INTEGRATING COVER CROPS INTO STRIP-TILL CROPPING SYSTEMS IN A SEMI-ARID ENVIRONMENT

A Thesis

by

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ABSTRACT

Integration of strip tillage and cover cropping has potential to improve soil tilth and reduce input costs of cropping systems in south Texas. Quantification of effects on crop yield and soil properties are necessary in this region. The objective of this experiment was to assess the effects of integrated strip tillage and cool-season legume cover cropping in a continuous cotton (*Gossypium hirsutum* ‘DP 0935’)-sorghum (*Sorghum bicolor* ‘GA 3696’) rotation with limited irrigation in Beeville, TX, and an irrigated cotton-corn (*Zea mays* ‘GA 3696’) rotation establishment year in Uvalde, TX. Trials were planted in a randomized complete block design with split-split plots. The main effect was row crop, with split-plots strip-tilled into the residue of four legume species (*Medicago polymorpha* ‘Armadillo’; *M. minima* ‘Devine’; *M. lupulina* ‘BEEBLK’; or *Trifolium hirtum* ‘Hykon’), or control (plow-tilled/winter fallow). At the Beeville site, the split-split plot treatment was cutting and removal of the cover crops from half of each plot. Herbage mass of the cover crops was not different ($P > 0.20$) between species at Beeville in either year. There were no interactions ($P > 0.41$) between cover crop/tillage and cutting regime for cotton and sorghum yields in either year. In the establishment year, cutting regime tended to reduce ($P > 0.10$) sorghum yield. In Year 2, no differences in cotton ($P > 0.56$) or sorghum ($P > 0.15$) yield occurred among treatments. In Uvalde, Armadillo had greater ($P = 0.003$) herbage mass in Year 2. Cover crop treatments did not affect ($P > 0.22$) target crop yields, although, in Year 2, treatments with cover crops cut and removed had increased ($P = 0.08$) cotton yield and boll count (*P* = 07). Changes in soil nutrient status in response to cover cropping were not consistent. Initial results indicate that integrated strip tillage and cover cropping will not negatively affect yields in southern Texas, but additional years of replication are necessary to evaluate potential improvements in soil tilth.

DEDICATION

To my grandfather, “Popo” Calvin George Pelzel.

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NOMENCLATURE

a.i.	Active ingredient
a.e.	Acid equivalents
CP	Crude protein
DM	Dry matter
g	Gram
ha	Hectare
kg	Kilogram
MAP	Mean annual precipitation
MAT	Mean annual temperature
NDF	Neutral detergent fiber
NO_3-N	Nitrate-nitrogen
SOC	Soil organic carbon

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CHAPTER I

INTRODUCTION

The stability of agricultural production throughout many regions of Texas is at risk due to requirements of very limited, expensive, or unreliable resources. Steadily decreasing water availability, more frequent and severe drought conditions, and increasing costs of fuel, fertilizer, and labor require maximum efficiency for economically and environmentally stable agricultural systems. It is more critical now, than ever, to work toward developing systems that conserve resources, while continuing efficient food and fiber production (United Nations, 2011).

Conservation tillage (no-till and strip-till) systems are based on the principles of reduced soil disturbance and the associated benefits of leaving a minimum 30% of surface residue intact. Across the southeastern U.S. these systems have been readily adopted and implemented because of improvements in soil erosion control, soil structure, tilth, water use efficiency, and reduced input costs (Reeves, 1994; Unger and Vigil, 1998). Conservation tillage has not, however, been largely accepted or applied among Texas growers because of uncertainty of potential benefits in their specific cropping climate and environment. Plow-till cultivation systems are predominant in semi-arid regions of Texas, which increase the likelihood of decline in soil condition, leading to undesired consequences such as soil erosion and evaporative water loss.

Cover cropping is the practice of planting a supplemental crop during an otherwise fallow period with the intent of preventing erosion, increasing water infiltration, and contributing to soil organic matter (West and Post, 2002). In addition, legume cover crops can contribute additional nitrogen to the system that will ultimately become available to the target crop (Dubach and Russelle, 1994; Russelle et al., 1994; Høgh-Jensen and Schjoerring, 2001). To date, cover cropping is rare in arid and semi-arid areas of Texas due to required moisture to support a cover crop. Since increases in soil organic C (SOC) and decreases in mechanical soil disturbance are two hallmarks of strip-tillage systems, a strip-tillage system is expected to improve water capture and availability. Conservation till systems with adequate surface residue accumulation which decreases evaporation and increases soil water holding capacity will counterbalance water use from the cover crop. Leguminous cover crops are expected to supply more nitrogen to the soil and subsequently the main crop (Dubach and Russelle, 1994; Russelle et al., 1994).The combination of leguminous cover cropping and strip-tillage has the potential to improve nutrient cycling and better conserve limited resources while maintaining target crop production levels.

Integrated cover cropping and strip-tillage agricultural system research has not been conducted in semi-arid agricultural regions of south Texas. Integrating cool-season, legume cover crops in cotton (*Gossypium hirsutum* L.), sorghum (*Sorghum bicolor* [L.] Moench), and corn (*Zea mays* L.) strip-till systems may provide valuable and sustainable benefits. In addition to decreasing erosion, securing soil tilth, and improving soil quality, strip-till/cover cropping systems have the potential to increase carbon sequestration (Reeves, 1997), and maintain or increase yields with less water, fuel, and inorganic fertilizer inputs (Dubach and Russelle, 1994; Russelle et al., 1994).

The objectives of this experiment were to evaluate whether integrated strip tillage and cool-season legume cover crops are a feasible alternative to conventional cropping systems (plow-till, winter fallow). The hypothesis of this project is that the benefits of strip-tillage combined with cool season legume cover cropping will manifest in yields comparable to, or greater than, those of conventional systems. In semi-arid regions, moisture used by the cover crop must not negatively affect the economic return of the main crop. Results from this research will provide producers in the Northern Rio Grande Plain major land resource area a factual basis for understanding the agronomic implications of converting from conventional tillage to legume cover cropping and strip-tillage systems. Information obtained through this study can be combined with annual economic trends, as well as needs for sustainable farming systems, and improving soil tilth as part of a holistic assessment of sustainable cropping systems. Ultimately, results from this work will contribute to developing agricultural systems in Texas that can be competitive and produce more sustainable yields through improved water use efficiency, nutrient cycling, and securing the soil resource for future needs.

CHAPTER II

LITERATURE REVIEW

Conventional Agriculture Systems, Soil Management, & Perceived Problems

More cotton is produced in Texas than any other state, accounting for more than 43% of the cotton grown in the USA (USDA-NASS, 2007). Other important warm-season row crops in Texas are grain sorghum and corn. Conventional agricultural systems consist of plow tillage in rotation with winter fallow. These full tillage systems often compromise soil to erosion from wind and water and reduce soil moisture available to the crop by allowing more soil evaporation.

Conventional till and fallow agricultural systems are known to foster erosion and loss of valuable top soil and soil nutrient abuse (Montgomery, 2007a). Conservation tillage is used on less than 17% of cotton farm land in Texas, whereas in the southeastern United States it is utilized by 71% of farmers (USDA-ERS, 2007). There is an estimated 1% loss of soil each year through erosion primarily due to agriculture practices (Montgomery, 2007b).

In the next 40 years, the world human population is predicted to exceed 9 billion (United Nations, 2011). This increase in human populations will demand substantial increases in production, efficiency, and ultimate system sustainability. Additionally, climate change and socioeconomic developments are requiring a reevaluation of conventional crop production systems, especially in semi-arid regions or marginal environments. Climate change creates uncertainty in long term water supply, while increased populations and changing demands in urban and peri-urban systems suggest that water resources traditionally allotted for agricultural production can no longer be assumed available as demand escalates (Pimentel et al, 1997). With predicted continued escalation of fuel and fertilizer costs and reduced water availability, agriculture faces a challenge to minimize inputs and sustain production, while preserving and improving soil.

Cover Cropping in Semi-arid Regions

Cover crops are planted to cover soil at times when fields would otherwise be left fallow, in the interest of managing soil fertility, security and water. Hall et al. (1984) assessed soil and water loss and herbicide movement in no-till systems with living cover crops or residue mulches compared to un-mulched, conventional till systems. Runoff, erosion, and herbicide movement was reduced in systems with intact residue. When cover crops are utilized, soils benefit from contribution of nutrients and prevention of soil erosion, while surface residue can improve water infiltration (Triplett et al., 1968) and retention, and reduce weed pressure.

Due to water requirements, cover crops are not commonly planted in semi-arid environments because of limited rainfall and society's increased sensitivity to water supply and demand (Reeves, 1994), and available soil moisture is typically only adequate to support one crop annually. Accumulation of surface residue can increase infiltration while decreasing evaporative loss (Reeves, 1997; Kay and VandenBygaart, 2002). Therefore, water input requirements have potential to decrease upon the establishment of adequate crop residue, justifying initial resource expenses (Reeves, 1994). The additional moisture required to grow cover crops in semi-arid regions is a limiting factor that must be assessed. Research in humid and sub-humid regions of the eastern U.S. and semi-arid regions of the northern Great Plains indicates that although water is lost from cover crops through evapotranspiration, total soil moisture can increases when conservation tillage is also used (Reeves, 1994; Unger and Vigil, 1998), especially with early termination of the cover crop (Munawar et al, 1990).

