COMPARISON OF TWO TILLAGE PRACTICES ON A SEMI-ARID ROTATIONAL CROPPING SYSTEM

A Thesis

by

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ABSTRACT

Conventional tillage (CT) increases the exposure of soil to erosion and is associated with lower soil moisture and organic matter than conservation tillage. Conservation tillage may benefit farmers in semi-arid regions of south Texas due to limited rainfall and lower input costs of no-till (NT) systems. The objective of this long-term study was to evaluate the effects of NT in a dryland cotton-sorghum cropping rotation system on soil moisture, bulk density, penetration resistance, C:N, N, P, K, and crop yields. This randomized block design experiment was established on a Victoria soil in Corpus Christi, TX, and has four replicates of cotton (*Gossypium hirsutum* 'DPL 1044') and sorghum (*Sorghum bicolor* 'DKS 53-67') rotated under NT or CT. Soil samples were taken with a 30-cm push probe with depth increments of 0 to15 cm and 15 to 30 cm. Soil moisture, pH, EC_w, NO_3-N, P, K, Ca, Mg, S, Na, total N, SOC, and penetration resistance were measured before planting and after crop harvest beginning in 2014 after four years of tillage treatment. Cotton yield was not different between treatments, except for the drought year of 2013 when 88% greater cotton yield occurred with NT than CT. Sorghum did not produce grain in 2013 regardless of treatment, and yields were only effected by treatment in 2012 when yield was 33% greater in NT than CT. Sorghum had 69% residue coverage, which was 12% greater than the cotton residue coverage. The average crop residue coverage for both crops was 58% greater with NT than CT. Soil moisture and bulk density was not impacted by treatment; however, bulk density was 6% greater at 15-30 cm than 0-15 cm for CT. Soil pH, EC_w, NO_3-N, P, K, Ca, Mg, S, Na was not effected by NT; however, NT had greater total soil N content than CT in the 0 to 15 cm depth and lower in the 15 to 30 cm depth and SOC was greater in the 0 to 15 cm depth in 2014 with NT than CT, but lower in the 15 to 30 cm depth. No-till had a lower surface penetrometer resistance than CT in year five. No-till is an economically viable alternative to CT in this region because of risk mitigation in drought years.

DEDICATION

For Casey Scarborough.

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NOMENCLATURE

a.i.	Active ingredient
a.e.	Acid equivalent
CT	Conventional tillage
EC	Electrical conductivity
GSM	Gravimetric soil moisture
GWC	Gravimetric water content
HSD	Honest significant difference
mph	Mile per hour
NASS	National Agriculture Statistics Service
NOAA	National Oceanic and Atmosphere Administration
NRCS	Natural Resource Conservation Service
NT	No-till
SAS	Statistical Analysis Software
SEM	Standard error mean
SOC	Soil organic carbon
SOM	Soil organic matter
USDA	United States Department of Agriculture

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CHAPTER I

INTRODUCTION

Conventional tillage (CT) is the predominant tillage practice across Texas (USDA-ERS, 2012); however, the long-term sustainability of this practice in arid to semi-arid environments with Vertisol soils had not been adequately researched. The number one limiting factor in crop production in semi-arid regions is water, and the ability of soil to maximize capture and efficiently utilize the water is critical. It has been documented from previous studies that depending on the soil type, cultivation may increase water infiltration in the short-term, but it is rarely sustainable for a long period of time (Azooz et al., 1996). In land areas where soil has a high clay percentage (38.5%), water infiltration is often decreased due to the surface of the soil crusting upon water contact (Brady and Weil, 1996). This crusting effect occurs because water carries loose soil particulates from cultivation into soil pores which block the soil pore. This blockage creates surface crust and increases water run-off from the field. Due to this process, soil erosion occurs and the nutrient rich top soil is lost with water (Pimentel et al., 1995). The inability of a cropping system to utilize precipitation sufficiently often proves detrimental to crop yields and subsequently the farmer's income (Nielsen et al., 2005).

Along with the potential environmental impacts, farmers also have to consider input costs which are associated with full tillage practices. Research has indicated that an average CT farm may require six or more tillage passes each year (West and Marland et al., 2002). The increase in fuel and energy costs can be detrimental to a farmer in years of drought when low yield returns may exceed the profit (Varner et al., 2011; Klose et al., 2013).

Conservation tillage practices have been integrated into farming operations across the United States because of their benefits (USDA-ERS, 2012). These benefits include an increase in infiltration rates, soil water holding capacity, residue coverage, soil nutrients, and a decrease in soil erosion and input costs (Unger, 1990; Triplett et al., 2008). Conservation tillage is defined as a reduced tillage system which leaves at least 30 percent of the crop residue on the soil surface post crop harvest (USDA-NRCS, 1996). No-till (NT) farming is included in this definition, and NT crops are grown and harvested without prior tillage of the soil. No-till has been implemented in approximately 35 percent of row crop farming operations in the United States, but only 9 percent in Texas, with an even lesser percentage in the semi-arid climates of Texas (USDA-NASS, 2012). Implementation of this practice is slow in Texas partly because farmers believe that annual precipitation amounts are unpredictable and cannot support a tillage system other than CT; however, research has shown that NT conserves moisture and can economically benefit farmers (Morrison et al., 1990; Varner et al., 2011).

Rotating crops on an annual basis has been a production practice used by farmers for decades and has been studied extensively. Crop rotations provide several benefits to the soil and the grower. Introducing different plant root systems annually has shown to decrease soil compaction and increase soil porosity (Lal, et al., 1994). It has also been successful as a weed and pest reduction practice (Reeves, et al., 1994).

There is limited published research on the feasibility of integrating NT into dryland cropping rotation systems in the semi-arid region of south Texas. A transition into this crop production practice from CT has the potential to secure natural resources for future generations and increase financial profitability to the farmer.

The objective of this experiment was to compare NT and CT in a cotton-sorghum rotational cropping system in the semi-arid region of south Texas and determine if integrating NT would benefit soil conditions and crop yields.

The hypotheses of this experiment were:

- Hypothesis 1. Minimum soil disturbance in combination with increased crop residue coverage on soil surface would aid in capturing and retaining precipitation while improving the composition of the soil.
- Hypothesis 2. No-till would produce greater crop yields compared to CT during drought conditions due to the increased soil water and improved soil conditions.

CHAPTER II

LITERATURE REVIEW

2.1 Concerns of Conventional Tillage and Soil Security

With the growing demand for crop production, in combination with intensive tillage practices, concerns for soil security are rising in the agriculture community. McBratney et al. (2013) defined soil security as the preservation and improvement of soil resources that will enable the food and fiber industry to continue providing food, water, and energy to the world. Conventional tillage has been the dominant tillage practice in the United States and much of the world, but concerns have arisen on the long-term sustainability of this farming practice. Research has shown that continuous cultivation of soils has a detrimental effect on soil structure and has resulted in soil degradation (Dam et al., 2004). Soil degradation is of particular concern to farmers in south Texas, where the environment is often quite extreme with limited precipitation (average annual precipitation of 737 mm), high temperatures (22°C average), and winds consistently greater than 13 mph (NOAA, 2014).

A key component to soil security is strengthening the soil physical structure through stabilization of soil aggregates. Soil aggregates are formed when particulates of soil adhere more strongly to some soil particles than others (USDA-NRCS, 1996). Formation of aggregates leaves pore spaces between the aggregates and allows for water infiltration and permeability and movement of oxygen within the soil. Aggregate stability can be defined as the ability of aggregates to remain whole and resist to disruption from environmental conditions such as water and wind or from human mechanical traffic (USDA-NRCS, 1996). Conventional tillage systems weaken soil physical structure through continuous cultivation, compaction of the soil by mechanical equipment, and leaving the soil bare and fallow-between growing seasons. Sainju et al. (2009) found that tilled and fallow fields reduce soil aggregation by exposing the soil to water and wind erosion. This erosion resulted in reduced quantities of soil organic matter (SOM; Sainju et al., 2009).

Soil organic matter has many effects on soil security and one of these is contribution to maintaining soil stability against erosive forces. Soil organic matter acts as a binding agent for soil particles and assists in creating and maintaining soil aggregates (Oades et al., 1984). Research has proven that CT depletes soil of organic matter and therefore, destroys aggregate stability. No-till is an alternative farming practice which facilitates accumulation of organic matter and stable aggregate formation. There have been several long-term studies conducted in the past century on the differences between NT and CT and their effects on soil structure. In the majority of these studies, NT resulted in increased soil organic matter, aggregate stability, porosity, and soil water content (Derpsch et al., 2010). These positive attributes are the result of reduced cultivation, less mechanical traffic, and the presence of crop residues left on the soil surface after crop harvest. After 13 years in a sandy clay loam soil in Athens, Georgia, soil organic matter increased 18 percent in the top 15 cm of soil under NT management in a grain sorghum and winter rye double crop system (Beare et al., 1994).

