# DEVELOPING AND TESTING A TRAFFICABILITY INDEX FOR PLANTING CORN AND COTTON IN THE TEXAS BLACKLAND PRAIRIE

A Thesis

by

ADAM JEFFRY HELMS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2009

Major Subject: Soil Science

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Approved by:

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# ABSTRACT

Developing and Testing a Trafficability Index for Planting Corn and Cotton in the Texas Blackland Prairie. (December 2009)

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Co-Chairs of Advisory Committee: Dr. Cristine L.S. Morgan
Dr. Gaylon D. Morgan

The Texas Blackland Prairie is one of the most productive agricultural regions in Texas. This region provides a long growing season coupled with soils that have a high water holding capacity. However, the soils also provide significant challenges to producers because the high water holding capacity is a product of a high clay percentage. This research was aimed to develop and test an expert-based trafficabililty index, based upon soil moisture, for planting cotton (*Gossypium hirsutum* L.) and corn (*Zea mays* L.) on the Texas Blackland Prairie. Testing the index focused on quantify the potential effect of high soil moisture at planting on seed furrow sidewall compaction and associated plant growth response. Once the trafficability index was developed, three workable soil moisture regimes were recreated in no-tillage and conventional tillage plots at the Stiles Farm Foundation in Thrall, Texas. The index nomenclature included: “Dry-Workable”, “Optimal” and “Wet-Workable”. After planting corn and cotton into conventional and no tillage plots, 0.45 x 0.20 x 0.15 m intact soil blocks were removed from each plot and kept in a controlled environment. At 28 days, each block was destructively harvested to quantify plant root and shoot growth responses. Each of the three soil moisture indexes was replicated thrice per crop, and the whole experiment was replicated twice in time, n = 48 blocks.

The trafficability index was created using three producer experts, and over 10 interviews to collect a range in soil moisture samples. From “Wet Workable” to “Dry Workable”, the gravimetric soil moistures were 0.17, 0.22, and 0.26 g $g^{-1}$. For corn and cotton, a positive relationship between plant growth factors and planting at soil moisture existed. Plants planted at the highest soil moisture emerged faster and developed more root and shoot biomass than those planted at the lowest soil moisture. No evidence of a detrimental plant response because of seed furrow, sidewall compaction from planting at too high a soil moisture content could be quantified. Furthermore, the cotton plants in no-tillage performed better than in conventional tillage, but corn performed better in conventional tillage. Because the results showed an advantage to plant growth by planting in the “Wet Workable” index, the tillage practice that allows the producer to enter the field with a planter at higher moisture contents appears to have an advantage.

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## CHAPTER I

## INTRODUCTION:  THE BLACKLAND TRAFFICABILITY INDEX

### Introduction

The Texas Blackland Prairie is among the most productive soils in the state of Texas.  The soils of the Blackland Prairie are characterized by high organic matter, high water holding capacity and high clay percentage.  These soils are classified as USDA prime farmland (USDA 2006) because of high yield potential and geographic location, which allows for an optimum growing season.  Although these soils have a high capacity for producing profitable crops, the large quantities of smectite clays require keen management.

Though Texas Blackland soils require keen management because of their unique properties, producers are becoming less familiar with their soils because farms have become larger to maintain profitability.  Producers rent land across a wide geographical area and are therefore becoming less familiar with the fields they farm.  Precision agriculture and decision-aid instruments have become helpful to producer managing the agronomics and logistics of large acreages. Decision-aid tools, particularly precision agriculture tools, can address the within-field and real-time temporal variability of soils and crops and provide simulation results for making logistics and agronomic decisions. To provide decision aid tools for users in the Blackland Prairie, more needs to be quantified regarding the response of these soils, and subsequently planted crops, to tillage.

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This thesis follows the style of the Agronomy Journal.

Tillage is a principal soil management technique used for seedbed preparation, incorporation of fertilizers and crop residues, and weed control (Amezketa, 1999). Primary tillage at high water content produces large clods that require subsequent tillage operations and/or extended weathering (wet/dry cycles) to establish an adequate soil structure for crop establishment (Wolf and Lath, 1979). Subsequent tillage operations cost time and money for producers and increases in energy prices make unnecessary tillage even more costly. Tillage can also degrade soil structure, which is reflected by a decrease in water-stable aggregation (Tisdall et al., 1978). This decrease in water stable aggregation has the potential to decrease water infiltration and increase soil bulk density, which can limit root growth and yield. Additionally, planting crops at high water content causes soil compaction in traffic lanes, which can reduce yields as well (Carter, 1994).

Furthermore, planting at high moisture content in fine-textured soils can cause a compaction of the seed furrow sidewall. Sidewall compaction is caused by the planter spreading the soil to create the seed furrow combined with the inability of the planter to properly close the incision in the soil. Sidewall compaction presents two problems to seed emergence and development. First, the seed in the open seed furrow channel has poor soil contact, which slows down or prevents germination through seedling desiccation. Second, when the smeared sides of the seed furrow dry out, the locally dry, compacted soil might confine the seedling roots to the seed furrow because of increased penetration resistance of soil on the sidewall. The restriction caused by the sidewall smearing can cause an increase in seedling mortality (Iqbal, 1998). Iqbal's observations are linked to Carter's (1994) because they present eventual yield problems for a crop due to compaction. Producers on the Texas Blackland Prairie have reported similar observations where the roots initially grow within the seed furrow channel caused by the planter (personal communication, Abrameit, 2006).