Legume Cover Cropping

When legumes are planted as cover crops, nitrogen is provided to the system through decomposition of the legume roots and remaining surface litter by soil microbes, decreasing the amount of inorganic nitrogen fertilization required by the system (Dubach and Russelle, 1994; Russelle et al., 1994; Høgh-Jensen and Schjoerring, 2001). Accumulation of soil organic matter can increase soil organic C (West and Post, 2002). Therefore, establishment and preservation of leguminous residue can also increase carbon sequestration (Reeves, 1997) along with nutrient availability (Parr et al., 2011). Aside from benefits to the soil, legume cover crops can increase farm diversity by providing high quality forage for livestock production (Ball et al., 2002). Many legumes suitable for integration into these systems can be grazed or harvested for hay.

Conservation Tillage

Conservation tillage is defined as at least 30% of the soil surface being covered with residue. Conservation tillage has been shown to decrease soil erosion, soil temperatures, and evaporative water loss, and increase water infiltration (Pimentel et al., 1995; Reeves, 1997; Kay and VandenBygaart, 2002). However, excessive seedbed residues can contribute to suboptimal stand establishment conditions, if the "no-till" planter is unable to cut through the layer of residue to achieve seed to soil contact and the desirable depth (Janovicek et al, 1997). Strip-tillage minimizes this problem by tilling a narrow seedbed enabling proper planting and germination while leaving beneficial surface residue covering the inter-row space. (Fig. 2.1). In addition to maintaining residue over a 65-80% of the surface, strip-tillage can enable precision placement of fertilizer for maximum efficiency.

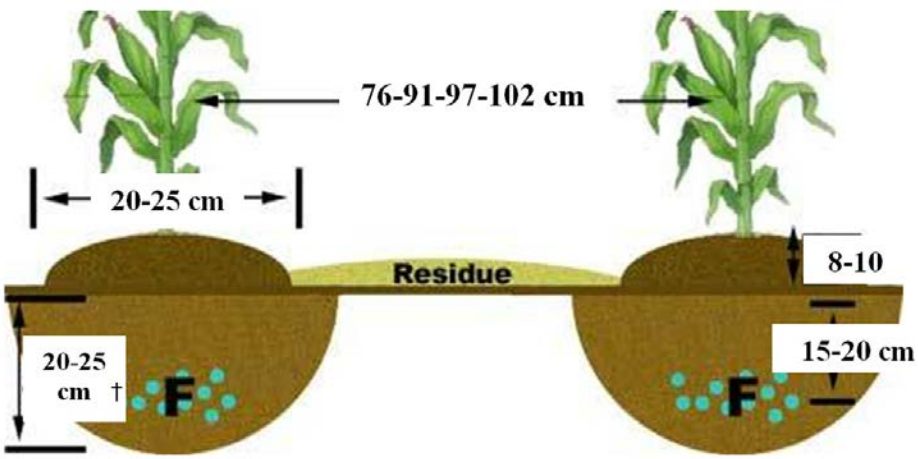

Fig. 2.1. Example of two rows within a strip tillage field including potential residue coverage and fertilizer placement. Adapted from FHR, 2007.
† F, fertilizer.

It is common for conventional systems to be tilled up to 6 times annually and lead to high fuel, equipment depreciation, and labor expenses (West and Marland, 2002). Considering the longevity of a farm's production in continuous cropping, soil security becomes a critical element of sustainability. Conservation tillage has potential to reduce erosion and even contribute to positive soil formation and accumulation. Hall et al (1984) found that untilled systems reduced runoff (water loss) 86-99% and eliminated 97-100% of soil losses. Therefore, reduced tillage and conservation till systems have potential to achieve increased resource efficiency by reducing fuel and labor input requirements and simultaneously conserving soil and water. Adequate production incorporating these practices will enable greater prospective sustainability.

System Integration of Cover Cropping and Conservation Tillage (Pros, Cons)

Cover crops and conservation tillage management practices have been integrated intensively in the eastern U.S. and yielded encouraging results. In North Carolina, Parr et al. (2011) quantified nitrogen supplied by legume cover crops in no-till corn systems. Almost all cover crops tested obtained 70-100% of their N from the atmosphere, and in one instance, a hairy vetch (*Vicia villosa* Roth) cover crop cultivar contributed up to 217 kg ha^{-1} N to the system. Sainju et al. (2005) indicated that no-till or strip-till systems with legume cover crops may increase root C and N compared to chisel-till and no cover crops in cotton and sorghum systems in central Georgia. Research investigating the potential of this system integration has not been conducted in semi-arid South Texas.

CHAPTER III

EFFECT OF INTEGRATING COVER CROPPING INTO STRIP-TILL SYSTEMS ON CROP YIELD AND SOIL NUTRITIVE STATUS IN A SEMI-ARID ENVIRONMENT

Introduction

Throughout many agricultural regions of Texas, the sustainability of traditional crop production systems is in question. The high input-high return nature of current conventional agricultural systems lacks environmental stability in an ecosphere of limited resources. With continually increasing fuel and fertilizer prices and water restrictions, farmers are faced with the challenge to implement cropping systems that maximize the allocation and efficiency of resources while continuing to increase production to meet expanding global population needs.

Conservation tillage (no-till and strip-till) systems have been adopted and implemented across the southeastern U.S. due to known benefits to soil moisture, water use efficiency, soil security, and reduced input costs (Pimentel et al., 1995; Reeves, 1997, Kay and VandenBygaart, 2002). These systems have not, however, been largely accepted or applied among Texas growers due to uncertainty of potential benefits in their specific cropping climate and environment (Unger and Vigil 1998), and the expensive transition of equipment.

Cover cropping is another management practice commonly used to prevent erosion, increase water infiltration and retention, and contribute organic matter to the soil (Reeves, 1997; West and Post, 2002). To date, cover cropping is rare in arid- and semi-arid areas of Texas due to required moisture to support a second crop.

Conservation till systems with adequate surface residue accumulation which maximize soil water holding capacity may balance the water cycle within these fields. Such an outcome of combined cover cropping and conservation tillage may result in net neutral soil moisture loss, but allow for improved soil security.

Research investigating the integration of cover cropping and strip-tillage agricultural systems has not yet been conducted in semi-arid agricultural regions of south Texas. Integrating cool-season, legume cover crops in cotton (*Gossypium hirsutum* L.), sorghum (*Sorghum bicolor* [L.] Moench), and corn (*Zea mays* L.) strip till systems may provide valuable and sustainable benefits. In addition to decreasing erosion, securing soil tilth and improving soil quality, strip-till/cover cropping systems have potential to increase carbon sequestration, and maintain or increase yields with decreased water, fuel, and inorganic fertilizer inputs.

The overall objective of this experiment is to evaluate whether integrated strip tillage and cool-season legume cover cropping can be as productive a cropping system, with greater soil nutritive status and water balance, as conventional cropping systems (plow-till, winter-fallow). Since increases in SOC and a decrease in mechanical soil disturbance are two hallmarks of strip-tillage systems (West and Post, 2002), a strip-tillage system is expected to have improved water capture and availability. Additionally, leguminous cover crops should supply more nitrogen to the soil and subsequently the main crop (Dubach and Russelle, 1994; Russelle et al., 1994).

Methods

Experimental Sites and Design

Two 2-year experiments were planted in a completely randomized factorial design with four plot (278.7 m^2) replicates each at Beeville (28°27'15.56"N, 97°42'18.27"W; 73 m) and Uvalde (29°12'34.47"N, 99°45'5.97"W; 282 m), TX. The main effect was row crop with split-plots strip-tilled into the residue of four legume species [*Medicago polymorpha* L. cv. Armadillo (burr medic), *M. lupulina* L. cv. Bee Black (black medic), *M. minima* (L.) L. cv. Devine (little burr medic), *Trifolium hirtum* All. cv. Hykon (rose clover)], or the control (conventional tillage/winter fallow). Cover crop vegetative mass was cut and removed (simulating a hay harvest) from half of each treatment as a split-split plot.

Experiment 1: Continuous Cropping System

Beeville is in the Northern Rio Grande Plains ecoregion of Texas and has a mean annual precipitation of 789 mm, and mean annual temperature of 21.5˚C. Soil is classified as a Parrita sandy clay loam (loamy, mixed, superactive, hyperthermic, shallow Petrocalcic Paleustoll). Soil characteristics were 200 g kg^{-1} clay, 84 g kg^{-1} silt, 716 g kg^{-1} sand, 21.2 mg kg^{-1} NO_3-N, 3.7 mg kg^{-1} P, 111 mg kg^{-1} K, and pH of 7.2 at experiment initiation. In Beeville, cover crops were planted using a Tye Pasture Pleaser no-till drill (The Tye Co., Lockney, Texas) on November 8, 2011 and November 12, 2012. Seeding rates were the same as those commonly recommended and were 11 kg ha^{-1} for Armadillo and Bee Black, 6.7 kg ha^{-1} for Devine, and 28 kg ha^{-1} for Hykon. On split-split plots receiving the "hay cutting" treatment, vegetative mass was harvested to a

5-cm stubble height on March 15, 2012 and March 1, 2013 using a lawnmower with a bag attachment. All cover crops were terminated on March 16, 2012 and March 3, 2013 using glyphosate at 3.17 kg a.e. ha^{-1}. Conventional control plots were plow-tilled prior to planting and following the harvest of the target crop. The cover cropping (or fallow) treatment and cutting regime applied to individual plots in Exp. 1 was maintained for both years.