Aggregate stability has a direct relationship with soil compaction. Soil compaction is prevalent in high intensity tillage systems because of heavy machinery traffic (Hamza et al., 2005). As a result of this compaction, the pore spaces within the soil collapse, resulting in decreased infiltration and air movement. Soil compaction can be determined by measuring the bulk density or penetration resistance of the soil. The relationship between aggregate stability and bulk density is that as bulk density increases, aggregate stability decreases (Blanco-Canqui and Lal, 2009).

2.2 Tillage Systems and the Conservation of Water in Heavy Clay Soils

One of the greatest challenges faced in dryland crop production is availability and utilization of precipitation. Aside from limited precipitation, Vertisols (soils with greater than 30% clay in the solum) present a challenge in water availability. Vertisols are characterized by smectite clay minerals that expand and shrink upon wetting and drying (Wilding and Puentes, 1988). When the soils are dry, large cracks form. Upon rainfall, water rapidly enters the soil through the cracks, but after the soil is wet, the cracks close and water infiltration decreases rapidly, resulting in increased surface runoff, erosion, and evaporation (Potter and Chishester, 1993). No-till cropping reduces the consequences of the shrink and swell characteristics of Vertisols by leaving crop residue on the soil surface to increase water infiltration and retention and protect the soil from erosion (Unger, 1990). Multiple research studies on crop residue and water infiltration relationships have been conducted throughout the past several decades. It is documented in the majority of the studies that infiltration is decreased under CT when compared to NT, due to the residue removal under conventional practices (Blanco-Canqui and Lal, 2009). A study by Morrison et al. (1990) found that crop-residue with NT management increased water infiltration in a Vertisol soil by reducing runoff and erosion. This research demonstrates that NT can be successful in heavy clay soils; however, it has had limited implementation in the semi-arid regions of south Texas where many Vertisols are farmed.

2.3 Tillage Systems and Soil Nutrients

Maintaining adequate amounts of soil nutrients for crop production is essential in any form of tillage management system. However, intensive cultivation systems require a greater amount of nutrients than what is removed by the crop each year, due to nutrient leaching and top soil erosion. The greatest concentration of soil organic matter is found in the top soil. Soil organic matter is nutritionally rich and these nutrients are critical for crop establishment and growth. It is documented that eroded soil contains approximately three times the amount of nutrients than the remaining soil (Pimentel et al., 1995). This nutrient loss by erosion can decrease crop productivity and has many adverse effects on the environment.

2.4 The Feasibility of Integrating No-till

It can be concluded from research that integrating NT into cropping systems can benefit many regions of the world. There is an increasing demand throughout the United States for agronomic tillage practices that will produce equivalent crop yields and conserve the natural resources of the land (MacDonald et al., 2013). When compared with an intensive tillage practice, NT improves soil physical and chemical composition and crop yields, while conserving soil moisture. Due to the practicality and successes of integrating NT (Huggins and Reganold, 2008), the investigation of such a practice has been prompted in the semi-arid environments of Texas to determine if the results are comparable to other findings and if this conservation practice is attainable for farmers in these regions.

CHAPTER III

MATERIALS AND METHODS

3.1 Experimental Site

This tillage experiment was initiated in 2010 at the Texas A&M AgriLife Research and Extension Center in Corpus Christi in the Gulf Coast Prairie of Texas (27°46’ N, 97°34’ W; Figure 3.1). The Gulf Coast Prairie of south Texas represents a semi-arid region with a mean annual precipitation of 737 mm and an annual mean air temperature of 22 °C. Precipitation and temperature data was collected from National Oceanic and Atmosphere Administration (NOAA).

The soil of this site was classified as a Victoria series (fine smectitic hyperthermic Sodic Haplusterts), using Web Soil Survey of the USDA-NRCS. The surface soil characteristics were 45% sand, 17% silt, and 38% clay with 38.5 mg kg^{-1} NO_3-N, 33 mg kg^{-1} P, 380 mg kg^{-1} K, and pH of 8.0 at the initiation of the experiment. This soil was developed from a clayey deltaic and marine sediment and is characterized as being well drained with a very slow permeability. The fine smectitic prefix describes clay minerals that have the ability to expand and contract as it adsorbs water or dries out. This soil has a mean annual soil temperature of 22°C or greater than other soil series and exchangeable sodium percentage of 15 or more within 100 cm of the mineral surface (USDA-NRCS, 2010).

Figure 3.1 Location of the experiment at the Texas A&M AgriLife Research and Extension Center in Corpus Christi, Texas.

3.2 Crop and Tillage Treatments

Two tillage methods and two crop species were chosen for the experiment, with a randomized block design and four replicate plots (30 × 100 m; Figure 3.2). Tillage was the same for each plot in each year; however, the cotton (*Gossypium hirsutum* ‘DPL 1044’) and grain sorghum (*Sorghum bicolor* ‘DKS 53-67’) were rotated each year. The two tillage methods were NT and CT. No-till plots were only disturbed at crop planting and harvesting or when chemical application was necessary for weed or insect control. Conventional tillage plots were cultivated before planting, after planting between crop rows, after harvest in late fall, and rows bedded during winter. Soil cultivation depth was 7 cm, plowing was 22 cm, and bedding height was 15 cm. Cotton and grain sorghum were planted on 91 cm centers (16 rows per plot) and were rotated on a yearly basis. Planting dates were highly dependent on precipitation for the year, but cotton and sorghum were generally seeded in April and March, respectively. Seeding rates for both the crops followed the recommended rates for the area, at 22,200 seeds ha^{-1}.The crop harvest was based on the maturity of cotton and sorghum; however, the harvest period for both crops ranged from July to August, respectively.

NT	CT	NT	CT	NT	CT	NT	CT
NT	CT	NT	CT	NT	CT	NT	CT

Figure 3.2 Experimental design of a conventional tillage (CT) and no-tillage (NT) experiment in Corpus Christi, Texas, with four replicate plots (16 rows on 91 cm centers × 100 m) of each treatment.

3.2.1 Crop Management

Land preparation began following the prior year harvest. Conventional grain sorghum was disked (John Deere 210, Moline, IL) in the fall after harvest and then sweep-plowed (John Deere custom model, 20 in. sweeps, Moline, IL) in early winter. The NT grain sorghum was sprayed with glyphosate (Roundup WeatherMax, Monsanto) at 2.2 kg a.e. ha^{-1} up to two times during the fall. Cotton CT plots were plowed and then sweep plowed similarly to sorghum CT plots. To kill remaining cotton stalks and seedlings, application of 2,4-dichlorophenoxy butyric acid (Butyrac 200, Albaugh LLC) was made in 2013 and 2014 at 2.2 kg a.i ha^{-1} or 2,4-dichlorophenoxyacetic (2-4, D Amine, Albaugh LLC) was applied in 2015 at 2.2 kg a.i. ha^{-1}. In December of each year, CT plots were bedded (John Deere, 986, Moline, IL), to a height of 15 cm. In January, CT plot rows were run with a row sweep and bed topper (John Deere, 986, Moline, IL) to reshape the bedded rows. To prepare the NT plots for planting, glyphosate at 2.2 kg a.e. ha^{-1} was applied in January of each year. In February of 2014, all plots were fertilized by broadcast with 43 kg ha^{-1} N and 59 kg ha^{-1} of P_2O_5 according to soil report recommendations. In April of 2015, cotton plots were fertilized by broadcast with 56 kg ha^{-1} N and 34 kg ha^{-1} P_2O_5, and sorghum plots were fertilized with 45 kg ha^{-1} N and 38 kg ha^{-1} P_2O_5 according to the most recent soil report recommendations.