The overall goal of this project was to develop a planting trafficability index for the Texas Blackland Prairie that could be incorporated into a biophysical precision agriculture model. Once the Blackland Trafficability Index (BTI) was created, we wanted to test the response of corn and cotton to planting at three soil moisture contents indentified in the index. The specific objective of Chapter I of this thesis is to develop an expert-based trafficability index for planting cotton and corn on the Texas Blackland Prairie using the knowledge of producers who farm the Texas Blackland Prairie. The hypothesis of Chapter I is that farmers with experience in agricultural production in the Blackland prairie had similar concepts of optimal soil moisture for tillage and that the optimal soil moisture would be different in conventional tillage versus no-tillage. Another component of Chapter I is reporting on calibration of a soil moisture probe for the Blackland Prairie soils. In Chapter II, the objectives are to identify the response to corn planted at three moisture contents in both tillage and no tillage and quantify any differences in aggregate stability after planting at three soil moistures. In Chapter III, the objective was to identify the response to cotton planted at three moisture contents in both tillage and no tillage, particularly the growth response of the cotton tap root.

*Tillage Regimes*

There are several different tillage operations used on the Texas Blackland Prairie such as no-tillage, strip tillage, and conventional tillage. Conventional tillage requires a producer to make multiple passes through the field with a tractor and tillage implement. Chisel plows, disc harrows, field cultivators and bedders are some of the more common implements used on the Texas Blackland Prairie. One purpose of conventional tillage is to incorporate residue from the previous crop into the soil. An intensive conventional tillage regime can leave less than 15% residue cover of the topsoil after the tillage operation is complete (Stichler et al., 2006). In addition to residue incorporation, conventional tillage also disturbs the topsoil in an effort to loosen it to increase water infiltration as well as to prepare a seed bed. However, conventional tillage can break down water-stable soil aggregation, thereby reducing infiltration (Tisdall et at., 1978). Furthermore, multiple passes through the field with machinery are needed for conventional tillage, but can cause more compaction and reduced yield (Carter, 1994). The tillage implement also has been observed to cause a subsurface compaction known as the plow layer (Soane et al., 1982).

No-tillage requires tractor traffic through the field for planting, fertilizing and pest control, but the soil is generally left alone between harvest and planting. Even under a no-tillage operation, fertilizing, planting and weed control require trafficking events through the field, but no cultivation of the soil is required. A no-tillage operation can save a producer time, reduce fuel cost, and reduce equipment wear. Research on no-tillage on the Texas Blackland Prairie has shown that crop yields, crop rooting, soil strengths, soil bulk densities, and economic returns are similar if not better than conventional tillage (Morrison et al., 1990). These observations lend themselves to the characteristic of USDA prime farmland and the abilities of these soils to retain high soil moisture contents with a long growing season. Compaction can still be a problem in a no-tillage operation; therefore, it is necessary to have controlled traffic lanes to confine compaction. Stichler et al. (2006) observed that some crops do not respond as well in a no-tillage operation as well as others. Corn is one the easiest crops to establish in a no-tillage situation while cotton is one of the most difficult crops to establish because cotton roots prefer drier soils and no-tillage soils have high soil moisture.

*Aggregate Stability*

Jury et al. (1991) reported that the stability of a soil aggregate depends on its ability to resist the disintegrating forces of water and mechanical manipulation. Water can break down aggregate stability by hydrating the aggregate causing it to swell and then the trapped air within the aggregate to causes an explosive effect when it escapes. In addition to breaking soil aggregate through physical means, rain drops can also chemically disperse soil aggregates. The dispersed soil particles fill soil macropores causing increased compaction and decreased porosity. The presence or absence of water stable aggregates is important because they influence the factors involved with sheet erosion, crust formation and runoff (Shouse et al., 1990). Shouse et al. (1990) also concluded that the spatial variability of aggregate stability index increases in fields that have been tilled due to the sheet erosion process.

Tillage mechanically manipulates the soil and causes a decrease in aggregate stability. Aggregate stability is important for plants because of plant-soil-water relations. A well aggregated soil ensures good infiltration, storage of plant available water, proper root aeration, and drainage. If a soil has poor aggregate stability, it is more susceptible to compaction and inhibits plant root growth. Compacted soils also can have low infiltration rates allowing water to runoff instead of being absorbed for plant use.

*Sidewall Compaction*

Seed furrow wall compaction, also known as sidewall compaction, is caused by the planter opening the soil causing compaction and improperly closing the incision. Seed furrow sidewall compaction will occur more in fine textured soils in a no-tillage operation rather than conventional tillage operations, because no-tillage systems generally have firm, wet soil at planting (Soane et al., 1975; Iqbal, 1998). Due to the potential of having sidewall compaction when planting in the Texas Blackland Prairie, planting at the correct soil moisture may be important for emergence and good seedling establishment. Morrison et al. (1990) reported the Texas Blackland Prairie has a very narrow range of water content at which the soil is friable; approximately 22 to 32% gravimetric water content on a dry basis. The narrow range of soil moisture magnifies the complexity of timing planting in the Texas Blackland Prairie.

**Materials and Methods**

The Blackland Trafficability Index (BTI) was developed by interviewing experienced cotton and corn producers on the Texas Blackland Prairie involved in conventional tillage, strip tillage, and no-tillage regimes. Producers were selected from the Blackland Conservation Tillage Alliance (an association aimed at progressive farming techniques and soil conservation) and interviewed as soil moisture in their fields changed over time. During the initial interview, the producers were asked preliminary background information about their fields. For each field sampled, the tillage and crops grown in the previous three seasons were documented. The producer was then asked to rate the soil moisture at a specific location in their field for planting corn, planting cotton and general tillage. They were asked to make the rating using a scale of one to five: 1 was "Too Dry"; 2 was "Dry Workable"; 3 was "Optimum"; 4 was "Wet Workable"; and 5 was "Too Wet". After the farmer made the rating, gravimetric water content and volumetric water content were measured using soil cores.