All treatments were fertilized with 112 kg ha^{-1} P_2O_5 and 90 kg ha^{-1} K_2O on February 7, 2012 according to soil report recommendations. A cotton (cv. DP 0935B2RF)-grain sorghum (cv. GA 3696) annual rotation was planted on April 5, 2012 and March 13, 2013, respectively. Weed species were managed by hand in 2012 and with glyphosate (RoundUp WeatherMax, Monsanto) at 1.70 kg a.e. ha^{-1} using a hooded bicycle sprayer and backpack sprayer in 2013. Grain sorghum was harvested July 12, 2012 and July 19, 2013. Cotton was treated with ethephon (SuperBoll, Nufarm Americas Inc.) at 2.2 kg a.i. ha^{-1} at maximum boll maturity, and then harvested August 16, 2012 and August 20, 2013 according to crop maturity. Precipitation and temperature data were recorded daily from the NOAA weather station on site and historic data (30-yr mean) were calculated from this weather station.

Experiment 2: Initiation of Cropping System

Uvalde is in the same ecoregion as Beeville but has a mean annual precipitation of 600 mm and mean annual temperature of 19.6 ˚C. Soil is classified as a Knippa clay (fine, mixed, superactive, thermic Vertic Calciustoll). Soil nutrient levels at 0-15 cm at experiment initiation in Uvalde were 38 mg kg^{-1} NO_3-N, 41 mg kg^{-1} P, 785 mg kg^{-1} K, and pH of 7.2. In Uvalde, cover crops were planted on November 11, 2011 and November 13, 2012 using the Tye Pasture Pleaser no-till drill and the seeding rates were the same as those for Exp. 1. Forage samples were collected on March 13, 2012 and February 27, 2013. Cover crops were terminated on March 14, 2012 and March 8, 2013 using glyphosate at 1.23 kg a.e. ha^{-1} and S-metolachlor (Dual Magnum, Syngenta) at 1.27 kg a.i. ha^{-1} was included in the tank mixture to provide preemergence control of grass and small-seeded broadleaf weeds. In Year 1 of Exp. 2, the cover crop herbage was terminated and left standing, except for the subsample collected from each plot. In Year 2 of Exp. 2, herbage mass was cut and removed from split-split plots at a 5-cm stubble height using a mower and rake.

A cotton-corn (cv. DKC 67-21[Bt/RoundUp Ready]) annual rotation was planted in Uvalde on March 15, 2012 and March 12, 2013. At target crop planting during both years, 4.97 kg ha^{-1} P_2O_5 and 1.48 kg ha^{-1} N_2 were applied to strip-till treatments, and 44.91 kg ha^{-1} P_2O_5 and 11.23 kg ha^{-1} N_2 were applied to the control. Center pivot irrigation was used as needed, and a total of 168.4 kg ha^{-1} N was applied via chemigation throughout the growing season. Cover crop treatments received 19 mm of irrigation in Year 1 and 229 mm in Year 2. Target crops received 206 and 235 mm in Years 1 and 2, respectively. Corn was harvested August 7, 2012 and July 31, 2013. Cotton was treated with ethephon (SuperBoll, Nufarm Americas Inc.) at 2.2 kg a.i. ha^{-1} at maximum boll maturity, and then harvested August 14, 2012 and July 31, 2013. Precipitation and temperature data were obtained through Texas A&M AgriLife Extension's "Texas ET

Network" (Texas A&M AgriLife, 2014) and through the National Oceanic and Atmospheric Administration (NOAA, 2014).

Data Collection and Analyses

Cover Crops

Duplicate herbage samples of the cover crops were taken to 5-cm stubble height within a 0.25 m^2 quadrat. Samples were dried at 65^{o}C in a forced air oven until weight loss ceased, and dry matter (DM) was determined (AOAC, 1990). Dried samples were ground to 2 mm particle size in a Wiley mill (Thomas Scientific, Swedesboro, New Jersey). Neutral detergent fiber (NDF) was determined with an Ankom Fiber Analyzer (ANKOM Technologies, Macedon, NY; Van Soest et al., 1991). Nitrogen and carbon were determined by rapid combustion using a macroelemental CN analyzer (Elementar Americas, Inc., Mt. Laurel, NJ) and crude protein (CP) calculated as N × 6.25. In Year 2, inadequate sample matter was available to accurately determine cover crop NDF, N, and CP; therefore, only herbage mass is reported for Year 2.

Target Crops

Lint (cotton) and whole grain (sorghum and corn) yields were quantified through hand harvesting a 0.61-m row length from the two center rows of each split-split plot. Cotton bolls, sorghum heads, and corn ears were counted per sample to quantify the seed head density per square meter. Seed cotton (total mass of seed and lint) was weighed and ginned (Continental Eagle 10-Saw Gin, Prattville, AL) and lint percentage was calculated with respect to seed cotton weight. Sorghum panicles were dried at 43°C to ~12% moisture, threshed (Almaco Plant and Head Thresher, Allan Machine Company, Ames, IA), weighed, and tested for moisture gravimetrically and subsampled for 100-grain weight. Grain yield was normalized at 12% moisture according to individual measurements. Corn was shelled (Black Hawk Corn Sheller, A.H. Patch, Clarksville, TN) and subsampled for moisture (GMT-Grind Grain Moisture Tester, AgraTronix, Streetsboro, OH), and 100-grain weight (also normalized at 12% moisture).

Soil

In Experiment 1, soil samples were collected from each split-split plot on June 6, 2012 (mid-growing season), then, in Experiments 1 and 2, prior to planting of cover crops (November 4, 2012) and prior to planting of target crops (March 3, 2013). A composite sample of five cores was collected from each split-split plot using push probes (2.22 cm in diameter), and separating the upper core (0-15 cm; Depth 1) from the lower core (15-30 cm; Depth 2). Soil pH was determined using a hydrogen selective electrode in solution (Schofield and Taylor, 1955). Phosphorus, K, Ca, Mg, S, and Na were extracted using the Mehlich III extractant and determined by ICP on a dry matter basis (Mehlich, 1978; Mehlich, 1984). Nitrate-N was extracted using a 1 N KCl solution and measured by reduction of nitrate (NO_3-N) to nitrite (NO_2-N) using a cadmium column followed by spectrophotometric measurement (Keeney and Nelson, 1982; Kachurina et al, 2000). Total N and C were determined by dry combustion using a carbon analyzer (McGeehan and Naylor, 1988). Inorganic C was measured using a modified pressure-calcimeter method (Sherrod et al, 2002), and SOC was calculated as the difference of total and inorganic C, Soil moisture was measured gravimetrically at both depths.

Statistical Analyses

The Glimmix procedure was used in SAS 9.3 to analyze cover crop herbage mass and chemical composition, row crop yield, cotton lint percentage, 100-kernel weight (sorghum and corn), and soil chemical composition and moisture. The models for cover crop herbage mass and chemical composition included cover crop, row crop species, and their interaction. In Beeville (Exp. 1) and year two in Uvalde (Exp. 2), the models for soil chemical composition, and target crop yield and quality included cover crop, tillage treatment, cutting regime, and their interactions. Soil nutritive status and target crop results in Uvalde (Exp. 2) year one, were analyzed according to cover crop and tillage treatment. Significant differences were declared at $P < 0.05$ and tendencies at $0.10 \geq P \geq 0.05$.

Results

Experiment 1

The establishment year for cover crops in Beeville (Exp. 1; 2011) experienced the most severe drought on record (Figure 3.1). In the first row-cropping cycle (2012), precipitation was greater than in 2011 but sporadic during the growing season, whereas, 2013 had more consistent and timely for crop growth. During the cover crop growing season, 134 mm of precipitation occurred and 32 mm of irrigation was applied in Year 1, and 89 and 203 mm in Year 2, respectively.   During the target crop growing season, 170 mm of precipitation occurred and 102 mm of irrigation was applied in Year 1 (2012), and 258 and 216 mm in Year 2 (2013), respectively. Average monthly temperatures did not vary from 30-yr averages throughout the 2-year experiment (Figure 3.2).

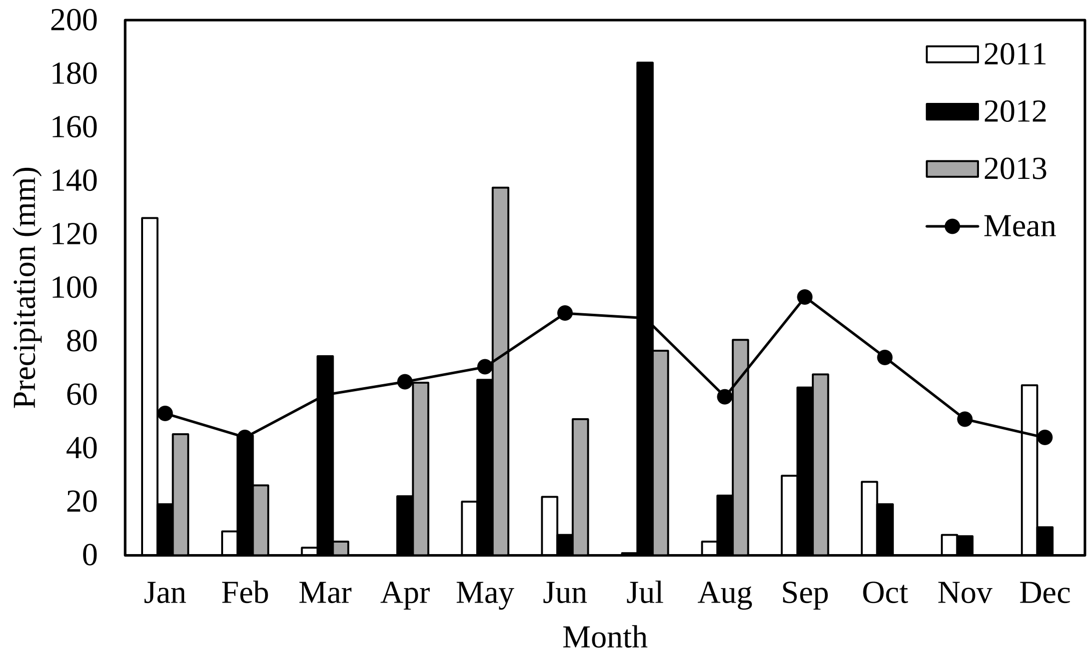

Figure 3.1 Average monthly precipitation during experimental years (2011-2013) compared to the 30-yr average in Beeville, Texas.

