) Rotation	
Rotation	Crop Secqunce	Rotation	Crop Secqunce
1	WW-CP-GS†	1	GS-WW-CP
2	WW-CP-C	2	GS-AWP-SF
3	WW-AWP-GS	3	GS-AWP
4	WW-SH-SF	4	GS-AWP-CN
5	WW-CN	5	GS-WW-SH
6	WW-WW	6	GS-WW-GS

† Winter wheat (WW), Grain Sorghum (GS), Corn (C), Sunflower (SF), Canola (CN), Cowpeas (CP) Austrian winter peas (AWP), Sunn hemp (SH)

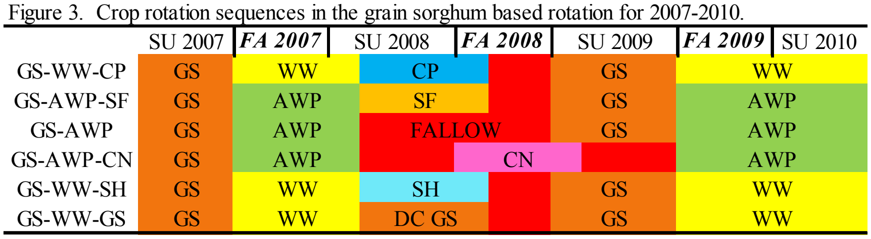
Figure 2. Crop rotation sequences in the winter wheat based rotation from 2006-2010.



	FA 2006	SU 2007	*FA 2007*	SU 2008	*FA 2008*	SU 2009	*FA 2009*	SU 2010
WW-CP-GS	WW	CP		GS	WW	CP		
WW-CP-C	WW	CP		C	WW	CP		
WW-AWP-GS	WW		AWP	GS	WW		AWP	
WW-SH-SF	WW	FALLOW		SF	WW	SH		
WW-CN	WW		CN		WW		CN	
WW-WW	WW		WW		WW		WW	

† Winter wheat (WW), Grain Sorghum (GS), Corn (C), Sunflower (SF), Canola (CN), Cowpea (CP), Austrian winter pea (AWP), Sunn hemp (SH)

Figure 3. Crop rotation sequences in the grain sorghum based rotation for 2007-2010.



	SU 2007	*FA 2007*	SU 2008	*FA 2008*	SU 2009	*FA 2009*	SU 2010
GS-WW-CP	GS	WW	CP		GS	WW	
GS-AWP-SF	GS	AWP	SF		GS	AWP	
GS-AWP	GS	AWP	FALLOW		GS	AWP	
GS-AWP-CN	GS	AWP		CN		AWP	
GS-WW-SH	GS	WW	SH		GS	WW	
GS-WW-GS	GS	WW	DC GS		GS	WW	

† Winter wheat (WW), Grain Sorghum (GS), Corn (C), Sunflower (SF), Canola (CN), Cowpea (CP), Austrian winter pea (AWP), Sunn hemp (SH), Double crop (DC)

Rotation main plots are 3 m wide by 15.2 m long with subplots 3 m wide and alleys are 6.1 m wide (Table 4). Nitrogen applications varied between N treatments within crops (Appendix A and B).

Table 4. Example of crop rotation and nitrogen applications within a plot.

101				102				103			
C†	D	B	A	D	B	C	A	B	A	D	C
Rotation 4				Rotation 6				Rotation 2			

† Nitrogen treatments: (A) N-rich strip, (B) Farmer practice, (C) Control, (D) N based on GreenSeeker™

To evaluate the effect of cover crops Austrian winter pea, cowpea, and sunn hemp were included in typical rotations for the region and all were chosen to maximize N contribution and biomass. Cover crops were usually grown for 60 d and then terminated by herbicide or frost. Cultural practices, such as planting and harvest dates, varied from crop to crop and are provided in Tables 5 and 6. A burn-down chemical application was applied prior to planting any crop. Plots were kept weed and pest free throughout the growing season by using best management practices.

The winter wheat and canola in all rotations was planted with a Great Plains no-till drill (Great Plains Mfg. Inc., Salina, Kansas) on 19 cm wide rows; corn, grain sorghum and sunflowers were planted using a Monosem NG Plus no-till planter (Monosem Inc., Edwardsville, Kansas) on 76 cm wide rows. Cash crop cultivars and planting populations are provided in Table 7. The cash crops were harvested using a Wintersteiger single plot harvester (Wintersteiger Inc., Ankeny, Iowa). The center of each plot was harvested for a total area of 23.3 m^2. Grain moisture was corrected to standard moisture contents of 12.5 g kg^{-1} for winter wheat and grain sorghum, 15.5 g kg^{-1} for corn, and 10 g kg^{-1} for canola and sunflower.

Table 5. Winter wheat based rotation cultural practices for the 2006-2010 growing season.