At each rated site, three volumetric soil cores measuring 7-cm diameter and 6-cm deep were collected, sealed in plastic bags, and placed in a cooler for transport to the laboratory. At the laboratory, samples were weighed, oven dried at $105^{o}$ C for 24 hrs then reweighed to calculate gravimetric and volumetric soil moisture. Additionally, a HH2 ThetaProbe (Delta-T Devices Ltd, Cambridge, UK) moisture meter reading was taken three times in close proximity to the soil cores. Sometimes, in the drier soil moisture conditions, more than three ThetaProbe measurements were taken when it was obvious that the soil-probe contact was poor (an unusually low voltage). In these cases, the very low values were not recorded and an additional reading was taken. These measurements were repeated until multiple samples of each BTI level were obtained for each tillage type including, conventional, strip (taken within planting row because soil moisture could vary outside of the strip tillage band), and no tillage. These measurements, after the removal of outliers, were averaged to determine the moisture ranges for each value of the BTI. Regression analysis was also used to obtain a continuous function for the BTI.

In addition to using the soil cores to develop the BTI, they were used to calibrate the ThetaProbe for the subsequent field experiment. The values from the three soil cores and three ThetaProbe measurements were each averaged and used as one value for analysis. The calibration of the ThetaProbe for Blackland Prairie soils at the Stiles Farm was made using regression analysis in SAS (2004).

**Results and Discussion**

Blackland Trafficability Index ratings for corn and cotton planting were developed using two producers on conventional tillage, three producers on strip tillage, and two producers on no-tillage located on six different farms (one producer operates a conventional and no-tillage management practice). A total of 28 field measured soil moistures ranged from 0.10 to 0.36 g $g^{-1}$ and 0.14 to 0.39 $m^3$ $m^{-3}$. The data collected from the producers to create the five Blackland Trafficability Index indices were averaged to determine the means to the corresponding moistures of “1, Too Dry”, “2, Dry Workable”, “3, Optimal”, “4, Wet Workable”, and “5, Too Wet” in gravimetric water content and volumetric water content (see Table 1.1 on p.11).

The friable range for gravimetric soil moisture in Texas Blackland Prairie soils was 0.17 to 0.26 g $g^{-1}$, whereas Morrison et al. (1990) discussed a range between 0.22 to 0.32 g $g^{-1}$. The friable range for soil volumetric water content was between 0.18 $m^3$ $m^{-3}$ to 0.28 $m^3$ $m^{-3}$. BTI planting moistures for corn and cotton were nearly identical and not significantly different from each other. Therefore, the same planting soil moistures could be used for corn and cotton.

Soil moisture data from producer interviews show that conventional tillage, strip tillage, and no-tillage regimes also have the same BTI ratings for planting corn (Fig 1.1) and cotton (Fig 1.2). Simple regression analysis in the corn BTI resulted in significant (p-value <0.05) slopes for both volumetric and gravimetric moisture, $r^2$ = of 0.81 and 0.68. In cotton, the slopes for volumetric and gravimetric BTI's were also significant (p-value <0.05), $r^2$ = 0.82 and 0.72, respectively. Soil moisture from the three middle indices, "Dry Workable", "Optimal", and "Wet Workable" were selected to be recreated for the field experiment portion of this project (Table 1.1).

The ThetaProbe calibration was linear with an $r^2$ of 0.77 and a RMSD of 0.03 g $g^{-1}$ for the gravimetric soil water content and an $r^2$ of 0.82 and a RMSD of 0.02 $m^3$ $m^{-3}$ for the volumetric soil water content (Fig. 1.3). The RMSD values for the ThetaProbe calibration were very good, considering that the average standard deviation of the triplicate gravimetric and volumetric measurements were 0.013 g $g^{-1}$ and 0.027 $m^3$ $m^{-3}$, respectively. Since the values for the corn and cotton BTI soil moistures were so similar, only one ThetaProbe calibration was used for this research, y = 0.00025x + 0.056. The variance around the calibration line increased around the higher water content measurements, this problem is fixable with a square-root transformation, but that transformation was not done for the BTI experiment. The regression results indicate the ThetaProbe a useful and reliable way to estimate water content of the Blackland Prairie soils, with volumetric measurements being the more accurate.

**Summary and Conclusions**

Collaborating with experienced producers on the Texas Blackland Prairie was crucial in establishing quantifiable, repeatable soil moisture contents for the planting establishment of corn and cotton across multiple tillage practices. One producer consistently rated his soil moistures lower than the others, which brought down the average. Additionally, the development of the ThetaProbe calibration was successful. In future applications, it is recommended to use a square-root transformation of the soil moisture for the ThetaProbe calibration.