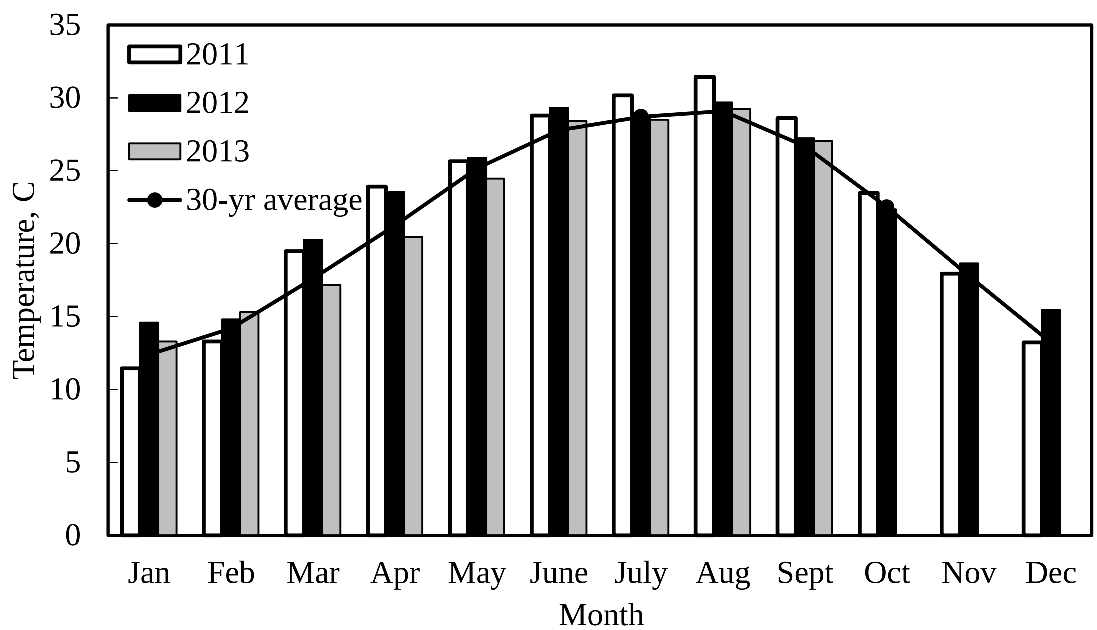

Figure 3.2 Average monthly temperatures from 2011-2013 and the 30-yr average in Beeville, Texas.

Cover Crops

In Year 1, cover crop herbage mass (Table 3.1) did not vary (*P* > 0.93) between species, and cultivars produced an average herbage mass of 2.02 ± 0.28 Mg DM ha^{-1}. Carbon:nitrogen ratio and crude protein (CP) concentration were not different (*P* = 0.39) among cultivars (average 22.6% CP DM basis). Nitrogen yield from cover crop herbage mass averaged 73 kg N ha^{-1}. Neutral detergent fiber did not differ (*P* = 1.0) between treatments, and averaged 27.0 ± 0.82% DM basis.

In Year 2, Armadillo tended (*P* =0.18) to have greater herbage mass (1.57 Mg DM ha^{-1}) (Table 3.1). Carbon:nitrogen ratio averaged 46.8 ± 10.6 kg N ha^{-1} and CP concentration averaged 23.5 ± 1.1% DM basis. Neutral detergent fiber concentration did not vary (*P* >0.93) between treatments (average 25.4 ± 1.7% DM basis).

Table 3.1 Herbage mass and chemical composition of cover crops grown in 2 growing seasons in Beeville, Texas (2012-2013).

Year	Cover crop cultivar ‡	Herbage mass, Mg DM† ha^{-1}	C:N ratio	CP, % DM basis	Total N Yield, kg ha^{-1}	NDF, % DM basis
2012	Armadillo	2.17	11.1	23.4	81.3	27.1
	Bee Black	1.94	11.2	23.1	70.3	26.9
	Devine	1.99	11.3	22.5	70.6	26.9
	Rose	1.94	11.7	21.7	65.9	27.1
	SEM	0.28	0.33	0.95	10.6	0.82
2013	Armadillo	1.57	11.2	22.8	56.4	26.0
	Bee Black	1.23	10.6	24.4	45.4	24.8
	Devine	1.09	11.0	23.8	43.3	25.9
	Rose	1.07	11.1	23.0	41.1	25.1
	SEM	0.269	0.477	1.10	10.6	1.70

† DM, dry matter; C:N, carbon:nitrogen ratio; CP, crude protein; NDF, neutral detergent fiber.

‡ Armadillo, *Medicago polymorpha* ‘Armadillo’; Bee Black, *M. lupulina* ‘Bee Black’; Devine, *M. minima* ‘Devine’; Rose, *Trifolium hirtum* ‘Hykon’; SEM, standard error of the mean.

Target Crops

There were no interactions ($P > 0.41$) between cover crop and cutting regime for cotton or sorghum yields in either year. In the establishment year (Year 1), cover crop treatments did not have a significant effect ($P > 0.57$) on cotton yields (average 0.41 Mg lint ha^{-1}) compared to the conventionally tilled control (1.06 Mg lint ha^{-1}; Table 3.2). Cotton yield was not affected by cutting regime, and neither lint % or bolls m^{-2} were impacted by cover crop or cutting regime. In Year 2, there were no differences ($P >$ 0.15) in cotton yield among treatments. Bolls m^{-2} was not affected by cover crop treatment; however, cotton grown after cover crops were cut and removed resulted in a greater ($P = 0.02$) lint percentage (average 45.1%) than when the herbage was not cut (average 44.2%).

Sorghum yield was not impacted by prior cover crop treatment; however, cutting regime tended ($P = 0.10$) to affect sorghum yield in the establishment year (Table 3.3). Treatments with herbage cut and removed averaged 1.0 Mg ha^{-1}, whereas, treatments not cut averaged 0.44 Mg ha^{-1}. Sorghum heads m^{-2} was not affected by cover crop treatment, cutting regime, or the interaction ($P > 0.34$). Neither treatments nor interactions had an effect on 100 grain weight ($P > 0.24$) in Year 1. In year two, sorghum yields were not affected by treatment ($P > 0.15$). Sorghum heads m^{-2} tended to differ ($P = 0.08$) between cut cover crop treatments (9.5 heads m^{-2}) and cover crop treatments that were not cut

(1.1 heads m^{-2}). Neither cover crop treatment nor cutting regime impacted (*P* > 0.32) 100 grain weight of sorghum.

Soil

There were cover crop x cutting regime and cover crop x target crop interactions (*P* < 0.05) in the soil nutrients; therefore, data are presented as cover crop x cutting regime x target crop. From the first to the second sampling event (Year 1), soil following cotton was more depleted (*P* < 0.0001) of NO_3-N than sorghum at Depth 1 (Table 3.4). There were cover crop x cutting regime and cover crop x target crop interactions (*P* < 0.02) for soil P. Soil following cotton and Armadillo that was cut and removed had greater (*P* = 0.01) P depletion than that not cut and removed. Soil P following sorghum was not affected (P > 0.10) by treatments, whereas, soil following cotton and Bee Black not cut or Devine cut and removed had less (*P* = 0.02) P depletion than conventional tillage. Cover crop plots with herbage cut and removed, and with herbage left standing, tended to result in less (*P* = 0.09) soil K depletion than conventional tillage. Cotton following Devine and Armadillo tended (*P* = 0.08) to have greater soil Ca than conventional cotton and sorghum following Bee Black. Soil where cotton following Devine was grown tended (*P* = 0.06) to have greater Na than sorghum following Bee Black. The change in soil Mg was affected (*P* = 0.002) by multiple cover crop x target crop interactions (Table 3.4). Accumulation of Mg tended to be greater (*P*= 0.06) in soil following cotton than that of sorghum. There was no (*P* > 0.21) treatment effect on the change of S, total N, or SOC. Cover crop and target crop tended (*P* = 0.09) to affect the change in soil H_2O. Sorghum treatments with Bee Black not cut and cotton

Table 3.2 Cotton lint yield, lint percent, and bolls per square meter as affected by cover crop treatment and cutting regime during two growing seasons in Beeville, TX (2012-2013).

Year	Cover crop cultivar[†]	Armadillo		Bee Black		Devine		Rose		Conv.	SEM
	Cutting regime[‡]	0	1	0	1	0	1	0	1	---	
2012	Yield, Mg lint ha^{-1}	0.136	0.213	0.363	0.359	0.267	0.262	0.460	0.582	1.06	0.225
	Lint %	41.6	39.8	38.0	42.5	42.7	41.2	40.4	41.5	43.3	2.32
	Bolls m^{-2}	10.1	13.0	20.4	19.9	12.3	12.3	22.9	29.8	50.7	10.2
2013	Yield, Mg lint ha^{-1}	1.74	1.78	1.14	1.68	1.36	1.29	1.60	1.41	1.29	0.273
	Lint %	43.7	45.4	44.4	45.6	44.7	44.3	43.9	45.3	45.2	0.58
	Bolls m^{-2}	88.1	89.2	53.3	81.1	80.5	67.2	86.3	68.1	65.5	13.1

[†] Armadillo, *Medicago polymorpha* 'Armadillo'; Bee Black, *M. lupulina* 'Bee Black'; Devine, *M. minima* 'Devine'; Rose, *Trifolium hirtum* 'Hykon'; Conv., winter fallow and plow-tilled; SEM, standard error of the mean.
[‡] 0, herbage mass left standing; 1, herbage mass cut and removed.