Season	Rotation	Crop	Planting date	Top-dress date	Harvest date
2006-2007	1,2,3,4,5,6	Winter Wheat	10/10/2006	10/24/2006	N/A†
2007-2008	5	Canola	10/2/2007	N/A	N/A
	6	Winter Wheat	10/2/2007	10/2/2007	6/12/2008
2008	2	Corn	4/7/2008	4/7/2008	8/11/2008
	4	Sunflower	4/22/2008	4/22/2008	8/25/2008
	1	Grain Sorghum	4/22/2008	5/25/2008	8/22/2008
	3	Grain Sorghum	6/12/2008	None	9/19/2008
2008-2009	1,2,3,4,5,6	Winter Wheat	10/10/2008	3/3/2009	6/18/2009
2009-2010	5	Canola	9/16/2009	3/22/2010	6/20/2010
	6	Winter Wheat	10/28/2009	4/1/2010	N/A

† N/A means crop was not harvested

Table 6. Grain Sorhgum based rotation cultural practices for the 2007-2010 growing season.

Season	Rotation	Crop	Planting date	Top-dress date	Harvest date
2007	1,2,3,4,5,6	Grain Sorghum	5/9/2007	6/25/2007	9/15/2007
2007-2008	1,5,6	Winter Wheat	10/2/2007	10/2/2007	6/12/2008
2008	2	Sunflower	6/12/2008	6/12/2008	10/27/2008
	6	DC Grain Sorghum†	6/12/2008	6/12/2008	10/27/2008
2008-2009	4	Canola	9/10/2008	3/3/2009	6/9/2009
2009-2010	1,2,3,5	Grain Sorghum	4/23/2009	6/17/2009	8/27/2009
	1,5,6	Winter Wheat	10/28/2009	4/1/2010	6/23/2010

†Double crop (DC)

Table 7. Cultivar and seeding rates of crops for the 2006-2010 growing season.

Year	Crop	Cultivar	Planting Population
2008	Corn	DeKalb DKC 52-63	54,340 seeds ha^{-1}
2008	Sunfower	Triumph s673	54,340 seeds ha^{-1}
2009	Sunfower	Triumph s671	54,340 seeds ha^{-1}
2007-2008	Canola	Wichita	6.72 kg ha^{-1}
2008-2009	Canola	Dekalb RR DKW47-15	5.6 kg ha^{-1}
2007	Grain Sorghum	NC+6B50-62	111,150 seeds ha^{-1}
2008	Grain Sorghum	DeKalb DKS 3707	135,850 seeds ha^{-1}
2006-2007, 2007-2008	Winter Wheat	OK Bullet	67.3 kg ha^{-1}
2008-2009, 2009-2010	Winter Wheat	Clearfield Centerfield	67.3 kg ha^{-1}

Nitrogen Management

Nitrogen management consisted of four treatments; 0 kg N ha^{-1}, typical farmer practice, N-rich strip, N rate based on GreenSeeker^{TM} Optical Sensor. The N-rich strip was a strip through each rotation (main plot) where N was applied pre-plant at a rate that N would not be limited during the growing season. GreenSeeker^{TM} readings were taken at the appropriate growth scale for crops that had an algorithm, such as winter wheat, grain sorghum, and corn. Readings were taken and the average NDVI across individual rotations of both the farmer's practice and the Green Seeker^{TM} treatment were placed in an equation on Oklahoma State University's nitrogen use efficiency website (http://www.nue.okstate.edu). Additional N was applied in the form of Urea or UAN 28 if needed (Appendix A and B). Since no algorithm currently exists for winter canola or sunflower, 112 kg N ha^{-1} was applied to all N treatments, with the exception of the control. Rotation, total N applied and crop grain yields are shown in Appendix A and B.

Statistical Analysis

Grain yield data and N management was analyzed using SAS software version 9.2 (SAS, 2001). Fixed effects for the field study were N practice and rotation. Rotation was removed when only one rotation was being analyzed in any given year. Analysis of variance was performed using PROC MIXED to determine differences between grain yield, rotation and N treatments. The experimental design was a split plot with crop rotation as the main plot and N management as the subplot with four replications.

CHAPTER IV

RESULTS AND DISCUSSION

1.1 Winter Wheat Based Rotation Experiment

1.1.1 *Grain Yield*

Since no significant interaction and N treatment was observed, grain yields were averaged across N treatments (Tables 8 and 9). Table 9 gives the average crop yield from 2007 through 2010. In most instances grain yields were average, except canola and sunflower grain yields which would be considered below average for the area; the county average for sunflower was 1232 kg ha^{-1} and 1456 kg ha^{-1} for canola (Table 10).

Table 8. Differences found in the winter wheat based rotaton.

Source	Winter Wheat 2008	Corn 2008	Grain Sorghum 2008	Sunflower 2008	Winter wheat 2009
Nitrogen	NS†	NS	NS	NS	NS
Rotation	NS	NS	S††	NS	S
Nitrogen x Rotation	NS	NS	NS	NS	NS

†NS: Means not significantly different at the 0.05 level; †† S, means significantly different at the 0.05 level

Table 9. Winter wheat rotation yield averaged across N treatments from 2007-2010.

Crop	Year	Yield
		kg ha^{-1}
Winter Wheat	2007-2008	2800
Corn	2008	5407
Grain Sorghum	2008	3499
Sunflower	2008	345
Grain Sorghum	2008	2458
Winter Wheat	2008-2009	1812
Canola	2009-2010	1040

Table 10. Average grain yield for 2009, Garfield County, Oklahoma.