**Table 1.1**. Results of the Blackland Trafficability Index in gravimetric and volumetric soil water contents for corn and cotton.

| Blackland Trafficability Index | Water content | Minimum/ Maximum | Standard deviation | Water content | Minimum/ Maximum | Standard deviation | Bulk density |
|---|---|---|---|---|---|---|---|
| | $g\ g^{-1}$ | $g\ g^{-1}$ | $g\ g^{-1}$ | $m^3\ m^{-3}$ | $m^3\ m^{-3}$ | $m^3\ m^{-3}$ | $g\ cm^{-3}$ |
| | | | -----corn----- | | | | |
| Too dry | 0.13 | 0.08/0.14 | 0.02 | 0.16 | 0.12/0.20 | 0.02 | 1.30 |
| Dry workable | 0.17 | 0.16/0.25 | 0.04 | 0.18 | 0.14/0.24 | 0.04 | 1.04 |
| Optimal | 0.22 | 0.16/0.31 | 0.05 | 0.24 | 0.20/0.32 | 0.04 | 1.13 |
| Wet workable | 0.26 | 0.23/0.27 | 0.02 | 0.28 | 0.21/0.27 | 0.04 | 1.05 |
| Too wet | 0.31 | 0.21/0.37 | 0.05 | 0.33 | 0.21/0.45 | 0.07 | 1.11 |
| | | | -----cotton----- | | | | |
| Too dry | 0.13 | 0.08/0.15 | 0.02 | 0.16 | 0.12/0.20 | 0.02 | 1.30 |
| Dry workable | 0.17 | 0.16/0.25 | 0.04 | 0.18 | 0.14/0.24 | 0.04 | 1.21 |
| Optimal | 0.22 | 0.16/0.31 | 0.05 | 0.24 | 0.17/0.31 | 0.04 | 1.10 |
| Wet workable | 0.26 | 0.22/0.26 | 0.02 | 0.28 | 0.33/0.41 | 0.02 | 1.23 |
| Too wet | 0.31 | 0.24/0.38 | 0.05 | 0.34 | 0.20/0.45 | 0.06 | 1.07 |

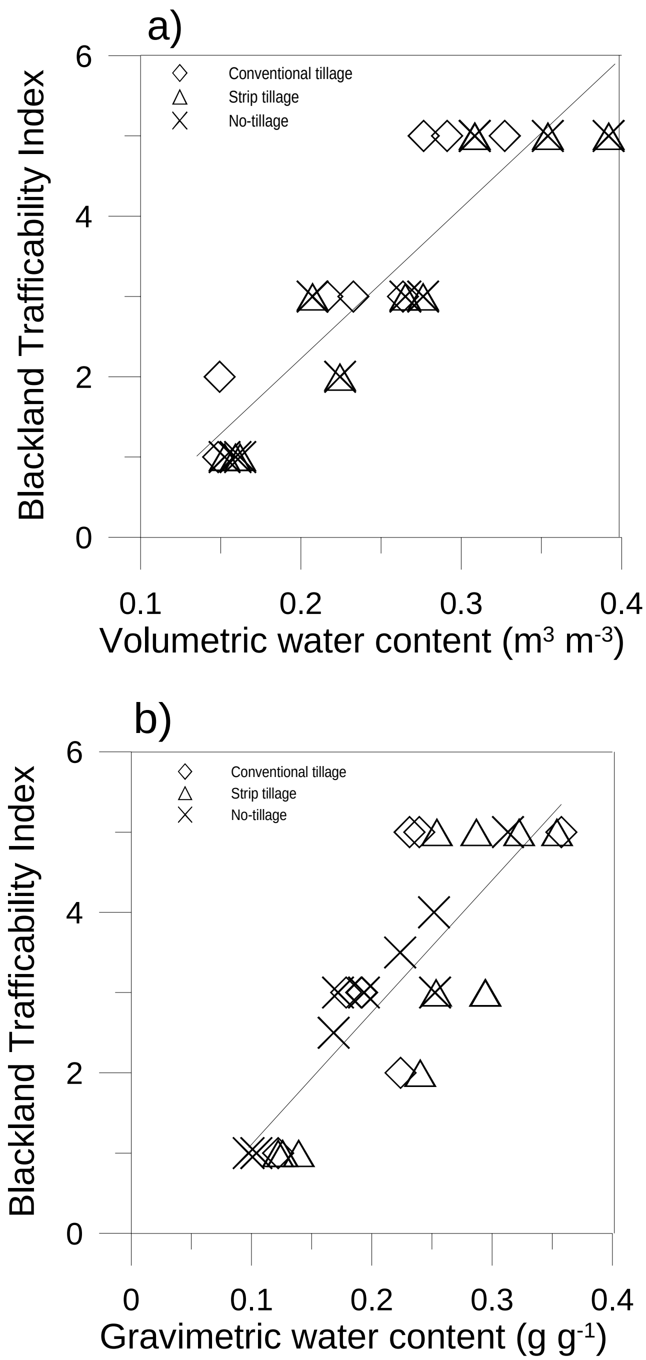



**Figure 1.1.** The Blackland Trafficability Index results for planting corn, expressed as a) volumetric soil water content and b) gravimetric soil water content.