Table 3.3 Grain sorghum yield, heads per square meter, and 100 grain weight as affected by cover crop treatment and cutting regime during two growing seasons in Beeville, TX (2012-2013).

Year	Cover crop cultivar[†]	Armadillo		Bee Black		Devine		Rose		Conv.	SEM
	Cutting Regime[‡]	0	1	0	1	0	1	0	1	---	
2012	Yield, Mg ha^{-1}[§]	0.623	0.638	0.336	0.240	1.217	0.339	1.78	0.523	2.12	0.574
	Head m^{-2}	9.4	9.9	7.0	5.2	8.3	7.0	7.4	5.8	12.3	1.8
	100 grain wt, g	2.18	2.48	2.43	2.38	2.60	2.35	2.88	2.43	2.88	0.265
2013	Yield, Mg ha^{-1}	2.57	1.64	2.29	2.42	3.58	2.48	3.54	2.64	3.71	0.640
	Heads m^{-2}	8.3	9.4	9.6	9.0	14.1	10.1	11.7	9.6	11.2	1.3
	100 grain wt, g	3.44	3.53	3.62	3.61	3.57	3.44	3.72	3.47	3.57	0.114

[†] Armadillo, *Medicago polymorpha* ‘Armadillo’; Bee Black, *M. lupulina* ‘Bee Black’; Devine, *M. minima* ‘Devine’; Rose, *Trifolium hirtum* ‘Hykon’; Conv., winter fallow and plow-tilled; SEM, standard error of the mean.

[‡] 0, herbage mass left standing; 1, herbage mass cut and removed.

§ Grain yield normalized on a 12% H_2O basis; Head ct, sorghum head count reported on a 1000 heads ha^{-1} basis.

with Devine cut tended to have greater moisture than sorghum with Devine not cut.

At Depth 2, soil following cotton and Bee Black or Devine that was not cut had less (P = 0.05) depletion of NO_3-N than conventional tillage. Treatments did not have an effect (P > 0.13) on the change in soil P, K, Ca, Mg, S, or total N. There was a cover crop target crop interaction for SOC, whereby, soil following cotton and Rose that was cut had greater (P = 0.005) SOC than cotton and Armadillo that was not cut. Soil following sorghum had greater (P = 0.05) soil H_2O than cotton.

Soil at Depth 1 following sorghum and Armadillo which was not cut in Year 2 had greater (P = 0.05) depletion of NO_3-N than that of other treatments (Table 3.5). Soil P following Devine cut and removed was more depleted (P = 0.05) than conventional tillage. Soil Ca and Mg following cotton and Devine, regardless of cutting regime, was more depleted (P = 0.03) than conventional tillage. Soil K, S, Na, total N, SOC, and H_2O were not affected (P > 0.14) by any treatment or interaction.

At Depth 2, the interactions of cover crop with cutting regime and target crop only tended (P = 0.09) to affect the change in soil NO_3-N. Soil following sorghum and Devine, regardless of cutting regime, had less (P = 0.05) K depletion than conventional tillage. Soil P, Ca, Mg, S, Na, total N, SOC, and H_2O were not affected (P > 0.08) by any treatment or interaction.

Table 3.4 Changes in soil NO_3-N, P, K, Ca, Mg, S, Na, total N, soil organic carbon (SOC), and gravimetric water content at two depths, as affected by target crop and preceding cover crop treatment, during the first cropping year (2011-2012) in Beeville, Texas.

Depth (cm)	Target crop	Cotton									Sorghum									
	Cover crop †	Armadillo		Bee Black		Devine		Rose		Conv.	Armadillo		Bee Black		Devine		Rose		Conv.	SEM
	Cutting regime	0	1	0	1	0	1	0	1	-	0	1	0	1	0	1	0	1	-	
0-15	NO_3-N	-1b-e	-5e	-3c-e	0a-e	3a-c	2a-e	-1b-e	-4de	-3c-e	7a	4a-c	2a-e	2a-e	3a-d	6a	5ab	7a	4a-c	2.6
	P	-1a-d	-6f	0ab	-2a-e	-2a-e	1a	-1a-d	-3b-f	-4d-f	-1a-c	-4c-f	-5d-f	-5ef	-4c-f	-3a-f	-1a-d	-1a-d	-3c-f	1.3
	K	30	13	28	29	48	46	38	24	10	38	19	26	7	30	31	50	44	16	11.4
	Ca	481	809	528	777	998	711	539	625	350	673	524	373	185	639	557	668	780	474	150
	Mg	38c-f	37c-f	47b-e	63a-c	79ab	86a	49b-e	40c-f	25ef	59a-d	39c-f	27d-f	10f	48b-e	40c-f	54a-e	61a-d	24ef	12.2
	S	3	2	1	1	2	2	2	0	1	1	1	0	2	2	2	0	0	1	1.3
	Na	40	48	42	54	67	56	47	56	49	48	62	31	31	52	42	45	48	51	7.8
	Total N	-12	-62	8	211	-109	311	-23	70	-45	80	-67	-421	-51	228	-314	60	-97	-461	335
	SOC	-0.5	0.6	1.6	1.1	0.3	2.0	0.4	1.7	0.2	1.3	-0.6	-2.7	0.8	2.3	-2.4	0.4	1.6	-9.2	5.2
	% H_2O	1	1	2	1	2	3	1	1	1	1	2	3	2	0	1	2	2	2	0.9
15-30	NO_3-N	-7ef	-9f	-3a-e	-6c-f	-2a-e	-5b-f	-7ef	-6d-f	-9f	0a-c	0ab	-1a-d	-1a-d	-3a-e	-1a-d	1a	1a	-2a-e	2.0
	P	0	-1	-2	0	-1	-4	-2	0	-1	-1	-3	-1	-2	-2	-2	-1	0	-2	1.2
	K	37	28	25	28	38	39	42	36	40	24	25	21	9	33	40	37	43	49	10.7
	Ca	1023	1115	1128	877	1381	1404	1250	1304	1457	956	1099	690	470	1204	1407	1167	1432	1370	291
	Mg	48	36	36	51	52	43	61	54	54	42	53	19	9	39	54	56	67	56	16.3
	S	3	2	0	2	2	0	1	2	2	0	0	-1	0	1	0	2	1	2	1.1
	Na	65a-d	63a-d	49cd	82a	73a-c	54b-d	64a-d	74a-c	77ab	57a-d	74a-c	54b-d	45d	61a-d	54b-d	79ab	61a-d	65a-d	9.6
	Total N	81	170	190	165	130	171	181	381	120	281	319	238	60	-63	143	202	125	129	127
	SOC	-1.7d	0.6a-d	1.1a-c	0.6a-d	0.3b-d	0.9a-d	1.7a-c	2.9a	0.7a-d	2.3ab	2.6ab	0.5a-d	0.2b-d	-0.4cd	-0.5cd	1.4a-c	0.7a-d	1.2a-c	930
	% H_2O	3b-d	3b-d	3b-d	3b-d	3b-d	3b-d	3a-d	2cd	1d	2cd	4a-c	5ab	4a-c	6a	3b-d	3b-d	3a-d	4a-c	1.0

† Armadillo, *Medicago polymorpha* 'Armadillo'; Bee Black, *M. lupulina* 'Bee Black'; Devine, *M. minima* 'Devine'; Rose, *Trifolium hirtum* 'Hykon'; Conv., winter fallow and plow-tilled; SEM, standard error of the mean.

‡ 0, herbage mass left standing; 1, herbage mass cut and removed.

a-f Different letters are significant ($P < 0.05$) within the row.

Table 3.5 Changes in soil NO_3-N, P, K, Ca, Mg, S, Na, total N, soil organic carbon (SOC), and gravimetric water content at two depths, as affected by cover crop treatment and preceding target crop, during the second cropping year (2012-2013) in Beeville, Texas.