Crop	Grain yield
	kg ha^{-1}
Winter Wheat	1713†
Grain Sorghum	3763
Corn	2822
Sunflower	1232
Canola	1456

† Source: NASS

Winter wheat was planted in 2006-2007, the first year of the experiment; however, this crop was not harvested due to freeze damage (Table 5). In 2007-2008, all plots were planted with cover crops with the exception of canola in the WW-CN rotation and winter wheat was again planted in WW-WW rotation. No significant differences were observed in crop rotation or N management (Table 8). Following the cover crops in 2008, multiple cash crops were planted: grain sorghum in WW-CP-GS and WW-AWP-GS, corn in WW-CP-C, and sunflower in WW-SH-SF. A significant difference in rotation was observed between grain sorghum plots in 2008, WW-CP-GS and WW-AWP-GS (Table 8).

The grain sorghum in WW-CP-GS was planted following cowpea and Austrian winter pea in WW-AWP-GS. The difference in grain yield was probably due to WW-CP-GS being a full season crop planted in April and WW-AWP-GS being essentially double cropped planted in June. The full season grain sorghum, WW-CP-GS, received rainfall throughout the growing season, especially during grain-fill (June, 2008) when adequate moisture is critical to achieve optimum grain yields. WW-AWP-GS, however, was planted in June and received very little rainfall in August when the crop was in grain-fill (Figure 1). This lack of moisture most likely reduced grain yield.

In 2008-2009 winter wheat was planted in all rotations and statistical analysis found significant differences between rotations (Table 8 and 11).

Table 11. Winter wheat rotation 2008-2009 winter wheat yields for each rotation.

Rotation	Previous Crop	Yield
		kg ha^{-1}
WW-CP-GS	GS	2217 b†
WW-CP-C	C	2248 b
WW-AWP-GS	GS	503 e
WW-SH-SF	SF	1938 c
WW-CN	CN	2751 a
WW-WW	WW	1126 d

† Means followed by the same letter are not significantly different according to LSD (0.05).

Winter wheat grain yield in the WW-CN rotation was 503 to 2248 kg ha^{-1} greater than wheat yield of all other rotations. The WW-CP-GS, WW-CP-C, WW-AWP-GS and WW-SH-SF rotations had a more intensified cropping system compared with WW-CN. The WW-CN rotation was one crop per year while the others were three crops in two years. Even though winter wheat grain yield in WW-CN was higher compared to WW-CP-GS and WW-CP-C, these two rotations had only slightly lower grain yields. Winter wheat grain yield in the WW-CN rotation was higher than the continuous winter wheat system (WW-WW). This increase is probably influenced by the inclusion of canola as a rotational crop. The WW-CN rotation is an example of a possible change from the continuous winter wheat system that is currently found in much of western Oklahoma. The addition of a winter broadleaf allowed incorporation of different chemicals to address weed problems that developed (Peeper, 2006). Not only were different chemicals used but studies have shown that mustards (*Brassica*) suppress a majority of weeds, compared with bare fallow, by competition in the fall and light interception in the spring (Snapp et al., 2005). Table 12 shows the total and average weed stand counts in the winter wheat rotation. Weed populations were lower in the WW-CN rotation compared to the WW-WW rotation. The highest weed stand counts were found in rotations that had grass crops, indicating that incorporating broadleaves helps break up grass weed cycles.

Table 12. Total weed populations found in winter wheat based rotation.

Rotation	Total weed population†
WW-CP-GS	13
WW-CP-C	16
WW-AWP-GS	322
WW-SH-SF	16
WW-CN	32
WW-WW	57

† Two random readings of weed plant populations were taken within a m^2 area within each rotation. Data taken in spring 2009.

Considering rotations with cover crops, the WW-CP-GS and WW-CP-C rotations cowpeas were planted in July of 2007 and were terminated by frost. The following April, corn and grain sorghum was planted and then harvested in mid August (Table 5). The winter wheat was then planted in all rotations in beginning of October. Due to the decreased rainfall in August and planting of another crop, this allowed little time for the soil moisture levels to re-establish compared to the approximately 3 month fallow period that was observed with the WW-CN rotation. No doubt with an increase in cropping intensity the need for timely rainfall is great in order to establish the next crop. Research by Tanka et al. (2005) found that with increased precipitation in September, winter wheat can be established in early October. However, precipitation received prior to September is subject to high evaporative losses due to high temperatures during this time frame (Tanka et al., 2005). Raun et al. (2002) stated that dryland wheat production is highly dependent on rainfall soon after planting.

The WW-CP-GS and WW-CP-C rotation winter wheat grain yields were greater than the WW-SH-SF rotation. All rotations had cash crops planted in April. The WW-SH-SF rotation included sunflower which may have caused a depletion of soil moisture deeper in the profile compared with corn or grain sorghum. Small grains can deplete soil moisture over 1 m deep; sunflower and corn are deep rooted crops and can deplete soil moisture up to 2 m deep (Peel, 1998). This reduction in stored soil moisture may have limited the yield potential of the following wheat crop (Halvorson et al., 2000). However, Halvorson et al. (2000) has also found that spring wheat yields following sunflower in rotation are increased in minimum and no-till systems compared to conventional till during most years with adequate N fertility. Also during particularly dry years, reduced tillage treatments did not store enough additional water to significantly enhance yield potential over the conventional tillage system and that nitrogen fertilizer responses were non-existent during these dryer years (Halvorson et al., 2000).