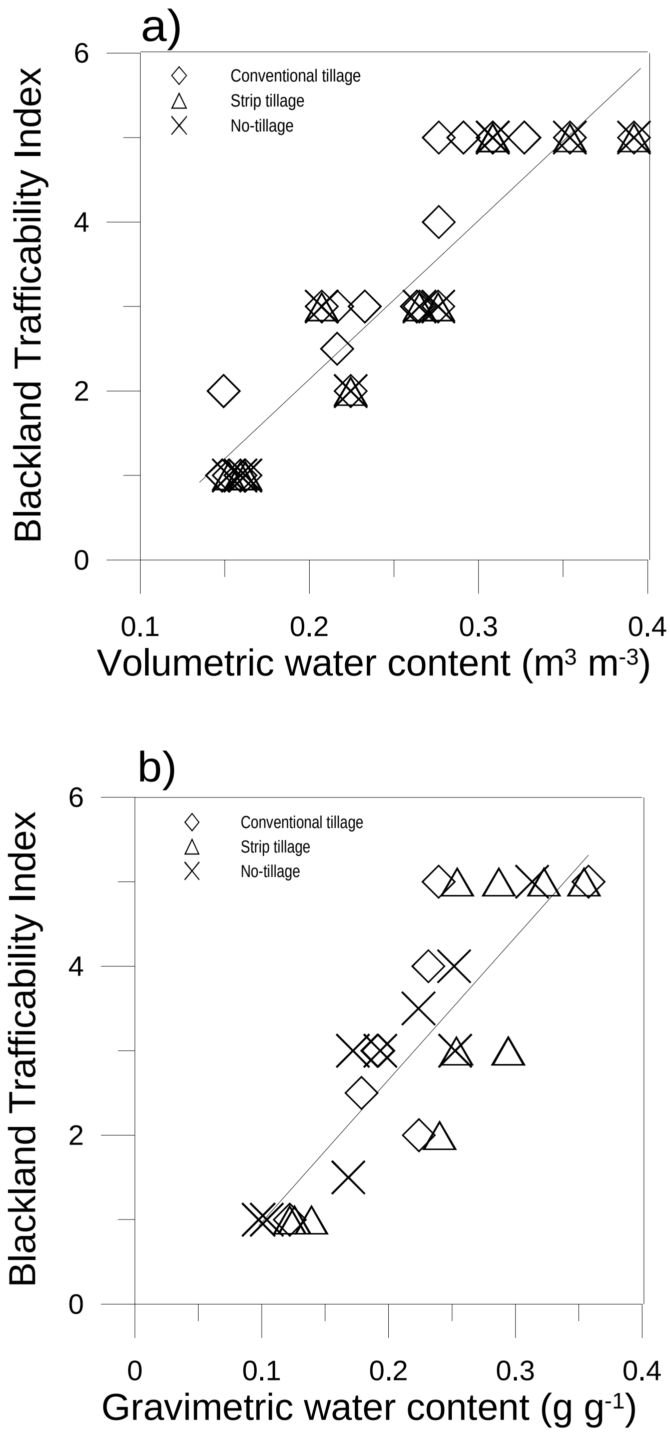



**Figure 1.2.** The Blackland Trafficability Index results for planting cotton, expressed as a) volumetric soil water content and b) gravimetric soil water content.

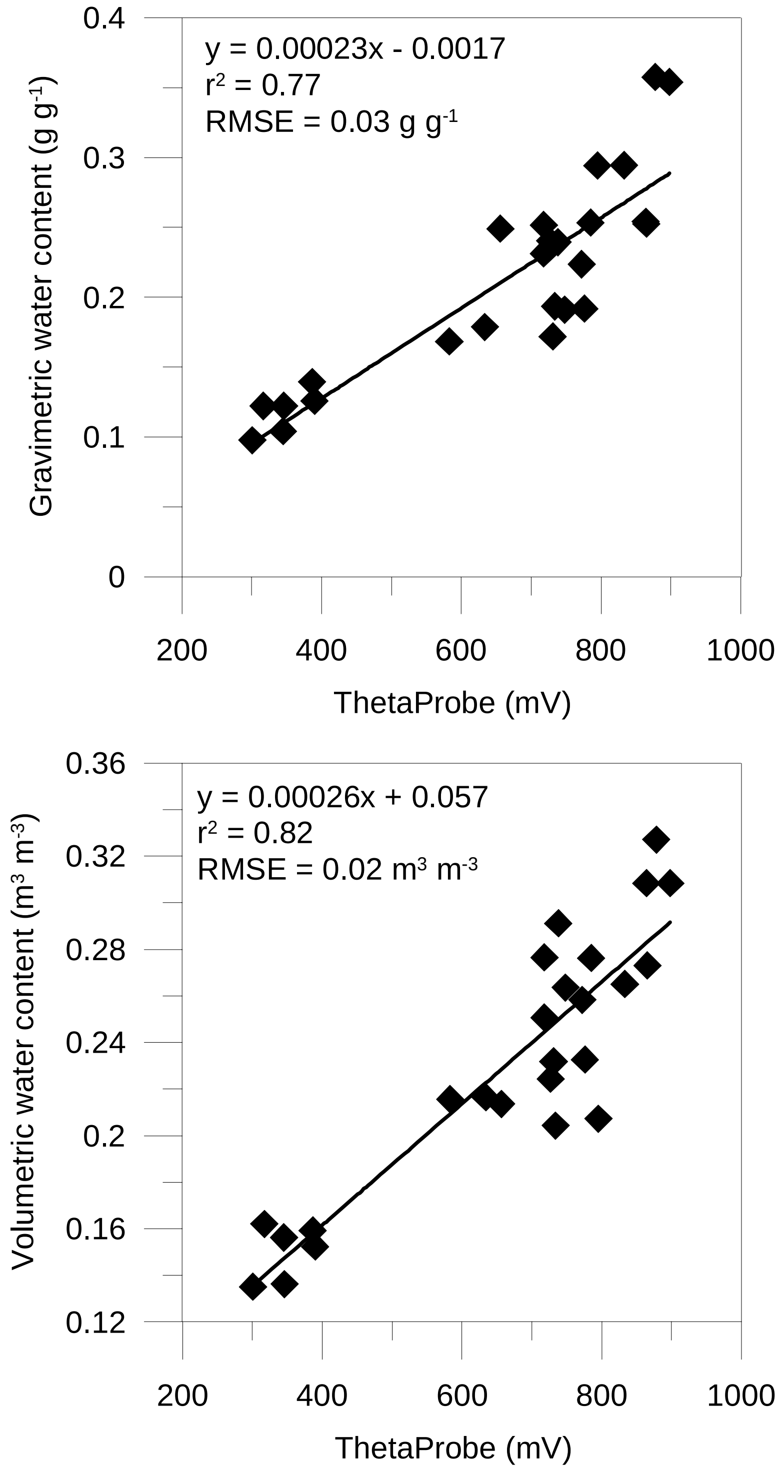



**Figure 1.3.** Calibration lines for converting mV ThetaProbe measurements into gravimetric and volumetric water content. RMSE is root mean squared error.