Cotton was planted April 1, 2014, and April 9, 2015, with a 7300 Max Emerge 2 planter (John Deere, Moline, IL). Weeds were controlled in NT cotton plots with glyphosate at 2.2 kg a.e. ha^{-1} and additionally with a sweep cultivator Lilliston Rolling Cultivator, Bigham, Lubbock, TX) in the CT plots. Cotton fleahoppers

(*Pseudatomoscelis seriatus*) were problematic in 2015 and thiamethoxam (Centric 40WG, Syngenta Crop Protection LLC) at 0.08 kg a.i. ha^{-1} was applied in early-June and imidacloprid (Quali-Pro) at 0.14 kg a.i. ha^{-1} in mid-June. On July 29, 2014, cotton plots were defoliated with thidiazuran (Ginstar, Bayer Crop Science) at 0.21 kg a.i. ha^{-1} + ethephon phosphonic acid (Ethephon 6, RealEagle International) at 0.56 kg a.i ha^{-1}. On June 27, 2015, mepiquat chloride (Mepiquat Chloride 4.2%, Makhteshim Agan of North America Inc.) at 0.14 kg a.i. ha^{-1} was applied on NT and CT cotton plots. Thidiazuron defoliant (Ginstar, Bayer Crop Science) at 0.04 kg a.i. ha^{-1} was sprayed on cotton plots on August 13, 2015.

Grain sorghum was planted on March 19, 2014, and April 9, 2015, with the same planter. In 2015, preemergent herbicide S-metolachlor (Dual II Magnum, Syngenta Crop Protection) at 1.5 kg a.i. ha^{-1} was applied after planting to both CT and NT sorghum. Weeds present at planting of NT sorghum in 2015 were treated with glyphosate at 2.2 kg a.e. ha^{-1}.

In April and May of 2014, the cultivator was used to control weeds in the CT Sorghum plots. Weeds between rows in NT sorghum were sprayed with glyphosate at 2.2 kg a.e. ha^{-1} in May 7, 2014, with a hooded sprayer (Red Ball, Conservation Hooded Sprayer, Willmar, MN) between rows. All sorghum plots were treated with glyphosate at 1.5 kg a.e. ha^{-1} using the hooded sprayer on May 28, 2014. In June 2014, sugarcane aphid (*Melanaphis sacchari*) was controlled with application of sulfoxaflor (Transform WG, Dow AgroSciences) at 0.09 kg a.i. ha^{-1} and was applied with a spray coupe (Melroe 230 Spray Coupe, Bismark, ND).

3.2.2 Crop Sampling and Processing

Cotton boll samples were collected by hand at maturity on August 11, 2014, and August 18, 2015, at row length of 4.2 m from four center rows and the samples were weighed. The number of bolls per plant were a representation of three random plants with the given area. These samples were processed with an Eagle Cotton Gin (Continental Gin Co., Birmingham AL) to determine the cotton lint yield.

Sorghum grain samples were collected by hand at row length of 4.2 m from four center rows on July 14, 2014, and July 30, 2015, and threshed (Almaco Plant and Head Thresher, Allan Machine Company, Ames, IA). The numbers of panicles were counted. Samples were dried at 135°C for 2 hr before grain yield calculated on a dry matter basis.

Crop residue percentage was measured by line transect method with a 30-m tape placed across the middle rows at a 45° angle (Laflen et al., 1981). Presence or absence of residue at each 0.3 m mark was determined and crop residue coverage calculated.

3.3 Soil Physical Analysis

Soil moisture content was evaluated by using gravimetric and volumetric water analysis methods. Gravimetric water content was determined from a composite sample of six soil cores that were collected with a 30 cm push probe (2.2-cm diameter). Each soil core was divided into two depths with increments of 0 to 15 and 16 to 30 cm. Composite samples were collected prior to crop planting on Feb. 14, 2014, and shortly after on May 1, 2015. Sample collection after crop harvest occurred on Oct. 28, 2014, and Oct. 16, 2015. Soil volumetric water content and soil porosity was calculated from soil bulk density samples that were collected from each individual plot. Bulk density samples were taken with a 30-cm split core sampler (5 cm diameter; AMS Inc. American Falls, ID). Surface penetrometer resistance was measured with a 6.8 kg dynamic cone penetrometer (Humboldt, Elgin, IL) on the same dates as the gravimetric water samples were collected. The instrument was tipped with a 45° vertex angle cone with a base diameter of 3.8 cm and the resistance was determined at three random locations within each plot.

3.4 Soil Chemical Analysis

Nutrient concentration, pH and electrical conductivity of soil solution (EC_w) were measured from soil samples taken prior to planting and after crop harvest. Macro- and micronutrients, pH, and EC_w were analyzed at the Soil, Water and Forage Testing Laboratory in College Station, TX. Nitrate-nitrogen (NO_3-N) was analyzed using the cadmium reduction (Cd) method (Keeney and Nelson, 1982; Kachurina et al, 2000). Phosphorus, K, Ca, Mg, Na, and S were evaluated using the Mehlich III extraction method and determined by inductively coupled plasma (ICP) (Mehlich, 1978; Mehlich, 1984). Soil water pH was determined by using a 1:2 soil:water extraction with deionized water (DI, H_2O) and evaluated by a hydrogen selective electrode (Schofield and Taylor, 1955). Electrical conductivity was determined by using a 1:2 soil:water extraction with DI H_2O and assessed with a conductivity (Rhoades, 1982). Total C and N content were determined by dry combustion with a carbon analyzer (McGeehan and Naylor, 1988; Elementar, Mt Laurel, NJ, USA). Inorganic carbon was determined by using the modified pressure-calcimeter method (Sherrod et al., 2002). Soil organic carbon was calculated from the difference between total and inorganic carbon.

3.5 Statistical Analysis

Statistical analyses were conducted with JMP® Pro 12 statistical software (SAS Institute Inc., 2012). Significance between treatments, depths, and years, was determined at the 0.05 (Table 3.1), except for volumetric water content, bulk density, and surface penetration resistance for which significance was determined at the 0.10 probability level. Student's t-test was used to compare means and determine the least squares means.

Table 3.1 Example of an analysis of variance table that is used to determine significant difference.

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	20237344	2248.594	51.8835
Error	30	1300179	43.339	Prob > F
Corrected total	39	21537523		< 0.0001*

*Significant difference at the 0.05 probability level.

CHAPTER IV

RESULTS

4.1 Climatic Conditions of Experimental Site

This tillage experiment began in 2011, but soil moisture and quality measurements, except for yield, did not begin until 2014. Precipitation through the experiment period was variable, though the most severe drought in Texas history occurred during 2012-13 (Figure 4.1). The site only received 360 mm of precipitation the first year of crop harvest (2011). The drought continued the following three years (2012-2014), but precipitation amounts increased with each consecutive year (480, 580, and 690 mm, respectively). In 2015, precipitation increased to 1150 mm, which was greatly above the 30-yr average. The monthly average temperature did not differ from the 30-yr average during the experiment (Figure 4.2).

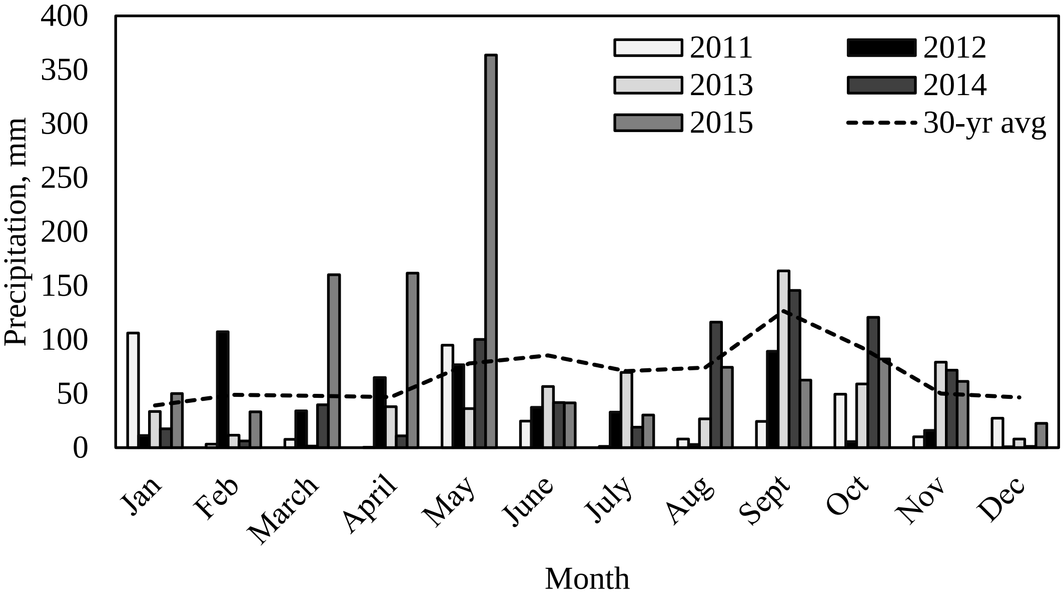

Figure 4.1 Monthly average precipitation (mm) during the five-yr experiment (2011-2015) and 30-yr average for Corpus Christi, Texas.