The WW-SH-SF winter wheat grain yield was higher than the continuous winter wheat rotation. This difference may have been primarily because the WW-SH-SF rotation had less weed pressure compared to the WW-WW rotation (Table 12). Both rotations had a fallow period but WW-SH-SF did receive 112 kg N ha^{-1} for the sunflower crop. Some of that N could have been unused and left behind for the following winter wheat crop. This additional N might have helped the winter wheat establish itself since there was a lack of precipitation during the winter months (Figure 1). Halvorson et al., (2000) found that responses to N fertilization were insignificant during dry years and resulted in increased residual spring soil NO_3-N levels. Spring wheat yields exceeded the two-year average and indicate that farmers can successfully produce spring wheat following sunflower in annual cropping rotations that do not include a fallow period. Halvorson et al. (2000) suggests that farmers consider producing a crop with lower water use requirements than spring wheat during periods with low soil water recharge to avoid uneconomical spring wheat grain yields.

Lastly, winter wheat grain yield of the continuous winter wheat rotation was higher yielding than the WW-AWP-GS rotation. This can be explained by the fallow period found in the continuous winter wheat rotation. The three month fallow period allowed moisture to build in the soil and become available to the following winter wheat crop. The WW-AWP-GS rotation had a grain sorghum crop that was harvested in late September and the subsequent winter wheat crop was planted less than a month later (Table 5). Soil moisture was probably lacking and the following months did not receive much additional rainfall to help sustain the winter wheat crop through the winter months (Figure 1). Research has found that a no-till treatment containing a fallow period from winter wheat to grain sorghum resulted in the greatest water storage of multiple treatments; this in turn provided the highest water content at grain sorghum planting with enhanced water storage efficiency (Unger, 1954). Also, the WW-AWP-GS rotation had a severe grass-weed infestation (Table 12). This additional weed pressure throughout the growing season would have stressed the winter wheat crop and in turn negatively affected grain yields. It is interesting that the Austrian winter peas did not break up the weed cycle more. It has been reported that sweetclover and its residues suppressed weeds throughout a 20-mo fallow period (Blackshow et al., 2001). Cover crops can also control weeds through competition, allelopathy, soil environmental changes, physical effects, enhancement of weed seed decay, and maintaining surface residues (Snapp et al., 2005).

Dyck et al., 1995 has found that a legume's N source could decrease weed interference with crop growth by the slow release of N that would remove any early competitive advantage for the weeds and benefit crops with later occurring maximum growth and N uptake rates.

Overall, the incorporation of cover crops or additional rotational crops appeared to be an improvement over the typical monoculture winter wheat rotation that is predominant in western Oklahoma. The incorporation of a broadleaf cash crop seemed to break up the weed cycle within the rotations. The cover crops provided ground cover, additional biomass, and most importantly supplementary N to the following crops and seemed to work best when there was a longer fallow period which gave them time to establish and mature.

1.1.2 Nitrogen management

As previously stated, statistical analysis showed no significant differences in N practice and grain yield. Since there was not an impact on grain yield, this indicates some N contribution from the legume. For instance, the WW-CP-GS and WW-CP-C rotations were not different. This is interesting in the fact that grain sorghum can remove more nitrogen than corn (Carter et al., 1989; Vitosh et al.; Erickson, 2005). In looking at the total N applied (Appendix A), less total N was applied to the WW-CP-GS rotation than the WW-CP-C rotation. Clearly the cowpeas were adding some N to the rotations. Meyer (1987) found that spring wheat grain yield was about 10% greater after a green manure sweetclover crop was incorporated, regardless of whether wheat was fertilized with 56 kg N ha^{-1} or not. Blackshaw et al., (2001) found that sweetclover, when compared with tilled fallow treatments, had 16 to 56 kg ha^{-1} more available N at seeding of the succeeding spring wheat crop that resulted in grain yields 47 to 75% greater than conventional fallow. Reduction in fertilizer cost with maintained grain yields can increase profitability and compensate the immediate cost of cover crop establishment (Snapp et al., 2005). Liebig et al., 2002 found that N fertilization had a greater effect on soil properties at the surface than crop sequence but overall a corn-soybean-grain sorghum –oat clover sequence had higher levels of potential mineralizable N during the growing season.

The use of GreenSeeker™ technology is a useful tool to determine in season N applications. When reviewing total N applied to all rotations the use of the GreenSeeker™ decreased N use compared to the farmer's practice (Table 13). The lowest percent reduction is seen when a fallow period is involved. The greatest percent reduction was found in the WW-CP-GS rotation and the WW-AWP-GS rotation, both with winter wheat and grain sorghum having an algorithm for N applications.

Table 13. Total N applied to the winter wheat based rotation from 2006-2010 showing percent reduction by use of GreenSeeker™.