Depth (cm)	Row	Cotton									Sorghum									
	Winter	Armadillo		Bee Black		Devine		Rose		Conv.	Armadillo		Bee Black		Devine		Rose		Conv.	SEM
	Cuttings	0	1	0	1	0	1	0	1	-	0	1	0	1	0	1	0	1	-	
0-15	NO_3-N*	-12e-g	-6ab	-10a-g	-13g	-10b-g	-11d-g	-11c-g	-10a-g	-7a-e	-12fg	-6ab	-7a-d	-5a	-7a-c	-8a-f	-10a-g	-8a-g	-7ab	1.7
	P	-1a-c	3ab	-1a-c	0a-c	1a-c	-3c	0a-c	2a-c	4a	0a-c	-1a-c	2a-c	4a	3ab	1a-c	-2bc	-1a-c	1a-c	2.0
	K	18	43	44	35	6	1	6	54	67	37	27	46	51	47	31	4	22	41	16.0
	Ca	499a-d	302b-d	684a-c	288b-d	-168d	-60cd	316b-d	539a-d	1115a	333b-d	428a-d	527a-d	728ab	558a-c	501a-d	94b-d	-34b-d	417b-d	274
	Mg	29a-d	42a-d	40a-d	22a-d	-12cd	-13d	17a-d	54a-c	64a	26a-d	15a-d	43a-d	59ab	44a-d	46a-d	3b-d	-9cd	38a-d	23.5
	S	-1	-1	0	0	-1	0	0	2	1	1	0	0	1	-1	0	1	0	1	0.92
	Na	10	5	25	11	-16	2	12	6	28	11	-3	-7	5	10	16	1	-1	3	13.8
	Total N	-59	282	322	131	196	70	336	93	175	188	423	199	266	-77	294	101	161	482	210
	SOC	-1	1	2	1	1	1	2	0	1	2	4	2	1	-1	2	1	1	4	1.7
	% H_2O	-1	0	-1	-1	-1	-1	0	-1	0	-2	0	-1	-1	-1	0	-1	-1	-1	0.6
15-30	NO_3-N	-4	-3	-5	-4	-3	-7	-5	-5	-5	-5	-4	-2	-3	-2	-5	-3	-3	-5	1.2
	P	-1	0	0	-1	0	1	-1	-2	2	-1	0	-1	1	1	0	0	-1	-1	1.0
	K	20a-c	21ab	20ab	21ab	0bc	6a-c	1bc	-2bc	19a-c	13a-c	12a-c	27ab	34a	12a-c	5a-c	4a-c	1bc	-6c	10.6
	Ca	-57	-160	43	20	-694	-158	-442	-585	-464	-206	-501	229	175	-114	-585	-278	-375	-580	280
	Mg	-19	-10	-13	-17	-26	-8	-47	-27	3	-9	-27	-6	7	-2	-33	-26	-41	-33	14.1
	S	0	1	3	0	-1	0	1	1	0	0	1	1	1	0	2	1	0	0	0.9
	Na	-15a-c	-9a-c	-6ab	-23a-c	-30bc	0a	-27a-c	-26a-c	-24a-c	-12a-c	-27a-c	-22a-c	-9a-c	-1a	-16a-c	-33c	-18a-c	-23a-c	9.3
	Total N	-67	-113	-287	-246	-93	-265	-273	-83	31	-120	-57	-190	25	-71	-130	-118	-164	22	103
	SOC	-1	-2	-3	-2	-2	-2	-3	-1	0	-2	0	-2	0	-2	-1	-1	-2	0	1.2
	% H_2O	0	-1	0	0	-1	2	0	1	0	1	0	-2	-2	0	0	0	1	0	1.0

[†] Armadillo, *Medicago polymorpha* ‘Armadillo’; Bee Black, *M. lupulina* ‘Bee Black’; Devine, *M. minima* ‘Devine’; Rose, *Trifolium hirtum* ‘Hykon’; Conv., winter fallow and plow-tilled; SEM, standard error of the mean.

[‡] 0, herbage mass left standing; 1, herbage mass cut and removed.

[a-e] Different letters are significant ($P < 0.05$) within the row.

Experiment 2

Year 1 of Exp. 2 was an extreme drought, whereas, in Year 2 there was greater, yet still sporadic precipitation (Figure 3.3). During the cover crop growing season, 94 mm of precipitation occurred and 19 mm of irrigation was applied in Year 1, and 48 and 229 mm in Year 2, respectively. During the target crop growing season, 140 mm of precipitation occurred and 206 mm of irrigation was applied in Year 1, and 259 and 235 mm in Year 2, respectively. Temperatures were similar to the 30-year average throughout the experiment (NOAA, 2014; Texas A&M AgriLife, 2014; Figure 3.4).

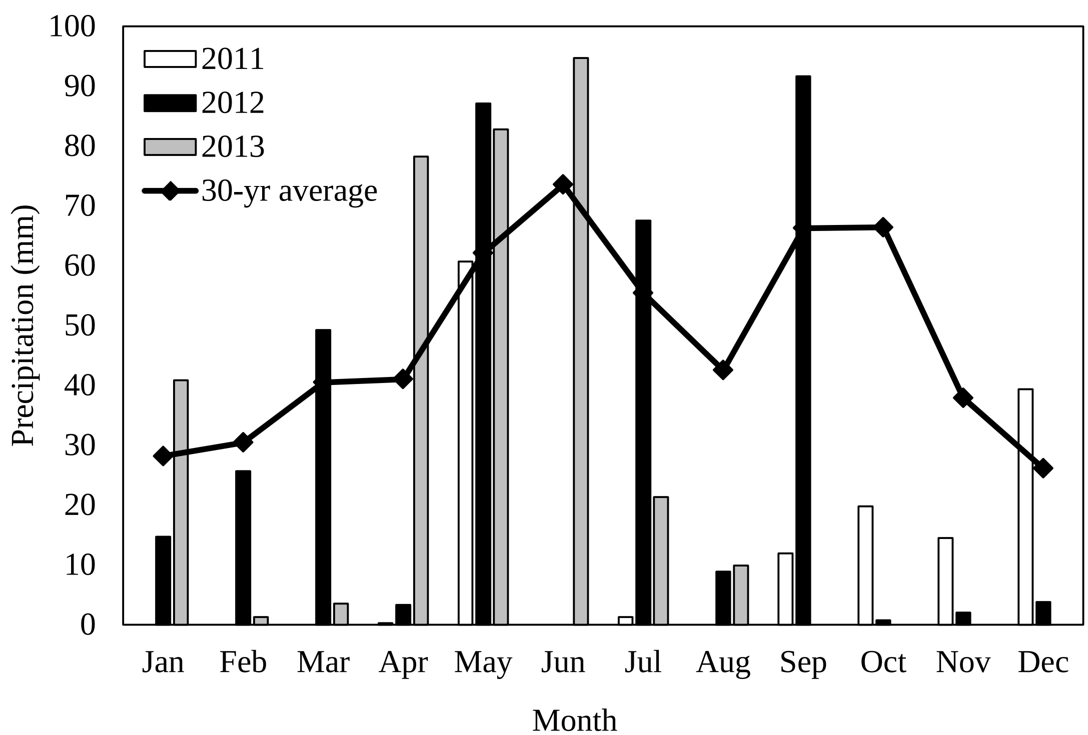

Figure 3.3 Average monthly precipitation during experimental years (2011-2013) compared to the 30-yr average in Uvalde, Texas.

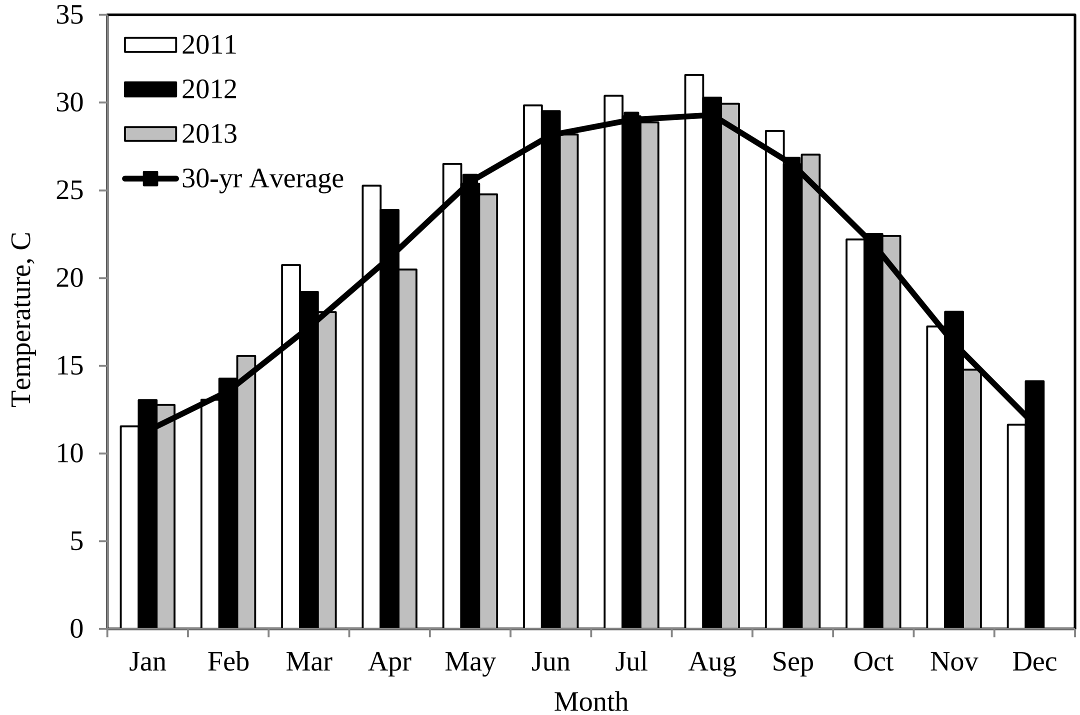

Figure 3.4 Average monthly temperatures from 2011-2013 and the 30-yr average in Uvalde, Texas.

Cover Crops

During Year 1 in Exp. 2, Armadillo tended (*P* > 0.11) to have greater herbage mass (1.73 Mg ha^{-1}) and nitrogen yield than the other cover crop cultivars (Table 3.6). There were no statistical differences (*P* > 0.19) for C:N or CP concentration of cover crops. Due to drought conditions, cover crops did not perform as well in Year 2 (average herbage mass of 0.158 Mg ha^{-1}), and Armadillo herbage mass was greater (1.02 Mg ha^{-1}, *P* = 0.003) than other cover crop cultivars.