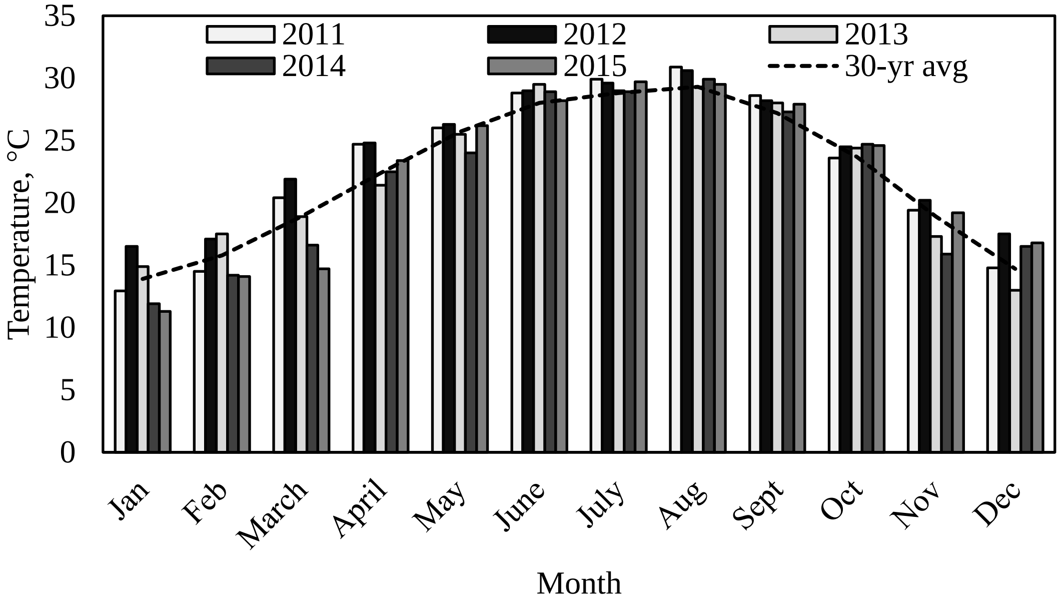

Figure 4.2 Monthly average temperature (°C) during the five-yr experiment (2011-2015) and 30-yr average for Corpus Christi, Texas.

4.2 Crops

No-till treatment affected ($P \leq 0.05$) cotton yields in some years (Table 4.1). Cotton yields for 2011 and 2012 were not different ($P = 0.60$; 1.10 Mg ha^{-1} and 1.72 Mg ha^{-1} average yields, respectively) between treatments, but yield was greater in 2012 than 2011. The NT cotton yield (0.76 Mg ha^{-1} average) for 2013 was greater ($P < 0.01$) than CT (0.09 Mg ha^{-1} average). Cotton yields were not different between treatments ($P > 0.05$) in either 2014 (0.99 Mg ha^{-1} average) or 2015 (2.4 Mg ha^{-1} average), and were greatest in 2015. Cotton lint percentage progressively increased from 2011 to 2015 with a nadir in 2013. The average lint yield was (32.2%), but no difference ($P > 0.05$) occurred between treatments or years. The number of bolls increased from 2014 (average of 10 bolls plant^{-1}) to 2015 (average of 29 bolls plant^{-1}), and 2015 was greater for NT cotton than CT cotton.

Table 4.1. Cotton yield, lint percentage, and boll count for no-till (NT) and conventional tillage (CT) systems by year (2011-2015) in Corpus Christi, Texas, on Vertisol.

Tillage systems	2011	2012	2013	2014	2015	SEM†
Yield (Mg ha^{-1})						
NT	1.13	1.69	0.76*	0.92	2.63	0.09
CT	1.08	1.76	0.09*	1.07	2.26	
Lint (%)						
NT	28	28	27	38	40	0.0003
CT	28	29	26	39	40	
Bolls (3 plant average)						
NT	-	-	-	9	58*	0.002
CT	-	-	-	12	30*	

* Significantly different within column at the 0.05 probability level.
† Standard error of mean (SEM).

Sorghum yields also varied by year (Table 4.2), and there was no difference (*P* = 0.7) between treatments in 2011 (4.06 Mg ha^{-1} average). Sorghum grown under NT had 33% greater (*P* = 0.04) grain yield than CT in 2012. There was no grain produced in 2013 due to severe drought conditions. There was no difference ($P \geq 0.24$) between treatments in 2014 (1.12 Mg ha^{-1}average) or 2015 (4.19 Mg ha^{-1}average), and yields were greater in 2015. The panicle count for 2014 was not affected (*P* = 0.96) by treatment; whereas, in 2015 CT sorghum had 10% more (*P* = 0.02) panicles than NT sorghum. In 2015, crop residue was 58% greater (P < 0.01) with NT than CT and sorghum (69% coverage) residue was greater (*P* < 0.01) than cotton residue (52%).

Table 4.2. Sorghum yield and panicle count for no-till (NT) and conventional tillage (CT) systems by year (2011-2015) in Corpus Christi, Texas, on Vertisol.

Tillage systems	2011	2012	2013	2014	2015	SEM†
Yield (Mg ha^{-1}, DM basis)						
NT	4.12	4.42*	-	1.06	3.53	0.40
CT	3.99	2.96*	-	1.17	4.85	
Panicle (4.2 m^{-1})						
NT	-	-	-	51	55*	0.002
CT	-	-	-	50	61*	

* Significantly different within column at the 0.05 probability level.
† Standard error of mean (SEM).

4.3 Soil

Gravimetric soil moisture (GSM, %) was not affected by treatment (*P* = 0.33) nor was it significantly different between depths (*P* = 0.26), but there was a yearly effect (Table 4.3). Volumetric water content (VWC) was also not affected by treatment or depth (*P* = 0.38). Soil porosity remained constant between treatments (*P* = 0.68) for total depth and discrete depths (*P* = 0.07). There was no difference (*P* = 0.59) between NT and CT for bulk density (g cm^{-3}) from 0 to 15 cm depth, but were different at the 15 to 30 cm depth. Bulk density was not different (*P* = 0.30) between sampling depths for NT. Conventional tillage had 6% greater (*P* < 0.04) bulk density in the lower depth than the upper CT and the lower NT depths.

Table 4.3 Comparison soil GSM and VWC, porosity, and bulk density at two depths in no-till (NT) and conventional tillage (CT) systems during the fourth and fifth cropping years (2014 and 2015) in Corpus Christi, Texas.

		2014		2015	
	Tillage	NT	CT	NT	CT
Depth	Properties				
0-15 cm	Moisture, GSM, %	10.33*	11.63*	14.13*	15.40*
	Moisture, VWC, g cm^{-3}	-	-	26.23	26.01
	Porosity, %	-	-	0.54	0.55
	Bulk Density, g cm^{-3}	-	-	1.23	1.20**
15-30 cm	Moisture GSM, %	9.53*	9.53*	17.72*	18.36*
	Moisture VWC, g cm^{-3}	-	-	32.71	29.98
	Porosity, %	-	-	55	52
	Bulk Density, g cm^{-3}	-	-	1.21‡	1.27**‡

* Significant within column at the 0.05 probability level.
** Significant within column at the 0.10 probability level.
‡ Significant within row at the 0.10 probability level.

Soil chemical properties, including pH, EC_w, NO_3-N, P, K, Ca, S, and Na, were not different between years (2014 and 2015) or treatments (Table 4.4). In 2014, NT had a greater total N (mg ha^{-1}; *P* = 0.02) content in the upper depth than the lower depth and between treatments in the upper depth, but no significant difference occurred in 2015. Soil organic carbon was greater (*P* < 0.02) in the 0 to 15 cm depth in 2014, with NT than CT, but lower in the 15 to 30 cm depth. No significant difference (*P* > 0.83) was found between treatments in 2015. Surface penetrometer resistance (J cm-^{1}) was greater (*P* < 0.10; Figure 4.3) in CT than NT after five years of treatment, but no significant difference was found between crops (*P* = 0.20).

Table 4.4 Comparison of soil pH, EC_w, NO_3-N, P, K, Ca, Mg, S, Na, total N, and SOC % at two depths in no-till (NT) and conventional tillage (CT) systems during the fourth and fifth cropping years (2014 and 2015) in Corpus Christi, Texas.