Rotation†	N-Rich Strip	Farmer's Practice	Control	Green Seeker™	Percent Reduction††
	A	B	C	D	
		kg ha^{-1}			
WW-CP-GS	528	343	0	207	40%
WW-CP-C	544	343	0	231	33%
WW-AWP-GS	528	343	0	202	41%
WW-SF-SH	432	315	0	200	36%
WW-FALLOW-CN	628	360	0	253	30%
WW-WW	808	503	0	357	29%

†Winter wheat based rotation, ††Percent reduction of N apllied comparing in-season sensing using GreenSeeker™ to the farmer's practice

1.2 Grain Sorghum Based Rotation Experiment

1.2.1 Grain Yield

Grain sorghum was planted in all rotations in the first year of the experiment (Table 6). No significant interactions between N treatment and rotation were observed; however, differences were found within N treatment and rotation (Table 14). Table 15 shows average grain yields for 2007-2010 averaged across N treatments. In most instances grain yield would be considered average for the area (Table 10).

Table 14. Significant differences found in the grain sorghum rotation.

Source	GS 2007	WW 2008	DC GS 2008	SF 2008	CN 2009	GS 2009	WW 2009
Nitrogen	S††	S	NS	NS	NS	S	S
Rotation	S	S	N/A†††	N/A	N/A	S	NS
Nitrogen x Rotation	NS†	NS	NS	NS	NS	NS	NS

†NS: Means not significantly different at the 0.05 level; †† S, means significantly different at the 0.05 level.

††† N/A statistical analysis not run because only one rotation was examined.

Table 15. Grain sorghum rotation yields averaged across N treatments.

Crop	Year	Yield
		kg ha^{-1}
Grain Sorghum †	2007	3413
Winter Wheat †	2007-2008	2982
Sunflower	2008	1068
DC Grain Sorghum	2008	2555
Canola	2008-2009	1013
Grain Sorghum †	2009	1411
Winter Wheat	2009-2010	1186

†Crops listed were statistically significant within their rotation.

The 2007 grain sorghum, 2007-2008 winter wheat, and 2009 grain sorghum grain yields were all significant within their rotations.

In 2007, grain sorghum grain yields were higher in the GS-AWP-SF and GS-WW-SH rotations compared with others (Table 16). It is unclear as to why grain yields were higher than the other rotations since this was the beginning of the experiment and the entire study area was planted to soybean the previous year. Differences in grain yield were also found in the winter wheat that was planted after the grain sorghum in 2007-2008. The GS-WW-CP, GS-WW-SH, and GS-WW-GS rotations winter wheat grain yields were all different from each other with yields ranging from 2784 to 3317 kg ha^{-1} (Table 16). These results are surprising since the previous crop was grain sorghum. No other crops showed any statistical differences besides the 2009 grain sorghum (Table 16). The grain sorghum yielded 1677 to 1224 kg ha^{-1} (Table 16). The GS-WW-CP, GS-AWP-SF, GS-WW-SH and GS-WW-GS rotations had higher grain sorghum grain yields than the GS-AWP rotation. This was due to the extended fallow period in the GS-AWP rotation compared to the rest of the rotations. Intensified rotations including more than one cash crop yielded the highest; winter wheat had the three highest grain yields followed then by the rotation including sunflower. Grain yields of the GS-WW-GS rotation were higher than the GS-AWP-SF rotation when following double crop grain sorghum compared to sunflower. Sunn hemp and cowpea were found in the two most productive rotations. Allowing a fallow period before planting grain sorghum seemed to noticeably reduce yields in the GS-AWP-SF rotation and especially in the GS-AWP rotation. The additional ground cover might have protected the soil moisture from evaporation (Peel, 1998; Halvorson et al., 2000; Hartwig, Ammon, 2002; Sullivan, 2003).

Table 16. Effect of rotation on grain yields for the grain sorghum rotation.

Year	Rotation	Current Crop	Previous Crop	Yield
				kg ha^{-1}
2007	GS-WW-CP	GS††	N/A	3247 b†
	GS-AWP-SF	GS	-	3710 a
	GS-AWP	GS	-	3291 b
	GS-AWP-CN	GS	-	3356 b
	GS-WW-SH	GS	-	3612 a
	GS-WW-GS	GS	-	3233 b
2007-2008	GS-WW-CP	WW	GS	3087 b
	GS-WW-SH	WW	GS	3317 a
	GS-WW-GS	WW	GS	2784 c
2009	GS-WW-CP	GS	CP	1628 a
	GS-AWP-SF	GS	SF	1438 a
	GS-AWP	GS	AWP	1224 b
	GS-WW-SH	GS	SH	1677 a
	GS-WW-GS	GS	DC GS	1598 a

† Means followed by the same letter are not significantly different according to LSD (0.05).

††Farmer planted soybeans prior to grain sorghum in 2007.

1.2.2 Nitrogen management

As shown in Table 15, significant differences were found between N treatments in four out of seven crop years. The grain yields in the 2007 and 2009 grain sorghum crops were the same in all N treatments with the exception of the control (Table 17). However, in 2007 the GS-WW-CP, GS-AWP, GS-AWP-CN, and GS-WW-GS rotation and all of 2009 grain yields were below the county average (Table 10). In 2007 the GreenSeeker^{TM} treatment (D) was similar to the farmer's practice (B); in 2009 both the farmer's practice (B) and GreenSeeker^{TM} (D) yield were the same and only slightly lower than the N rich strip (A) (Table 17). This shows that the GreenSeeker^{TM} was a useful tool in determining in season N applications and could be a great alternative to the farmer's practice. The winter wheat grain yields in 2007-2008 were the same in all N treatments except for the control. For winter wheat grain yields in 2010, treatments A and B were the same, followed by treatment D and the control (C). One possible explanation for the reduced yield of the GreenSeeker^{TM} based treatment is the top-dressing period was a little late based on Feekes scale, stage nine of stem elongation (Large, 1954). This delayed N application might have been applied too far into maturity and could have affected the winter wheat grain yields (Table 6). Studies have found that an NDVI reading taken at Feekes growth stages 5, 9, and 10.5 were good predictors of harvest relative index and is useful to determine response to additional N at earlier stages of growth (Mullen et al., 2003).