Table 3.6 Herbage mass and chemical composition of cover crops grown in two growing seasons in Uvalde, TX (2012-2013).

Year	Cover crop cultivar [‡]	Herbage mass, Mg DM[†] ha^{-1}	C:N ratio	CP, % DM basis	Total N Yield, kg ha^{-1}
2012	Armadillo	1.02	13.1	19.0	31.0
	Bee Black	0.612	14.5	17.4	18.1
	Devine	0.813	14.9	16.9	22.8
	Rose	0.595	13.6	16.9	16.2
	SEM	0.136	0.72	0.87	4.35
2013	Armadillo	0.340 a	-	-	-
	Bee Black	0.168 b	-	-	-
	Devine	0.0538 b	-	-	-
	Rose	0.0702 b	-	-	-
	SEM	0.0467			

[†] DM, dry matter; C:N, carbon:nitrogen ratio; CP, crude protein; NDF, neutral detergent fiber.
[‡] Armadillo, *Medicago polymorpha* 'Armadillo'; Bee Black, *M. lupulina* 'Bee Black'; Devine, *M. minima* 'Devine'; Rose, *Trifolium hirtum* 'Hykon'; SEM, standard error of the mean.
[a-b] Different letters represent significant differences ($P < 0.05$) between treatments within years.

Target Crops

Cover crop cultivar did not affect ($P > 0.64$) cotton yields, lint percent, or bolls m^{-2} in Year 1 (Table 3.7). There were no interactions ($P > 0.37$) between cover crop cultivar and cutting regime in Year 2. Cover crop cultivar did not impact cotton yield in Year 2; however, cotton grown after cutting and removing forage tended ($P = 0.08$) to have increased cotton yield. Lint percentage of cotton was not affected by treatments, whereas, bolls m^{-2} tended ($P = 0.07$) to be greater when cover crops were cut and removed.

Corn grain yields averaged 6.41 Mg ha^{-1} in Year 1 and 13.3 Mg ha^{-1} in Year 2, and there were no differences in yield ($P > 0.22$) among treatments in either year (Table 3.8). No treatment effect occurred for ears m^{-2} or grain weight in the establishment year. In Year 2, Devine with herbage cut and removed or conventional tillage tended (P = 0.09) to result in greater corn grain weights than Armadillo or Bee Black with herbage cut and removed.

Soil

During Year 2, soil chemical composition and soil water were not impacted (P > 0.21) by treatments, except for a greater ($P = 0.03$) increase in soil S following corn than cotton at Depth 1 and a greater ($P = 0.05$) depletion of soil Mg following cotton and Armadillo at Depth 2 (Table 3.9). Soil at Depth 1 following cotton tended to result in a greater loss of soil Ca ($P = 0.10$) than soil following corn regardless of cover crop or cutting regime. At Depth 2, soil following cotton tended ($P = 0.08$) to result in greater accumulation of soil S than corn. Cover crop tended ($P = 0.10$) to increase SOC compared to conventional tillage.

Discussion

Drought conditions likely contributed to the outcome of this study, especially the establishment year. Although not significant, cotton and sorghum yields (Exp. 1) were numerically greater in conventional treatments than cover cropped/strip-till treatments in Year 1. Especially cotton, the conventional till treatment had about twice the yield. Kornecki et al. (2012) concluded that severe drought conditions preceding the establishment of cover crops resulted in lesser biomass production and cotton yield. In

Table 3.7 Cotton lint yield, lint percent, and bolls per square meter as affected by cover crop treatment and cutting regime during two growing seasons in Uvalde, TX (2012-2013).

Year	Cover crop cultivar †	Armadillo		Bee Black		Devine		Rose		Conv.	SEM
	Cutting regime ‡	0	1	0	1	0	1	0	1	---	
2012	Yield, Mg lint ha^{-1}	1.73	---	1.80	---	1.82	---	1.64	---	1.88	0.208
	Lint %	42.1	---	42.3	---	42.3	---	41.5	---	42.5	0.601
	Bolls m^{-2}	105	---	110	---	112	---	100	---	109	11.3
2013	Yield, Mg lint ha^{-1}	1.25	1.78	1.36	1.41	1.36	1.61	1.27	1.30	1.55	0.233
	Lint %	48.2	43.8	43.9	44.1	44.1	43.6	43.7	43.9	44.6	1.58
	Bolls m^{-2}	73.5	101	79.3	84.1	79.6	96.6	76.7	81.1	90.8	12.4

† Armadillo, *Medicago polymorpha* 'Armadillo'; Bee Black, *M. lupulina* 'Bee Black'; Devine, *M. minima* 'Devine'; Rose, *Trifolium hirtum* 'Hykon'; Conv., winter fallow and plow-tilled; SEM, standard error of the mean.
‡ 0, herbage mass left standing; 1, herbage mass cut and removed.

Table 3.8 Corn grain yield, ears per square meter, and 100 grain weight as affected by cover crop treatment and cutting regime during two growing seasons in Uvalde, TX (2012-2013).

Year	Cover crop cultivar †	Armadillo		Bee Black		Devine		Rose		Conv.	SEM
	Cutting Regime ‡	0	1	0	1	0	1	0	1	---	
2012	Yield, Mg ha^{-1}	7.16	---	6.84	---	5.53	---	5.00	---	7.51	0.886
	Ears m^{-2}	6.1	---	5.7	---	5.6	---	5.9	---	6.1	1.1
	100 grain wt, g	31.1	---	31.0	---	31.3	---	31.6	---	31.6	1.80
2013	Yield, Mg ha^{-1}	12.58	12.24	12.65	12.28	13.97	13.91	13.38	15.11	13.65	1.056
	Ears m^{-2}	7.8	7.6	7.8	8.3	8.7	8.5	8.3	9.6	7.6	0.67
	100 grain wt, g	39.1	38.0	39.0	37.5	38.9	40.3	39.0	38.6	40.2	0.70

†Armadillo, *Medicago polymorpha* 'Armadillo'; Bee Black, *M. lupulina* 'Bee Black'; Devine, *M. minima* 'Devine'; Rose, *Trifolium hirtum* 'Hykon'; Conv., winter fallow and plow-tilled; SEM, standard error of the mean.
‡ 0, herbage mass left standing; 1, herbage mass cut and removed.

Table 3.9 Changes in soil NO_3-N, P, K, Ca, Mg, S, Na, total N, soil organic carbon (SOC), and gravimetric water content at two depths, as affected by cover crop treatment and preceding target crop, during the second cropping year (2012-2013) in Uvalde, Texas.

Depth (cm)	Target Crop	Corn					Cotton					
	Cover Crop Cultivar †	Armadillo	Bee	Devine	Rose	Conv.	Armadillo	Bee	Devine	Rose	Conv.	SEM
0-15	NO_3-N	-18.0	-17.2	-13.9	-17.4	-16.9	-20.3	-18.7	-18.7	-15.3	-18.6	2.2
	P	-0.6	-1.3	0.7	-0.7	-1.5	-3.7	1.3	-1.0	0.4	-2.4	1.8
	K	-144	-113	-73.5	-72.7	-84.1	-132	-86.0	-110	-94.8	-136	36.8
	Ca	-1480	-1010	-1170	-451	-1070	-1270	-1620	-1190	-905	-2360	459
	Mg	-41.9	-25.3	-19.3	-16.9	-23.0	-34.2	-21.9	-31.8	-23.3	-50.7	12.3
	S	1.5	1.0	3.2	3.7	1.8	-0.6	2.5	-1.3	-0.2	-0.1	1.7
	Na	-7.0	-3.5	0.2	-1.8	-3.0	2.1	-5.0	-5.9	-2.1	-9.5	5.5
	Total N	86.4	73.1	-26.3	-5.6	-9.5	-31.8	88.2	4.9	-8.0	79.6	66.6
	SOC	0.9	0.8	2.1	1.4	1.4	0.4	1.5	0.9	1.0	2.7	0.78
	% H_2O	-4.4	-4.7	-4.6	-4.7	-3.9	-3.6	-3.9	-4.4	-2.5	-5.5	0.9
15-30	NO_3-N	-17.5	-13.2	-10.9	-12.5	-11.5	-19.4	-15.8	-14.3	-14.9	-13.4	3.3
	P	-2.6	-1.9	-0.9	-0.1	-1.1	-1.7	-3.7	0.7	-0.6	-0.4	1.2
	K	-105	-80.0	-72.3	-45.7	-69.9	-107	-109	-28.9	-71.2	-43.3	27.5
	Ca	-230	-744	-973	-953	-565	-1770	243	-733	-1180	-671	594
	Mg *	-15.8[b]	-26.8[a]	-29.2[a]	-18.0[ab]	-20.0[a]	-44.5[a]	-12.3[ab]	-2.9[ab]	-28.2[ab]	-11.0[ab]	10.0
	S	-0.5	-0.9	-2.3	-0.6	0.1	-1.1	1.7	0.3	-0.9	3.0	1.4
	Na	-5.2	-2.9	-9.6	-2.6	-4.4	-9.3	-2.2	-9.3	-5.1	-6.9	4.5
	Total N	-127.2	-21.0	12.2	44.7	-55.1	-44.4	-318.2	87.0	20.5	-14.9	101
	SOC	0.2	-0.4	0.9	1.7	0.7	0.9	-1.0	1.5	1.2	-0.1	0.9
	% H_2O	-8.4	-8.8	-8.0	-0.8	-8.4	-10.1	-9.6	-8.4	-8.1	-8.2	2.3

† Armadillo, *Medicago polymorpha* 'Armadillo'; Bee Black, *M. lupulina* 'Bee Black'; Devine, *M. minima* 'Devine'; Rose, *Trifolium hirtum* 'Hykon'; Conv., winter fallow and plow-tilled; SEM, standard error of the mean.