		2014		2015	
	Tillage	NT	CT	NT	CT
Depth	Properties				
0-15 cm	pH	8.12	8.14	8.30	8.35
	EC_w, umhos-cm^{-1}	354	370	295	297
	NO_3-N, ppm	7.38	11.31	6.50	6.00
	P, ppm	28.81	27.69	20.56	23.50
	K, ppm	320.44	321.69	327.94	310.63
	Ca, ppm	7430.13	7635.19	7318.19	7679.44
	Mg, ppm	404.63	418.44	410.38	420.38
	Na, ppm	146.56	150.00	152.00	161.19
	Total N, mg ha^{-1}	9.50*‡	8.92*‡	6.49	6.06
	SOC, %	66‡	48*‡	55	49
15-30 cm	pH	8.22	8.23	8.44	8.49
	EC_w, umhos-cm^{-1}	463	451	326	340
	N0$_3$-N, ppm	15.19	15.69	5.81	5.19
	P, ppm	8.88	10.69	11.75	11.94
	K, ppm	282.13	276.00	274.69	268.75

Table 4.4 Continued

		2014		2015	
	Tillage	NT	CT	NT	CT
Depth	Properties				
15-30 cm	Ca, ppm	9470.50	9243.19	8288.13	8553.56
	Mg, ppm	540.75	525.38	463.06	483.44
	S, ppm	20.50	18.63	13.00	14.00
	Na, ppm	422.81	389.57	258.06	297.44
	Total N, mg ha^{-1}	8.29*	8.69*	5.75	5.57
	SOC, %	63‡	80*‡	46	42

* Significant within column at the 0.05 probability level.
‡ Significant within row at the 0.05 probability level.

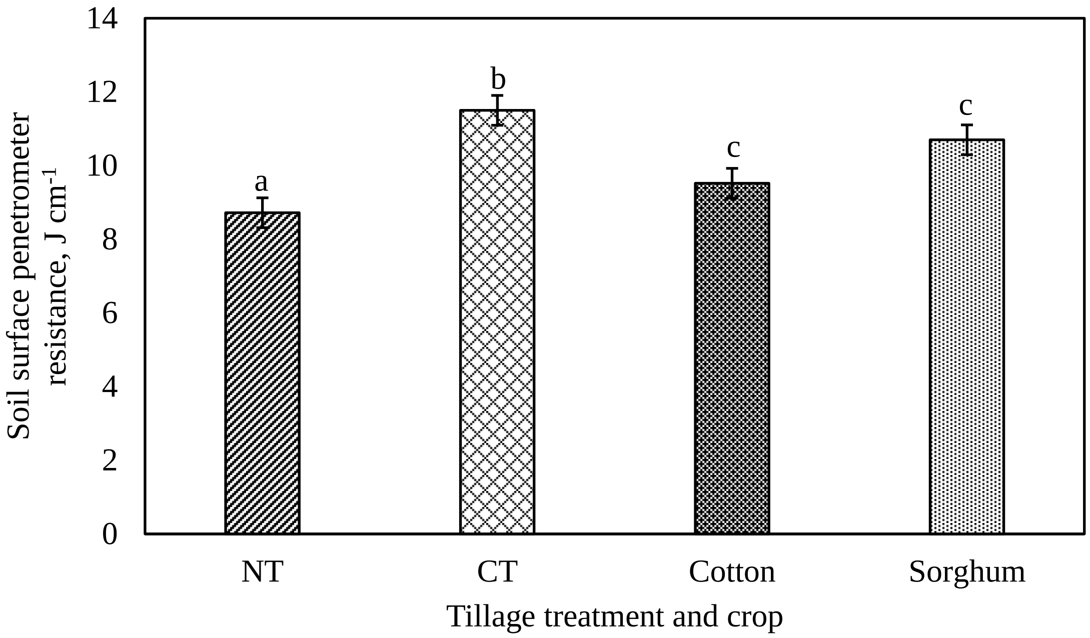

Figure 4.3 Soil surface penetrometer resistance for no-till (NT) and conventional tillage (CT) production systems after five years of the experiment (2011-2015) in Corpus Christi, Texas, on Vertisol. Different letters are significant at the 0.10 probability level.

CHAPTER V

DISCUSSION

5.1 Crops

Yield of cotton and sorghum were greater than county yields reported by the National Agriculture Statistic Service, but the trend of precipitation dependent yield fluctuations is the same. (USDA-NASS, 2016). Yields in this experiment are likely greater than the Nueces county average due to hand harvests of crops, which reduced losses inherent to mechanized harvesting. Also, cotton yields are likely greater than county averages due to the samples being processed with a small gin, which more efficiently recovers lint than commercial gins. In 2013, sorghum was not produced due to drought, and CT cotton yield was below the economic threshold for harvest (Ribera, personal communication, 2013). It can be surmised that during severe drought years, NT has the ability to retain more soil moisture than CT; unfortunately, soil moisture measurements for this study were not taken prior to 2014. In 2015, average crop residue coverage was 58% greater with NT than CT. Two dryland cropping experiments located in Colorado and Texas, indicate that crop residue increased soil water capture and moisture under NT management compared to other management practices (Baumhardt et al., 2002; Shaver et al., 2002). Similarly, in a long-term dryland maize (*Zea mays*) study in Mexico, soil under NT with crop residue had more moisture than CT and produced greater crop yields in erratic drought years likely due to the increased soil moisture (Verhulst et al., 2011).

During above 30-yr average precipitation years of 2014 and 2015, crop yields were not significantly different between treatments. There are reduced expenses associated with NT systems versus CT (Varner et al., 2011), so a lack of yield difference between the management practices indicates that NT is a viable management practice in south Texas.

5.2 Soil

Soil moisture was likely greater in 2015 due to 660 mm greater rainfall in 2015 than 2014. The lack of statistical difference between the NT and CT treatments on soil water content for the fourth and fifth year of this experiment are comparable with a similar study that was conducted on Vertisol in Temple, TX (Potter and Chishester, 1993). The study measured soil moisture content at three separate times in a ten year period and found no statistical differences between NT and CT. It is possible that soil moisture will not be influenced by NT until at least ten years of treatment.

Soil porosity is directly influenced by volume change (USDA-NRCS, 1996) and considering that the volumetric water content did not differ between treatments, porosity was not expected to change. The average soil bulk density was not influenced by NT at year five from 0-15 cm depth, but research has indicated that NT does not alter soil bulk density in a Vertisol until after year six of NT treatment (Potter and Chishester, 1993). The greater bulk density in the lower depth of CT may be the result of the soil hardpan, which is a problematic issue with CT practices (Raper et al., 2005). A study conducted in Australia on Vertisol soil demonstrated that penetrometer resistance began to decrease in year five after transitioning from CT to a NT system. The decrease in year five could also be attributed to increased soil moisture content in that year (Hamza and Anderson, 2005).

Soil fertility did not differ between tillage practices, but this was expected due to the fact that NT has only been established for five years. An eight year study in Alabama concluded that soil nutrient accumulation will depend upon the SOM content in the soil and that a significant increase in SOM with NT does not occur until after the eighth year of establishment (Rhoton, 2000). The increased total N and SOC in the NT practice for 2014, may be associated with the increased crop residue of the NT. Dalal et al. (1989) observed that total N and SOC content increased with crop residue coverage under NT management when compared to CT in a Vertisol. Dalal et al. (1989) also found that biological mineralization increased with residue coverage due to NT. It can be surmised from this study that NT with an increase in crop residue has a direct effect on total N and SOC quantities in the soil. The decrease of total N and SOC in 2015 may be attributed to the increase in precipitation amount (Aanderud et al. 2010).

The preliminary cotton and sorghum yield data indicate that yield results have been influenced by yearly precipitation and not by the NT treatment. Considering that soil moisture has not decreased under NT management and soil physical and chemical properties have stayed relatively the same, it can be deduced that an integration of NT into the current environment would not be detrimental to the farmer. Varner et al. (2011) demonstrated that NT is economically beneficial to dryland farmers in Oklahoma due decreased input costs and yield returns, but an investigation of the costs and returns are recommended for farmers in south Texas. It is also encouraged that future research focus on monitoring soil moisture content during the wet and dry periods of the year to compare the effects of NT on soil properties and crop yields.