Table 17. Significant average yields across N treatments.

Year	Crop	N tmt	Yield
			kg ha^{-1}
2007	Grain Sorghum		
		A†	4023 a††
		B	3704 a
		C	2075 b
		D	3832 a
2007-2008	Winter Wheat	A	3175 a
		B	3120 a
		C	2677 b
		D	3279 a
2009	Grain Sorghum	A	1630 a
		B	1619 a
		C	1185 b
		D	1619 a
2009-2010	Winter Wheat	A	1354 a
		B	1405 a
		C	730 c
		D	1257 b

† N treatments: N rich strip (A); farmer's practice (B); control (C); GreenSeekerTM (D). †† Means followed by the same letter are not significantly different according to LSD (0.05).

Overall, the use of the GreenSeeker$^{\text{TM}}$ reduced N applications in all rotations (Table 18). The greatest reduction was found in rotations containing winter wheat or grain sorghum since an algorithm exists for these crops. The greatest reduction was found in Rotation 6 (GS-WW-GS), which was the most intensified cropping system consisting of only cash crops. The GreenSeeker$^{\text{TM}}$ had reduced N application compared to the farmer's practice. This technology offers a potential reduction in N applications and costs in many current cropping systems. A study by Raun et al., (2002) found that midseason N application reduced N by 47 kg ha^{-1} and at \$0.55 kg^{-1} N fertilizer, savings would be near \$30 ha^{-1} with grain yields remaining the same. The comparison of treatments in the same study found that increased income would more than cover expected technology costs (\$4.00-\$5.00 ha^{-1}).

Table 18. Total N applied to the grain sorghum based rotation from 2007-2010 showing percent reduction by use of GreenSeeker$^{\text{TM}}$.

Rotation†	N-Rich Strip	Farmer's Practice	Control	Green Seeker$^{\text{TM}}$	Percent Reduction††
	A	B	C	D	
		kg ha^{-1}			
GS-WW-CP	799	556	0	388	30%
GS-AWP-SF	526	416	0	329	23%
GS-AWP	414	315	0	217	31%
GS-AWP-CN	610	472	0	374	21%
GS-WW-SH	799	556	0	388	30%
GS-WW-GS	1213	836	0	569	32%

†Grain sorghum based rotation, ††Percent reduction of N apllied comparing in-season sensing using GreenSeeker$^{\text{TM}}$ to the farmer's practice.

The establishment of intensified cropping systems seemed to work well in both the winter wheat and grain sorghum based rotations. Grain yields were generally average in all rotations, both winter wheat and grain sorghum based, even with additional crops present. The presence of a fallow period seemed to allow soil moisture to reestablish.

Unger (1954) found that a fallow period before grain sorghum provided adequate water throughout the growing season. Higher soil water content with no-tillage very likely persisted throughout the growing season and was largely responsible for the higher sorghum grain yields (Unger, 1954). Tanka et al., (2005) also found that fallow efficiency increased to 47% by including a summer annual crop and available precipitation through evapotranspiration approached 75% in a continuous cropping system.

The most effective rotations, based on management practices and grain yields, seemed to incorporate a broadleaf crop into the rotation which disrupted the weed cycle and allowed different herbicides to be used for control. The inclusion of cover crops was beneficial by providing ground cover at different periods of the year and additional N to the following crops. Miguez and Bollero (2005) found that corn following a winter cover crop yielded 24% more than corn following no cover crop. This winter cover crop provided benefits associated with reduced soil erosion and improved weed management. Another benefit of diversified systems is that variations in root systems tend to be complementary between grasses and legumes; the fine roots of grasses reduce shallow compaction and tap-rooted legumes reduce deep compaction (Snapp, 2005). Mutch and Snapp (2003) find that mixed cover crops are able to establish on degraded soils or fluctuating weather conditions. Summer cover crops need to be fast growing and heat tolerant. Crops such as cowpea and sunn hemp have been found to be tolerant of such heat as well as provide large amounts of biomass, suppress weed growth and provide additional N to subsequent crops (Mansoer et al., 1997; Ngouajio et al., 2003; Snapp et al., 2005).

Nitrogen management was enhanced by using of cover crops and GreenSeeker^{TM} technology (Appendix A and B). The percent reduction in all rotations by the GreenSeeker^{TM} compared to the farmer's practice shows that GreenSeeker^{TM} technology is not only effective in predicting additional in season N needed but proven to save money in traditional cash crop rotations and seems to be the best method for determining actual N contribution from legume cover crops. Raun et al. (2002) found that the largest difference in plant growth due to preplant N would be seen from in season NDVI measurements. GreenSeekerTM sensing and midseason application allows us to estimate needed N to obtain projected yields and determine grain yield increases (Raun et al., 2002).