*Different letters are significant ($P < 0.05$) within the row.

the first rotation of target crops, available soil moisture was likely depleted by the previous cover crop treatments, providing an initial advantage to the conventional control (Kornecki et al., 2012). This effect would be reduced in long term applications to established systems, although the limited moisture budget may not consistently allow for this type of "double cropping" in semi-arid environments (Unger and Vigil, 1998). In Year 2, target crop performance was much more comparable across treatments.

It is also probable that the cover crops utilized available NO^3-N as mineralization occurred, as indicated by the negative trend across all treatments in Year 2 (Tables 3.5 and 3.9). Reeves et al. (1997) reported greater soil N levels in fertilized systems than legume cover cropped systems at the end of the establishment year, but greater soil N with leguminous residue than fertilized systems in the second year, resulting in greater corn yields. Additional years of cover cropping and time for further mineralization of leguminous residue to occur may be necessary before positive changes in soil NO_3-N are observed.

Cotton treatments resulted in greater decreases in soil NO_3- N than sorghum. Past research indicates that cotton following winter legume cover crops had reduced N requirements but still required N fertilization (Brown et al., 1985), whereas cool season legumes have been shown to account for all N required by sorghum for optimum yield (McVay et al., 1989). Due to these differing nutritive requirements of target crops, sorghum may be a more suitable candidate for integration into legume cover cropped systems.

Cover crop treatments in Exp. 1 did not show consistent contributions to the changes in soil, and in Exp. 2, the change in soil nutrients in response to the cover cropping event was generally negative. Cover crop treatments that were not cut and removed generally resulted in greater remaining soil P. Other research indicates that P concentration in burr medic tissue generally decreases with increasing crop maturity (Bolland and Paynter, 1994). Considering that the cutting and removal of cover crops occurred prior to full maturity, substantial P may have been removed from the system in these treatments. Israel (1987) reports that critical soil P levels are required for legume N fixation. This could also explain why soil P levels generally decreased following cover crop treatments.

The slight negative changes in soil K following cover crops in Exp. 2 also indicate a considerable K requirement. McNaught (1958) identifies a significant legume response to potassium in potassium deficient soils. Due to the crop's demand and rapid decomposition of residue, greater accumulation of residue may be necessary before greater improvements in SOC can be observed (Wilhelm et al., 2007).

Conclusion

Cost and benefit must be carefully weighed, considering all limitations, as integration of these systems is further investigated. Feasibility, potential benefit, and cover crops used will have to be determined on a specific, case-by-case basis in semi-arid regions. Considering nutritive requirements of legume physiological development and N fixation, fertilization of other nutrients (P and K) may have a large benefit on the whole system. Cover crop species must be effective cyclers of nutrients to justify necessary fertilizer applications. Low phosphorus tolerant, drought tolerant, fast maturing, warm-season legumes might serve as a beneficial cover crop to immediately follow row crop harvest. This would allow for a greater recovery period before the next target crop planting, and possibly maintain sustainable benefits.

Strip-till applications hold potential to be more readily adopted, with or without a cover cropping component. The fundamental benefits of conservation tillage are not as sensitive to delicate environmental factors and system details as cover cropping might become in semi-arid environments. There is potential for expanding upon these benefits and refining techniques in region-specific studies.

CHAPTER IV

CONCLUSIONS

The results of this study indicate that integrating cover cropping into strip-till systems can become a viable option in semi-arid environments with careful consideration and further refinement of system structure and components. This research has primarily identified that, with proper management under specific, particularly limited irrigated conditions, established cover cropping systems are not detrimental to target crop yield in semi-arid environments. In the event that expected long term benefits to soil structure, nutritive status, and water balance occur, increases in yield will be more likely. Ultimately, increased target crop yield, or added value through cover crop harvest/utilization will be critical to the adoption of these systems. Otherwise, cover cropping systems are less likely to achieve economic feasibility, considering associated additional costs of cover crop seed, planting, and management.

Feasibility of adoption and large-scale integration will have to be determined on a specific, case-by-case basis in semi-arid regions. Considering nutritive requirements of legume physiological development and N fixation, other nutrients will be essential to the success of the system, and important to consider in the design of an appropriate fertility regime. Cover crop species used must be effective cyclers of nutrients in order to justify such fertilizer applications.

In retrospect, provided that adequate resources were available, this experiment may have been complimented by the addition of a strip-till, winter fallow treatment. This would have served as a valuable intermediate option independent of the potential negative aspects of cover cropping, while maintaining benefits of strip-tillage, such as reduced evaporative loss and lower vulnerability to erosion. The fundamental benefits of conservation tillage are not as sensitive to delicate environmental factors and system details as cover cropping might become in semi-arid environments. The associated improvements in erosion control provide ample justification, as soil conservation is fundamental to the longevity of all agronomic systems.

The course of this research has also provided for valuable growth in personal understanding of the methodology of agronomic research. The mechanisms of trial and error were made apparent, along with the importance of forming and executing realistic plans for data collection and experiment complexity. Rather than providing simple answers to the questions at hand, this research further exposed the multifaceted nature of the situation at hand, bringing to light important details to consider in future development of sustainable systems.

Considering the extensive warm season in South Texas, the possibility of following target crops with a warm season cover crop has been recognized. According to 30-year averages, the greatest precipitation in the Northern Rio Grande Plain typically occurs in September, after most conventional row crops have been harvested, whereas the period from November through March represents the least precipitation. Therefore, low phosphorus tolerant, drought tolerant, fast maturing, warm-season legumes such as cowpea (*Vigna unguiculata*) might serve as a beneficial cover crop to immediately follow row crop harvest. This would enable utilization of more likely rainfall, allow for a greater recovery period before the next target crop planting, and possibly maintain sustainable benefits.

Future research designs may compare the treatment constituents of this experiment with systems of similar design yet with the integration of other components. For example, non-leguminous cover crops such as ryegrass (*Lolium* spp.) are commonly used in other regions, and may contribute significant surface residue with a less nutritive demand than legumes. Another option to investigate is the incorporation of the cover crop as a green manure. Recommendations would be to include intermediate combinations of applied treatments. Examples might include all combinations of cool season treatments (leguminous cover cropping, non-leguminous cover cropping, winter fallow) and tillage treatments (plow-till, strip-till, no-till). As research continues in the areas of conservation tillage and cover cropping in semi-arid environments it is important to recognize and consider all limitations and variability within a given region or cropping system.

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APPENDIX A

SAS CODES USED FOR CHAPTER III

SAS codes used to analyze cover crop herbage mass, CP, C:N Ratio, and N yield for experiments 1 and 2 in years 1 and 2:

```
Data LocationCoverYear;
Input Year$ Cover$ Cut Block Plot Bag Yield CP CNR NYield;
Datalines;

Proc Glimmix Data = LocationCoverYear;
Class Cover Block;
Model Yield CP CNR NYield= Cover;
Random Block Block*Cover/;
LSMeans Cover/Diff Lines;
Run;
```

SAS codes used to analyze cotton lint yield, bolls ha^{-1}, and lint percentage in experiments 1 and 2 in years 1 and 2:

```
Data LocationCottonYear;
Input Year$ Cover$ Cuts Block Bolls LintPercent Yield;
Datalines;

Proc Glimmix Data = LocationCottonYear;
Class Cover Cuts Block;
Model Yield LintPercent Bolls = Cover Cuts Cover*Cuts;
Random Block Block*Cover/;
LSMeans Cover*Cuts/Diff Lines;
Run;
```

SAS codes used to analyze sorghum (Exp 1) and corn (Exp 2) yield, heads or ears ha^{-1}, and one hundred grain weight in years 1 and 2:

```
Data LocationCropYear;
Input Year$ Cover$ Cuts Yield HeadsPerHa HundredGrain;
Datalines;
Proc Glimmix Data = LocationCropYear;
Class Cover Cuts Block;
Model Yield HeadsPerHa HundredGrain = Cover Cuts Cover*Cuts;
Random Block Block*Cover/;
LSMeans Cover*Cuts/Diff Lines;
Run;
```

SAS codes used to analyze changes in soil NO_3-N, P, K, Ca, Mg, S, Na, total N, SOC, and % H_2O (gravimetric) in experiments 1 and 2 in years 1 and 2:

```
Data LocationSoilChange;
        Input Depth$ Block Cuts Cover$ TargetCrop$ NO3N P K Ca Mg Sulfur Na TN
SOC H2O;
        Datalines;

Data LocationSoilChangeTop;
Set LocationSoilChange;
If (Depth eq 'Top');
Run;

Proc Glimmix Data = LocationSoilChangeTop;
Class Cover TargetCrop Cuts Block;
Model NO3N P K Ca Mg Sulfur Na TN SOC H2O = Cover|Cuts|TargetCrop;
Random Block Block*Cover/;
Lsmeans Cover*Cuts*TargetCrop/diff lines;
Run;

Data LocationSoilChangeBottom;
Set LocationSoilChange;
If (Depth eq 'Bottom');
Run;

Proc Glimmix Data = LocationSoilChangeBottom;
Class Cover TargetCrop Cuts Block;
Model NO3N P K Ca Mg Sulfur Na TN SOC H2O = Cover|Cuts|TargetCrop;
Random Block Block*Cover/;
Lsmeans Cover*Cuts*TargetCrop/diff lines;
Run;
```