CHAPTER VI

CONCLUSIONS

The results of this study indicate that integrating NT into the semi-arid region of south Texas is a feasible farming practice that should be considered by farmers. One of the original hypotheses of the experiment was that soil moisture content would be increased under NT management, but in this experiment, the average soil water content was not different between CT and NT practices after 5 years of NT management. Despite not seeing an increase in water content, NT has produced equivalent or greater crops yields. Cotton and sorghum yield was more dependent upon precipitation than tillage management. No-till can produce a greater cotton and sorghum crop yield than CT in years of drought (2012 and 2013). Despite risk mitigation in drought years, a yield increase is not the determining consideration to drive the adoption of NT in south Texas. While economics were not a component of this experiment, it is a critical factor that must be evaluated thoroughly before integrating an alternative farming method into an existing cropping system. Following the experiment, an economic table was developed for the study that compared the input costs and returns for both cotton and sorghum under CT or NT management (Table 6.1). It can be concluded from the economic comparison that NT is economically superior to CT for this specific study. This demonstrates that NT can be an economically successful cropping system if adopted by farmers, and the economic savings of NT will be the primary consideration of farmers whom adopt NT management. The implementation of NT into the semi-arid environment of south Texas on a large scale basis will need to be integrated gradually and modified to accommodate each individual farm.

Table 6.1 Estimated costs and returns per acre ($ acre) (2015-2016 prices) based on means across five years and predicted costs and returns for 500 acres of cotton and sorghum under conventional tillage (CT) and no-till (NT) management in Corpus Christi, Texas.

	Conventional system		No-till system	
Item	Cotton	Sorghum	Cotton	Sorghum
Revenue based on mean yields across five years:				
Cotton				
Lint ($0.58 lb.)†	287.06	-	325.98	-
Seed ($0.14 lb.)†	127.77	-	147.00	-
Grain sorghum ($7.35 CWT)†	-	237.77	-	237.85
Total revenue	414.83	237.77	472.98	237.85
Production costs:				
Custom†				
Fertilizer Application	0.10	0.10	0.10	0.10
Pick and Module	69.30	-	78.68	-
Ginning-Picker	64.35	-	73.06	-
Custom Haul	-	11.32	-	11.32
Drying	-	3.24	-	3.24
Fertilizer†				
24-8-0	54.11	54.11	54.11	54.11
Herbicide				
Glyphosate	3.08		7.71	7.00
2-4, D Amine	8.38	-	8.38	-
Dual II Magnum	-	17.64	-	17.64
Insecticide				
Boll Weevil Program†	7.00	-	7.00	-
Fleahopper Control†	1.05	-	1.05	-
Transform WG	-	10.78	-	10.78
Headwork Control†	-	3.07	-	3.07
Stinkbug Control†	-	0.86	-	0.86
Defoliant				
Ginstar	6.45	-	6.45	-
Adjuvants				

Table 6.1 Continued

Item	Conventional system Cotton	 Sorghum	No-till system Cotton	 Sorghum
Revenue based on mean yields across five years:				
Crop Oil Concentrate	1.82		1.82	
Seed	81.95	14.30	81.95	14.30
Planting‡	16.57	16.57	20.29	20.29
Tillage Management‡	48.30§	64.71§	-	-
Fertilizer Management‡	6.34	6.34	6.34	6.34
Chemical Management‡	18.28	9.14	18.28	18.28
Miscellaneous†	4.87	2.71	84.88	47.64
Crop Insurance	19.00	19.00	19.00	19.00
Pickup Mileage Charge	3.88	3.88	3.88	3.88
Total costs	409.96	235.06	388.10	190.21
Net returns	4.87	2.71	84.88	47.64
Total revenue for farm	103,707.50	59,4442.5	118,245.00	59,462.50
Total costs for farm	102,490.00	58,765.00	97,025.00	47,552.50
Net returns for farm	1,217.50	677.50	21,220.00	11,910.00

† Adapted from Levi Russell, 2016 District 11 Texas Crop and Livestock Budgets, Texas A&M AgriLife Extension Service. http://www.agecoext.tamu.edu.

‡ Adapted from 2016 Texas Agricultural Custom Rates, Texas A&M AgriLife Extension Service. http://www.agecoext.tamu.edu.

§ Calculated based on custom price rate: cultivator, disc, moldboard, and shaping beds.

Future research may incorporate other soil measurements into the existing measurements to better quantify changes in soil structure and chemical composition over time of NT management. For example, measuring soil erosion, water infiltration and runoff rate, and soil compaction to a minimum depth of 30 cm. Also, evaluating seed germination and plant density would aid in determining if NT management may hinder plant growth and influencing the lack of increase in overall crop yield.

The results of this experiment should reassure farmers and researchers that an alternative method to CT is feasible in semi-arid regions. This study in combination with other semi-arid research supports the philosophy that conservation farming practices on row crops can contend with conventional methods and produce optimum crop yields with less expensive inputs, which provides economic gain for farmer. Semi-arid cropping studies across the globe have displayed encouraging results not only in crop yield and economic return, but also in areas of land and natural resource conservation. The positive attributes of NT make it a viable farming practice for farmers in semi-arid environments. It is recommend that farmers begin adopting this form of conservation tillage on their farms; however, it is advised that the integration process be gradual to insure farmer profitability and environmental sustainability. Through integrating conservation tillage practices, farmers have the opportunity secure resources that may enable the agriculture community to sustain the food and fiber industry for future generations.

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APPENDIX A

TREATMENTS

Conventional Tilled Plot Management

<u>Tillage</u>
Sweep cultivated cotton and sorghum (one pass)
Disked sorghum (one pass)
Sweep plowed cotton and sorghum (one pass)
Bedded cotton and sorghum rows (one pass)

<u>Average Chemical Application</u>
Dual II Magnum-sorghum (weeds)
Glyphosate-cotton (weeds)
Centric-cotton and sorghum (fleahopper)
Imidacloprid with Non-Ionic Surfactant (fleahopper)
Transform WG with Crop Oil Concentrate-sorghum (sugar cane aphid)
Ginstar defoliant-cotton
2-4, D Amine with Crop Oil Concentrate-cotton (seedlings)

No-Till Plot Management

<u>Average Chemical Application</u>
Dual II Magnum-sorghum (weeds)
Glyphosate-cotton and sorghum (weeds)
Centric-cotton and sorghum (fleahopper)
Imidacloprid with Non-Ionic Surfactant (fleahopper)
Transform WG with Crop Oil Concentrate-sorghum (sugar cane aphid)
Ginstar defoliant-cotton
2-4, D Amine with Crop Oil Concentrate-cotton (seedlings)
Glyphosate-sorghum (stalks and weeds)

APPENDIX B

STATISTICAL ANALYSIS

Crop Analysis of Variance and Least Square Means

Dependent Variable: Cotton Yield

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	20237344	2248.594	51.8835
Error	30	1300179	43.339	Prob > F
Corrected total	39	21537523		< 0.0001*

RSquare	RSquare Adj	Root MSE	Yield Mean
0.939632	0.921522	208.1809	1339.596

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	298135	6.8791	0.0136*
Year	4	4	18999261	109.5961	< 0.0001*
Trt*Year	4	4	939947	5.4220	0.0021*

Level	LSMean	Standard Error
CT, 2011	1084.2475	96.143637
CT, 2012	1762.5650	87.510164
CT, 2013	87.0625	45.733641
CT, 2014	1074.2425	57.527484
CT, 2015	2258.1950	178.52563
NT, 2011	1128.2000	96.143637
NT, 2012	1693.9775	87.510164
NT, 2013	761.1850	45.733641
NT, 2014	921.2600	57.527484
NT, 2015	2625.0200	178.52563

Dependent Variable: Cotton Lint %

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	1343.5954	149.288	273.7897
Error	30	16.3580	0.545	Prob > F
Corrected total	39	1359.9534		< 0.0001*

RSquare	RSquare Adj	Root MSE	Lint % Mean
0.987972	0.984363	0.738422	32.297

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	0.3842	0.7045	0.4079*
Year	4	4	1340.9816	614.8283	< 0.0001*
Trt*Year	4	4	2.2297	1.0223	0.4117*

Level	LSMean	Standard Error
CT, 2011	28.012500	0.23614845
CT, 2012	28.540000	0.17226793
CT, 2013	26.087500	0.37875155
CT, 2014	38.782500	0.41807489
CT, 2015	39.572500	0.52822324
NT, 2011	27.935000	0.23614845
NT, 2012	28.040000	0.17226793
NT, 2013	26.985000	0.37875155
NT, 2014	38.995000	0.41807489
NT, 2015	40.020000	0.52822324

Dependent Variable: Cotton Bolls

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	1371.0469	457.016	25.7247
Error	12	213.1875	17.766	Prob > F
Corrected total	15	1584.2344		< 0.0001*

RSquare	RSquare Adj	Root MSE	Boll Mean
0.865432	0.83179	4.214929	19.96875

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	28.8906	1.6262	0.2264
Year	1	1	1341.3906	75.5048	< 0.0001*
Trt*Year	1	1	0.7656	0.0431	0.8390