CHAPTER V

CONCLUSIONS

Intensified cropping systems are possible in areas of Oklahoma receiving greater than 762 mm of annual precipitation. Producers do have an alternative from the current winter wheat-fallow rotations. Rotations including additional crops appear to be possible with little effect on grain yields. Rotations are most effective when soil moisture is allowed to recharge but without extended fallow periods (>60 d). Incorporation of winter canola seemed to break up the weed cycle within a continuous winter wheat rotation.

Overall, the inclusion of cover crops had a positive effect on the cropping systems. The cover crops provided ground cover, additional biomass, and most importantly supplementary N to the following crops and worked best when used during the time that normally would be an extended fallow period, in effect shortening the fallow period in a system.

The use of GreenSeeker^{TM} technology to determine in season N application is feasible. The GreenSeeker^{TM} treatment reduced total N applied in all treatments. This technology offers a potential reduction in N applications and costs in many current cropping systems. The greatest reduction in applied N was found in rotations containing winter wheat or grain sorghum since an algorithm exists for both crops, the lowest reduction was seen with extended fallow periods longer than 60 days. The use of the GreenSeeker^{TM} may prevent over application of fertilizer N when grain yield increases are not likely, in turn increasing farmer returns and decreasing any risk to the environment.

Packaging a diversified crop rotation, cover crops, and use of GreenSeeker^{TM} appears to enhance current cropping systems by increasing grain production in a given year and decreasing inputs, especially N fertilizer.

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APPENDICES

Appendix A. Total nitrogen applied and grain yield for cash crops in the winter wheat based rotation.

Rotation	N Tmt	Pre-plant	Top-dress	Total N	Year and Yield (kg ha^{-1})			
					2006-2007	2007-2008	2008-2009	2009-2010
		kg ha^{-1}			WW			
WW-CP-GS†	A††	177	0	177	N/A †††			
	B	56	45	101	-			
	C	0	0	0	-			
	D	56	28	84	-			
						GS		
	A	207	0	207		3957		
	B	140	0	140		3487		
	C	0	0	0		3518		
	D	84	37	121		3035		
							WW	
	A	146	0	146			2243	
	B	28	73	101			2061	
	C	0	0	0			2233	
	D	28	15	43			2331	
					WW			
WW-CP-C	A	177	0	177	N/A			
	B	56	0	56	-			
	C	0	0	0	-			
	D	56	37	93	-			
						C		
	A	224	0	224		5794		
	B	140	0	140		5437		
	C	0	0	0		5487		
	D	84	57	141		4910		
							WW	
	A	146	0	146			2470	
	B	28	73	101			1904	
	C	0	0	0			2228	
	D	28	15	43			2392	

						WW		
WW-AWP-GS	A	177	0	177		N/A		
	B	56	45	101		-		
	C	0	0	0		-		
	D	56	28	84	-	-		
							GS	
	A	207	0	207			2696	
	B	140	0	140			2239	
	C	0	0	0			2490	
	D	84	0	84			2408	
								WW
	A	146	0	146				526
	B	28	73	101				525
	C	0	0	0				436
	D	28	15	43				524
						WW		
WW-SH-SF	A	177	0	177		N/A		
	B	56	45	101		-		
	C	0	0	0		-		
	D	56	28	84	-	-		
							SF	
	A	112	0	112			10268	
	B	112	0	112			9139	
	C	0	0	0			12877	
	D	112	0	112			11809	
								WW
	A	146	0	146				2055
	B	28	73	101				1962
	C	0	0	0				1800
	D	28	15	43				1936

					WW			
WW-CN	A	177	0	177	N/A			
	B	56	45	101	-			
	C	0	0	0	-			
	D	56	28	84	-			
							WW	
	A	146	0	146			2747	
	B	28	73	101			2517	
	C	0	0	0			3005	
	D	28	15	43			2736	
								CN
	A	196	112	308				1165
	B	45	112	156.8				1165
	C	0	0	0				1165
	D	45	112	157				1165
					WW		WW	
WW-WW	A	177	0	177	N/A		1134	
	B	56	45	101	-		947	
	C	0	0	0	-		864	
	D	56	28	84	-		1558	
						WW		
	A	280	0	280		2783		
	B	160.16	0	160.16		3100		
	C	0	0	0		2760		
	D	160.16	0	160.16		2558		
								WW
	A	207.2	0	207.2				N/A
	B	140	0	140				-
	C	0	0	0				-
	D	84	0	84				-

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† Winter wheat (WW), Grain Sorghum (GS), Corn (C), Sunflower (SF), Canola (CN), Austrian winter peas (AWP), Cowpeas (CP) Sunn hemp (SH)

†† Nitrogen treatments: A N Rich Strip; B Farmer practice; C Control; D Additional nitrogen based on GreenSeekerTM

††† N/A means not harvested

Appendix B. Total nitrogen applied and grain yield for cash crops in the grain sorghum based rotation.