# CHAPTER II

# TESTING THE BLACKLAND TRAFFICABILITY INDEX FOR CORN

## Introduction

Corn (*Zea mays* L.) acres on the Texas Blackland Prairie have increased 22% over the last 10 years by adding a yearly average of 14,000 acres of planted corn. The price increase of this commodity as well as the unstable prices of other commodities has assisted this acreage increase (USDA NASS 2009). The Texas Blackland Prairie provides a long growing season and the soils are classified as USDA prime farmland. The deep, fine textured soils have very high water holding capacity and because of good soil structure, also have high plant-available water (USDA 2006). Water holding capacity and subsequent availability are an advantage in Texas production because the soils have the potential to sustain a crop through dry-spells which are often experienced during a Texas summer. These fertile soils require experience to manage as they are often referred to as “noon day soils” – before noon they are too wet to work, and after noon they are too dry.

In conversations with Extension personnel, a potential problem with planting under wetter soil moisture conditions, in no-tillage, was identified. Producers and agronomists suspected that soil compaction in the side wall of the seed furrow opening was retarding root growth. In general, the suspect problem was that planting too wet caused local soil compaction, resulting in poor seed-to-soil contact and ultimately delayed emergence or seedling mortality (Iqbal, 1998, Abrameit, 2006).

This research aimed to test whether there is a measureable response in the corn plant (shoot & root) to planting at three soil moistures identified by farmers as “optimal” or “workable” soil moistures. The Blackland Trafficability Index, discussed previously, was developed using experienced producers on the Texas Blackland Prairie to quantify in their expert opinion, on soil moisture contents that were “Dry Workable”, “Optimal” and “Wet Workable” for corn planting. This research collected was used to expand the precision agriculture and decision-aid instrument “toolbox” for producers. These tools can be used for management decisions when coupled with model simulations of the within-field and real-time temporal variability of soil moisture. The Precision Agricultural-Landscape Modeling System (PALMS), is one such model that can predict within field variability of soil moisture and thus provide a basis for management-specific decision aides. PALMS simulates key hydrologic and biophysical processes at a scale of physical realism and spatio-temporal detail (spatially, 10- to 20-m resolution) sufficient to evaluate the physical consequences of specific cropping, tillage, and fertilizer management strategies (Molling et al., 2005).

Physiologically, it is important to plant corn on the Texas Blackland Prairie when there is substantial soil moisture and acceptable soil temperatures. Corn is generally planted before April 1 but no earlier than February 1. Corn requires that soil temperatures at planting depth be at a minimum of 10 to 13° C for at least five consecutive days after planting. However, optimal soil temperatures are 15 to 18° C. Planting early in the season is recommended for corn in Texas to minimize moisture stress in the critical reproductive stages of the growing season. Corn plants use up to 0.4

cm of water a day during the 6-leaf stage and 0.8 cm of water a day during tasseling and pollination, when the plant is at maximum leaf area index (Smith, 1995).

Cox et al. (1990a) cited that there are often delays in the growth and development of maize in the northern U.S. corn belt, but that the delayed growth and development did not always result in reduced grain yields. There research showed that corn under no-tillage practices emerged on average one day later than corn planted into conventional tillage and ridge tillage. This trend, on average, continued through the growth of the plant from emergence to $V_6$ to silking. However, there results did show that by the silking stage and throughout the grain-filling period, no-tillage corn had a slightly higher crop growth rate than corn planted into conventional or ridge tillage.

Cox et al. (1990b) concluded that delayed growth under no-tillage and ridge tillage in their 1987 data set was limited to the vegetative period and did not influence total and kernel phtyomass at physiological maturity. The data from Cox et al. (1990b) is supported by Al-Darby and Lowery (1986) who found that delayed early season growth under no-tillage did not influence late-season growth in a Wisconsin study. In the 1988 date set of Cox et al. (1990b), results differed. Cooler temperatures and excess rainfall throughout the growing season did not allow the no-tillage corn to recover from the delayed emergence throughout the growing season. They concluded that no-tillage corn production is site specific and greatly depends on climatic and soil conditions.

The overall objective of the research was to test the response of corn to planting at three soil moistures identified in the Blackland Trafficability Index in both conventional and no-tillage systems. The hypothesis of the research was that planting at too high of a soil moisture in no-tillage would create side-wall compaction in the seed furrow that would impede cotton emergence in wet soil moisture conditions because of poor soil-seed contact or impeded root growth through local soil compaction. To test this hypothesis, crop emergence, shoot growth and root growth were measured 28 days after planting into conventional and no-tillage plots at three soil moistures.

**Materials and Methods**

To test the BTI, field plots were established at the Stiles Farm Foundation in Thrall, Texas on a Burleson Clay (Fine, smectitic, thermic Udic Haplustert; 30$^{o}$ 35’43.09” N 97$^{o}$ 17’6.46”W). The field is slightly terraced with 1-3% slopes in a cotton–grain sorghum rotation. The field has been under a tillage treatment study for the past seven years with treatments of no tillage, strip tillage, and conventional tillage applied to 16 rows on 96.5 cm centers by 366 m long and replicated four times. Two soil samples from the top 15 cm were collected within the planting row on either side of the steel box for characterization. Composite samples were used for particle size analysis (hydrometer method, Gee and Bauder, 1979), inorganic carbon (modified pressure calicimeter, Sherrod et al. 2002), and total carbon (Nelson and Sommers, 1982; Soil Survey Staff, 1996). These samples were analyzed for the soil surface of the conventional tillage and no-tillage plots. Organic carbon was calculated by subtracting total carbon from inorganic carbon.