Level	LSMean	Standard Error
CT, 2014	12.375000	1.4781393
CT, 2015	30.250000	2.5880334
NT, 2014	9.250000	1.4781393
NT, 2015	28.000000	2.5880334

Dependent Variable: Sorghum Yield

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	57668773	8238396	10.9722
Error	24	18020168	750840	Prob > F
Corrected total	31	75688942		< 0.0001*

RSquare	RSquare Adj	Root MSE	Yield Mean
0.761918	0.692478	866.5104	3266.418

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	11931	0.0159	0.9007
Year	3	3	47939259	21.2825	< 0.0001*
Trt*Year	3	3	7838475	3.4799	0.0315*

Level	LSMean	Standard Error
CT, 2011	3992.0870	198.33778
CT, 2012	2959.0715	397.75853
CT, 2013	0	0
CT, 2014	1169.4444	181.63604
CT, 2015	4853.6033	715.57743
NT, 2011	4120.0242	198.33778
NT, 2012	4421.8103	397.75853
NT, 2013	0	0
NT, 2014	1060.7626	234.49112
NT, 2015	3527.3673	715.57743

Dependent Variable: Sorghum Panicles

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	350.94271	116.981	5.6680
Error	12	247.66667	20.639	Prob > F
Corrected total	15	598.60938		0.0118*

RSquare	RSquare Adj	Root MSE	Panicle Mean
0.586263	0.482829	4.543004	54.09375

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	22.60753	1.0954	0.3159
Year	1	1	258.17204	12.5090	0.0041*
Trt*Year	1	1	49.70430	2.4083	0.1467

Level	LSMean	Standard Error
CT, 2014	49.500000	2.0316933
CT, 2015	61.250000	2.2715022
CT, 2014	50.666667	2.6229048
CT, 2015	55.250000	2.2715022

Soil Analysis of Variance and Least Square Means

Dependent Variable: Gravimetric Soil Moisture

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	1402.9885	200.427	10.1789
Error	113	2225.0265	19.691	Prob > F < 0.0001*
Corrected total	120	3628.0151		

RSquare	RSquare Adj	Root MSE	GSM Mean
0.38671	0.348718	4.437398	13.46269

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	19.1120	0.9706	0.3266
Year	1	1	1129.7702	57.3764	< 0.0001*
Depth	1	1	24.7927	1.2591	0.2642
Trt*Year*Depth	1	1	0.7641	0.0388	0.8442

Level	LSMean	Standard Error
CT, 0-15, 2014	11.625583	1.2809664
CT, 0-15, 2015	15.408313	1.2809664
CT, 15-30, 2014	9.536063	1.2809664
CT, 15-30, 2015	18.357563	1.2809664
NT, 0-15, 2014	10.339615	1.2809664
NT, 0-15, 2015	14.133375	1.2809664
NT, 15-30, 2014	9.531563	1.2809664
NT, 15-30, 2015	17.724563	1.2809664

Dependent Variable: Volumetric Water Content

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	247.93801	82.6460	5.1904
Error	28	445.83804	15.9228	Prob > F
Corrected total	31	693.77605		0.0056*

RSquare	RSquare Adj	Root MSE	GWC Mean
0.357375	0.288522	3.990337	28.73281

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	17.39025	1.0922	0.3049
Depth	1	1	217.93500	13.6870	0.0009*
Trt*Depth	1	1	12.61275	0.7921	0.3810

Level	LSMean	Standard Error
CT, 0-15, 2015	26.013750	1.4107971
CT, 0-15, 2015	29.977500	1.4107971
NT, 15-30, 2015	26.232500	1.4107971
NT, 15-30, 2015	32.707500	1.4107971

Dependent Variable: Porosity

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.00292500	0.000975	1.7036
Error	28	0.01602500	0.000572	Prob > F
Corrected total	31	0.01895000		0.1890

RSquare	RSquare Adj	Root MSE	Porosity Mean
0.154354	0.063749	0.023923	0.53875

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	0.00020000	0.3495	0.5592
Depth	1	1	0.00061250	1.0702	0.3098
Trt*Depth	1	1	0.00211250	3.6911	0.0649

Level	LSMean	Standard Error
CT, 0-15, 2015	0.54875000	0.00845814
CT, 0-15, 2015	0.52375000	0.00845814
NT, 15-30, 2015	0.53750000	0.00845814
NT, 15-30, 2015	0.54500000	0.00845814

Dependent Variable: Bulk Density

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.02380938	0.007936	2.1086
Error	28	0.10538750	0.003764	Prob > F
Corrected total	31	0..12919688		0.1216

RSquare	RSquare Adj	Root MSE	Bulk Density Mean
0.184288	0.09689	0.06135	1.224688

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	0.00195313	0.5189	0.4773
Depth	1	1	0.00427813	1.1366	0.2955
Trt*Depth	1	1	0.01757813	4.6703	0.0394*

Level	LSMean	Standard Error
CT, 0-15, 2015	1.1975000	0.02169055
CT, 0-15, 2015	1.2675000	0.02169055
NT, 15-30, 2015	1.2287500	0.02169055
NT, 15-30, 2015	1.2050000	0.02169055

Dependent Variables: pH

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	1.9868977	0.397380	25.7343
Error	122	1.8838766	0.015442	Prob > F
Corrected total	127	3.8707742		< 0.0001*

RSquare	RSquare Adj	Root MSE	pH Mean
0.513308	0.493361	0.124264	8.283672

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	0.0315633	2.0440	0.1554
Depth	1	1	0.4197570	27.1835	< 0.0001*
Year	1	1	1.5334383	99.3056	< 0.0001*
Trt*Depth*Year	1	1	0.0010695	0.0693	0.7929

Level	LSMean	Standard Error
CT, 0-15, 2014	8.1384375	0.02690401
CT, 0-15, 2015	8.3515625	0.02690401
CT, 15-30, 2014	8.2414063	0.02690401
CT, 15-30, 2015	8.4660938	0.02690401
NT, 0-15, 2014	8.0954688	0.02690401
NT, 0-15, 2015	8.3201563	0.02690401
NT, 15-30, 2014	8.2215625	0.02690401
NT, 15-30, 2015	8.4346875	0.02690401

Dependent Variable: EC_w

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	433520.19	86704.0	26.7634
Error	122	395237.78	3239.7	Prob > F
Corrected total	127	828757.97		< 0.0001*

RSquare	RSquare Adj	Root MSE	EC_w Mean
0.523096	0.503551	56.91796	362.5156

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	840.50	0.2594	0.6114
Depth	1	1	140317.53	43.3125	< 0.0001*
Year	1	1	288610.03	89.0867	< 0.0001*
Trt*Depth*Year	1	1	3240.13	1.0001	0.3193

Level	LSMean	Standard Error
CT, 0-15, 2014	386.48438	12.323099
CT, 0-15, 2015	281.45313	12.323099
CT, 15-30, 2014	438.64063	12.323099
CT, 15-30, 2015	353.73438	12.323099
NT, 0-15, 2014	367.29688	12.323099
NT, 0-15, 2015	282.39063	12.323099
NT, 15-30, 2014	447.57813	12.323099
NT, 15-30, 2015	342.54688	12.323099

Dependent Variable NO_3-N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	1663.1756	219.498	7.6788
Error	122	5284.8703	40.382	Prob > F
Corrected total	127	6948.0459		< 0.0001*

RSquare	RSquare Adj	Root MSE	NO_3-N Mean
0.239373	0.2082	6.581687	9.132969

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	20.8981	0.4824	0.4886
Depth	1	1	29.5153	5.2983	0.0230*
Year	1	1	1365.8151	31.5295	< 0.0001*
Trt*Depth*Year	1	1	20.3203	0.4691	0.4947

Level	LSMean	Standard Error
CT, 0-15, 2014	12.319062	1.4249771
CT, 0-15, 2015	4.989063	1.4249771
CT, 15-30, 2014	13.288125	1.4249771
CT, 15-30, 2015	7.551875	1.4249771
NT, 0-15, 2014	9.801875	1.4249771
NT, 0-15, 2015	4.065625	1.4249771
NT, 15-30, 2014	14.189062	1.4249771
NT, 15-30, 2015	6.859063	1.4249771

Dependent Variable: P

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	6865.373	1373.07	26.0656
Error	122	6426.668	52.68	Prob > F
Corrected total	127	13292.041		< 0.0001*