Rotation	N Tmt	Pre-plant	Top-dress	Total N	Year and Yield (kg ha^{-1})			
					2006-2007	2007-2008	2008-2009	2009-2010
			kg ha^{-1}		GS			
GS-WW-CP†	A††	207	0	207	11518			
	B	140	0	140	11301			
	C	0	0	0	6124			
	D	84	47	131	10021			
						WW		
	A	177	0	177		12712		
	B	56	45	101		12246		
	C	0	0	0		10064		
	D	56	28	84		12823		
							GS	
	A	207	0	207			7388	
	B	140	3	143			7000	
	C	0	0	0			4251	
	D	84	2	86			6739	
								WW
	A	207	0	207				5239
	B	140	0	140				5486
	C	0	0	0				2770
	D	84	2	86				4555
					GS			
GS-AWP-SF	A	207	0	207	13009			
	B	140	0	140	12106			
	C	0	0	0	7686			
	D	84	47	131	11728			
						SF		
	A	112	0	112		38843		
	B	112	0	112		30819		
	C	0	0	0		35034		
	D	112	0	112		32037		
							GS	
	A	207	0	207			5466	
	B	140	3	143			5419	
	C	0	0	0			4935	
	D	84	2	86			5288	

					GS			
GS-AWP	A	207	0	207	7062			
	B	140	0	140	10272			
	C	0	0	0	6956			
	D	84	47	131	11333			
							GS	
	A	207	0	207			4071	
	B	140	3	143			3871	
	C	0	0	0			4850	
	D	84	2	86			5318	
					GS			
GS-AWP-CN	A	207	0	207	11978			
	B	140	0	140	10256			
	C	0	0	0	4789			
	D	84	47	131	11304			
							CN	
	A	146	0	146			59686	
	B	28	112	140			57118	
	C	0	0	0			36615	
	D	28	112	140			57234	
					GS			
GS-WW-SH	A	207	0	207	12921			
	B	140	0	140	11660			
	C	0	0	0	5761			
	D	84	47	131	13010			
						WW		
	A	177	0	177		12973		
	B	56	45	101		12555		
	C	0	0	0		10568		
	D	56	28	84		12622		
							GS	
	A	207	0	207			6314	
	B	140	3	143			7341	
	C	0	0	0			5160	
	D	84	2	86			6081	
								WW
	A	177	0	177				5180
	B	56	45	101				5988
	C	0	0	0				3071
	D	56	28	84				5451

					GS			
GS-WW-GS	A	207	0	207	12058			
	B	140	0	140	11070			
	C	0	0	0	4091			
	D	84	47	131	11583			
						WW		
	A	177	0	177		11766		
	B	56	45	101		12165		
	C	0	0	0		10619		
	D	56	28	84		12024		
						DC GS		
	A	207	0	207		2652		
	B	140	0	140		2660		
	C	0	0	0		2117		
	D	84	0	84		2791		
							GS	
	A	207	0	207			1604	
	B	140	0	140			1664	
	C	0	0	0			1000	
	D	84	13	97			1696	
								WW
	A	207	0	207				5831
	B	140	0	140				5384
	C	0	0	0				2914
	D	84	2	86				5080

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† Winter wheat (WW), Grain Sorghum (GS), Corn (C), Sunflower (SF), Canola (CN), Austrian winter peas (AWP), Cowpeas (CP) Sunn hemp (SH)

†† Nitrogen treatments: A N Rich Strip; B Farmer practice; C Control; D Additional nitrogen based on GreenSeekerTM

††† N/A means not harvested

Appendix C. Grain sorghum based rotation N treatment averages across rotations.

Year	Crop	Rotation	Avg. N applied
			kg ha^{-1}
2007	Grain Sorghum †	1,2,3,4,5,6	159
2007-2008	Winter Wheat †	1,5,6	120
2008	Sunflower	2	112
2008	DC Grain Sorghum	6	145
2008-2009	Canola	4	170
2009-2010	Grain Sorghum †	1,2,3,5,6	156
2009-2010	Winter Wheat †	1,5,6	144

†Crops listed were statistically significant within N treatments.

VITA

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Scope and Method of Study: An on-going experiment was established in Lahoma, OK to evaluate intensified cropping system and determine the possibility of including selected cover crops in rotation as well as evaluation of the use of GreenSeeker™ technology in determining in-season N applications. The experimental design was split plot with rotation being the main plot and N treatment as the subplot. The experiment was broken into two parts: a winter wheat based rotation and a grain sorghum based rotation. Within rotations, additional crops were included as well as legume cover crops. N treatments were comprised of a non-limiting N-Rich strip, N based on the farmer's practice, a control, and N based on GreenSeeker™ technology. Grain yield, N treatments, and interactions were statistically analyzed.

Findings and Conclusions: Incorporation of an intensified cropping system is feasible in areas of Oklahoma receiving >762 mm of annual precipitation. Rotations including additional crops appear to be possible with little effect on wheat and grain sorghum grain yields. Rotations are most effective when soil moisture is allowed to recharge but without extended fallow periods (>60 d). The most effective rotations seemed to incorporate a broadleaf crop into the rotation which disrupted the weed cycle and allowed different herbicides to be used for control. The inclusion of cover crops was beneficial by providing ground cover at different periods of the year and additional N to the following crops. The GreenSeeker™ treatment reduced total N applied in all treatments and had a cost savings ranging from$76 to $284 per hectare over the 3 year period. This technology offers a potential reduction in N applications and costs in many current cropping systems.

ADVISER'S APPROVAL: ______________________________

Dr. Chad Godsey