Corn was planted into no-tillage and conventional tillage at three moisture contents. The plot sizes were 3 $m^2$ and each soil moisture treatment were replicated four times. The three soil moisture treatments were chosen to represent the soil moisture rankings of 2, 3, and 4 from the Blackland Trafficability Index. The moisture treatments were randomized within each 13-m wide by 40-m long tillage type.

Two days prior to planting the crop, soil moisture in the top 10 cm in each plot were measured using the ThetaProbe moisture meter. This base moisture for each plot was used to determine the amount of irrigation needed to establish the desired moisture. It was necessary to irrigate two days leading up to planting to insure proper soil moisture levels and distribution for planting. The plots were irrigated using the local well water and Rain Bird R-13 Rotary Nozzles configured in a head-to-head design covering $4m^2$. The system required 19.72 L $min^{-1}$ of water and applied water at a rate of 1.25 mm $min^1$. The amount of water irrigated was monitored using a TM050-N electronic water meter (Great Plains Industries, Wichita, KS) to insure the flow to the irrigation system remained constant. The amount of water needed to reach a specified volumetric water content ($\theta_{BTI}$) to 100 mm deep was estimated by taking an initial soil moisture reading ($\theta_i$) using the ThetaProbe. Then the following equations were used,

$$\Delta\theta = \theta_{BTI} - \theta_{i},, \quad (2.1)$$

$$W_a = \Delta\theta \text{ x } 100 \text{ mm, and} \quad (2.2)$$

$$T = W_a/1.25. \quad (2.3)$$

Where $W_a$ is the amount of water needed in mm; 1.25 is the rate at which the sprinklers were calibrated in mm $min^{-1}$; and t is the amount of time to irrigate for a desired BTI in min.

On the day of corn planting a four-row John Deere Max Emerge planter's depth was adjusted for planting at a rate of 185,000 seeds $ha^{-1}$ and 4.5 cm deep using Croplan

Genetics 7558RB. The high planting rate was selected to insure the maximum number of plants per plot. The planter had to be adjusted separately for the conventional tillage and no-tillage plots to maintain the same planting depth.

After planting, 0.2-m wide x 0.15-m deep steel boxes for each moisture and tillage replicate were driven into the ground to collect 0.45 m of planted row. Before excavation, two soil cores, 7 cm dia. by 6 cm deep, were collected next to the steel planting boxes within the planting row. These cores were used to determine gravimetric water content, bulk density, and volumetric water content. After excavating, the steel boxes with the in-situ soil were placed into an enclosed trailer for transport to growth chambers.

Within 8 hr. of excavating the planter boxes, the boxes were placed inside two growth chambers in a completely randomized design on 12 hour day/night cycles for 28 days. The daytime temperature was set to 24$^{o}$ C and night temperature set to 21$^{o}$ C. The temperature was monitored every 15 minutes in each growth chamber using a thermocouple wired to a Campbell 7X data logger. All plants received 1L of water as needed in the growth chambers to prevent plant death.

Plant emergence was observed daily at the same time. Plant emergence rate was calculated using an Emergence Rate Index (ERI) which is summed from the first day after planting until complete emergence. The ERI was calculated by,

$$ERI = \sum^{n} [np - (np-1)] / dap, \qquad (2.4)$$

where np is percentage of plants emerged on day n, (np-1) is percentage of plants emerged on day n-1, and dap is number of days after planting (Erbach,1982). In addition to monitoring the emergence rate in the growth chamber studies, overall emergence was recorded in the field plots. Plot layout as well as the stand count for the field plots can be found in Appendix B.

While in the growth chambers, the samples for Planting 1 were watered 10 and 18 days after planting using 1L of distilled water per sample. Additionally, the samples were watered the day before destructive sampling to assist the dissection of the soil blocks. For Planting 1, there were two different destructive sampling days (28 and 32 days after planting) due to a malfunction in one growth chamber which caused one set of samples to have a reduced number of growing degree days. These delayed samples were allowed to stay in the growth chamber an additional four days so that both sets were in the chamber for the same growing degree days. For Planting 2, the samples were watered 8 and 16 days after planting using 1L of distilled water per sample and were watered 27 days after planting for the destructive harvest.

After 28 days in the growth chambers, the planter boxes were removed for processing for above-ground and root biomass. Root biomass was collected from three sections within the planter box, as shown in Fig. 2.1. Section 1 represents in-furrow roots to planting depth; Section 2 represents out-of-furrow roots to planting depth; and Section 3 represents all roots below planting depth. The soil was lifted 50 mm out of the steel planter boxes by placing a block of wood (0.35 m long x 0.15 m wide x 0.05 m deep) beneath the planter box, and pushing down the four corners of the planter box around the wood block (Fig. 2.1). First, the inner 50 mm of the planter box was sectioned off using a metal frame (0.45 m long x 0.05 m wide x 0.05 m deep). Root zone Sections 2 and 3 were also separated from each other. Then the soil and roots from each section were soaked for 24 hr. in water and Calgon soap. After soaking, the soil was washed from the roots using a Seedburo Equipment Company no. w 5/64" round (commercial) sieve and then were dried for 24 hrs at $60^{o}$ C and weighed.