RSquare	RSquare Adj	Root MSE	P Mean
0.516503	0.496687	7.257934	17.95687

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	31.2159	0.5926	0.4429
Depth	1	1	6632.5395	125.9081	< 0.0001*
Year	1	1	135.4637	2.5716	0.1114*
Trt*Depth*Year	1	1	65.8479	1.2500	0.2657

Level	LSMean	Standard Error
CT, 0-15, 2014	25.911656	1.5713888
CT, 0-15, 2015	25.288656	1.5713888
CT, 15-30, 2014	13.047234	1.5713888
CT, 15-30, 2015	9.555266	1.5713888
NT, 0-15, 2014	26.456328	1.5713888
NT, 0-15, 2015	22.964359	1.5713888
NT, 15-30, 2014	10.527219	1.5713888
NT, 15-30, 2015	9.904219	1.5713888

Dependent Variable: K

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	67306.54	13461.3	3.4863
Error	122	471072.54	3861.3	Prob > F
Corrected total	127	538379.08		< 0.0056*

RSquare	RSquare Adj	Root MSE	K Mean
0.125017	0.089157	62.13896	297.7723

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	1615.606	0.4184	0.5189
Depth	1	1	64290.974	16.6503	< 0.0001*
Year	1	1	655.881	0.1699	0.6810
Trt*Depth*Year	1	1	716.775	0.1856	0.6673

Level	LSMean	Standard Error
CT, 0-15, 2014	320.79916	13.453479
CT, 0-15, 2015	311.53909	13.453479
CT, 15-30, 2014	272.16716	13.453479
CT, 15-30, 2015	272.37266	13.453479
NT, 0-15, 2014	324.09553	13.453479
NT, 0-15, 2015	324.30103	13.453479
NT, 15-30, 2014	283.08172	13.453479
NT, 15-30, 2015	273.82166	13.453479

Dependent Variable: Ca

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	69374185	13874837	16.5311
Error	122	102396756	839317.67	Prob > F
Corrected total	127	171770941		< 0.0001*

RSquare	RSquare Adj	Root MSE	Ca Mean
0.403876	0.379445	916.1428	8202.314

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	731249	0.8712	0.3525
Depth	1	1	60332311	71.8826	< 0.0001*
Year	1	1	7525406	8.9661	< 0.0001*
Trt*Depth*Year	1	1	226640	0.2700	0.6043

Level	LSMean	Standard Error
CT, 0-15, 2014	7941.9608	198.35074
CT, 0-15, 2015	7372.8611	198.35074
CT, 15-30, 2014	9098.7767	198.35074
CT, 15-30, 2015	8697.9920	198.35074
NT, 0-15, 2014	7574.5164	198.35074
NT, 0-15, 2015	7173.7317	198.35074
NT, 15-30, 2014	9163.8867	198.35074
NT, 15-30, 2015	8594.7870	198.35074

Dependent Variable: Mg

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	288064.08	57612.8	21.2759
Error	122	330362.17	2707.9	Prob > F
Corrected total	127	618426.25		< 0.0001*

RSquare	RSquare Adj	Root MSE	Mg Mean
0.465802	0.443908	52.03736	458.2849

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	1688.74	0.6236	0.4312
Depth	1	1	257379.00	95.0479	< 0.0001*
Year	1	1	25158.41	9.2908	< 0.0001*
Trt*Depth*Year	1	1	3129.64	1.1558	0.2845

Level	LSMean	Standard Error
CT, 0-15, 2014	438.39220	11.266419
CT, 0-15, 2015	400.46348	11.266419
CT, 15-30, 2014	513.48138	11.266419
CT, 15-30, 2015	495.33156	11.266419
NT, 0-15, 2014	416.53356	11.266419
NT, 0-15, 2015	398.38375	11.266419
NT, 15-30, 2014	520.81098	11.266419
NT, 15-30, 2015	482.88227	11.266419

Dependent Variable: S

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	924.9910	184.998	9.9923
Error	122	2258.7264	15.514	Prob > F
Corrected total	127	3183.7174		< 0.0001*

RSquare	RSquare Adj	Root MSE	S Mean
0.290538	0.261462	4.302807	14.56943

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	11.86149	0.6407	0.4250
Depth	1	1	479.71370	925.9107	< 0.0001*
Year	1	1	414.65160	22.3965	< 0.0001*
Trt*Depth*Year	1	1	18.32319	0.9897	0.3218

Level	LSMean	Standard Error
CT, 0-15, 2014	14.448609	0.93158511
CT, 0-15, 2015	10.092203	0.93158511
CT, 15-30, 2014	17.681125	0.93158511
CT, 15-30, 2015	14.838125	0.93158511
NT, 0-15, 2014	14.418125	0.93158511
NT, 0-15, 2015	11.575125	0.93158511
NT, 15-30, 2014	18.929266	0.93158511
NT, 15-30, 2015	14.572859	0.93158511

Dependent Variable: Na

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	1274429.9	254886	26.5016
Error	122	1173364.7	9618	Prob > F
Corrected total	127	2447794.6		< 0.0001*

RSquare	RSquare Adj	Root MSE	Na Mean
0.520644	0.500998	98.07009	247.2106

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	718.9	0.0748	0.7850
Depth	1	1	1149241.9	119.4918	< 0.0001*
Year	1	1	115358.0	11.9943	< 0.0001*
Trt*Depth*Year	1	1	9025.5	0.9384	0.3346

Level	LSMean	Standard Error
CT, 0-15, 2014	194.06089	21.232798
CT, 0-15, 2015	117.22548	21.232798
CT, 15-30, 2014	365.14147	21.232798
CT, 15-30, 2015	321.89459	21.232798
NT, 0-15, 2014	170.89216	21.232798
NT, 0-15, 2015	127.64528	21.232798
NT, 15-30, 2014	378.83036	21.232798
NT, 15-30, 2015	301.99495	21.232798

Dependent Variable: Total N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	285092822	57018564	54.8757
Error	122	126763966	1039048.9	Prob > F
Corrected total	127	411856787		< 0.0001*

RSquare	RSquare Adj	Root MSE	Total N Mean
0.692213	0.679599	1019.337	7407.785

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	1218277	1.1725	0.2810
Depth	1	1	14268696	13.7325	< 0.0003*
Year	1	1	265575798	255.5951	< 0.0001*
Trt*Depth*Year	1	1	1054848	1.0152	0.3157

Level	LSMean	Standard Error
CT, 0-15, 2014	8841.2848	220.69304
CT, 0-15, 2015	6142.0039	220.69304
CT, 15-30, 2014	8660.0079	220.69304
CT, 15-30, 2015	5597.6072	220.69304
NT, 0-15, 2014	9522.8812	220.69304
NT, 0-15, 2015	6460.4805	220.69304
NT, 15-30, 2014	8368.6481	220.69304
NT, 15-30, 2015	5669.3672	220.69304

Dependent Variable: SOC %

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	3653.8706	730.774	4.4151
Error	26	4303.4356	165.517	Prob > F
Corrected total	31	7957.3062		< 0.0048*

RSquare	RSquare Adj	Root MSE	SOC % Mean
0.459184	0.355181	12.86533	55.84125

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	53.0450	0.3205	0.5762
Depth	1	1	917335	0.5542	0.4633
Year	1	1	2184.2745	13.1967	< 0.0012*
Trt*Depth*Year	1	1	592.7124	3.5810	0.0696

Level	LSMean	Standard Error
CT, 0-15, 2014	52.035625	5.5708519
CT, 0-15, 2015	44.119375	5.5708519
CT, 15-30, 2014	73.595625	5.5708519
CT, 15-30, 2015	48.464375	5.5708519
NT, 0-15, 2014	72.784375	5.5708519
NT, 0-15, 2015	47.653125	5.5708519
NT, 15-30, 2014	57.996875	5.5708519
NT, 15-30, 2015	50.080625	5.5708519

Dependent Variable: Surface Penetrometer Resistance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	348.78053	116.260	17.1938
Error	28	189.32902	6.762	Prob > F
Corrected total	31	538.10955		< 0.0001*

RSquare	RSquare Adj	Root MSE	SPR Mean
0.648159	0.610462	2.600337	11.797929

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Trt	1	1	45.28800	6.6977	0.0151*
Year	1	1	90.89051	13.4419	0.0010*
Trt*Year	1	1	212.60202	31.4419	< 0.0001*

Level	LSMean	Standard Error
CT, 2014	9.715417	0.91935783
CT, 2015	11.499881	0.91935783
CT, 2014	17.249821	0.91935783
CT, 2015	8.724048	0.91935783