Because the number of plants in each planter box varied, the weights for above ground (shoot) and below ground (root) biomass were normalized by dividing the mass of each box by the total number of plants in the box. Normalized biomasses from replicates each of the three sections and cumulative biomasses were averaged compared between treatments. A Root Ratio was determined by dividing the masses of normalized in-furrow roots (root zone 1) by the means of the normalized out-of-furrow roots (root zone 2 + root zone 3). If the Root Ratio is greater than 1, then there are more in-furrow roots than out-of-furrow roots. If the Root Ratio is less than 1, then there are more out-of-furrow roots than in-furrow roots.

Three attempts to made to replicate the “Dry Workable”, “Optimal”, and “Wet Workable” BTI’s into field conditions for the sowing of corn on August 14, 2007, August 31, 2007 (Planting 1) and November 9, 2007 (Planting 2). The first planting event, August 14, had technical and logistical problems, which led to samples that were not irrigated to the correct moisture according to eth experimental design. Therefore, the data from planting one are not included in the analysis. Five days of weather data leading up to Planting 1 and Planting 2 is found in APPENDIX E.

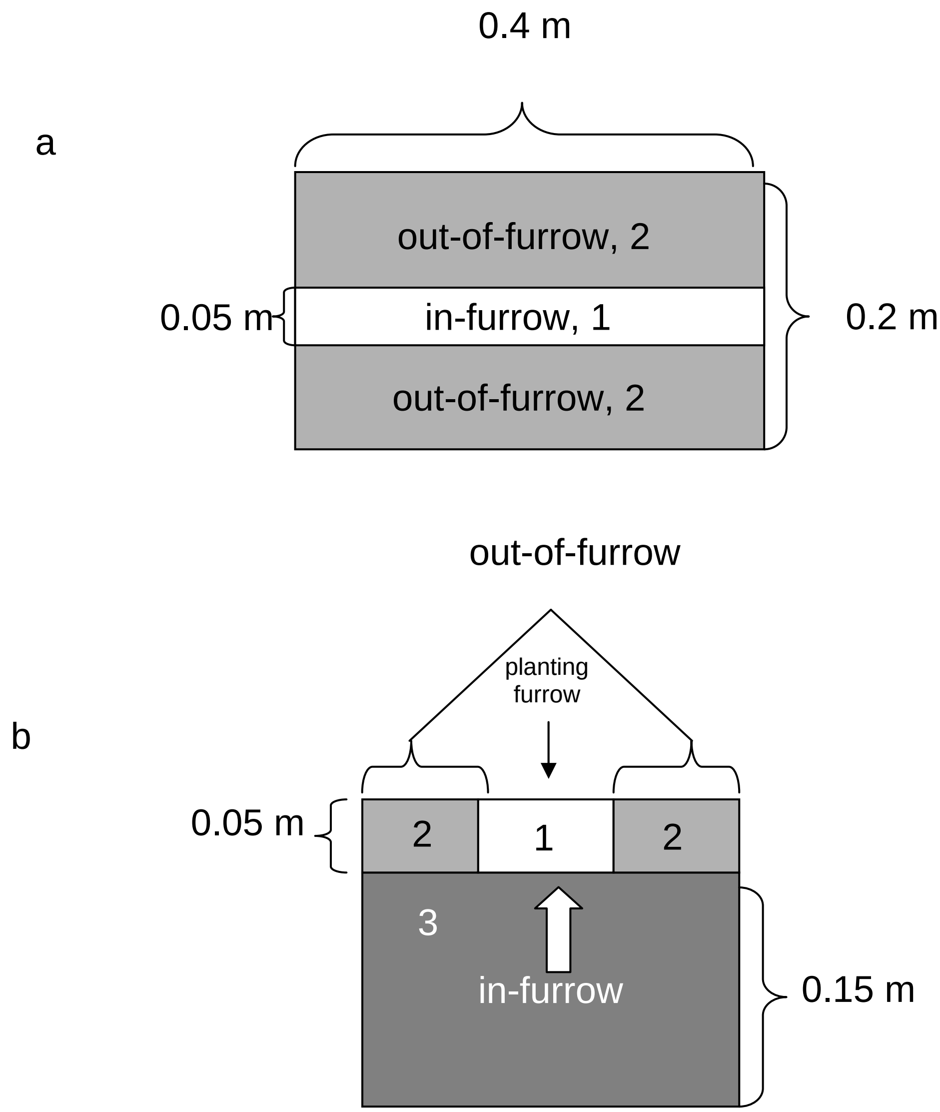



**Figure. 2.1**. Schematic of root biomass harvest from each planter box with root harvest sections labeled 1, 2, and 3. The aerial view a), shows dimensions of the box and planting sections, and the lateral view b), shows all root collection

Mean separations using Fischer's Protected LSD test at a p-value of 0.05 were used to compare plant response to soil moisture treatments using a completely randomized design (SAS, 2004). The time replicates were first compared to decide if the mean results of each planting could be combined, using the GLM procedure in SAS. If the means of each time repetition were not significantly different, analysis was combined so that n=8 for each soil moisture treatment, otherwise, n = 4.

**Results and Discussion**

*Site Characterization*

The tillage and no-tillage plots had similar texture and inorganic carbon amounts. The texture if the soil surface for both plots was clay loam with 33% clay. Organic carbon in the no-tillage plots averages 1.50 g $kg^{-1}$ which was significantly higher than the conventional tillage plots, which had 1.02 g $kg^{-1}$ of organic carbon. The particle size and inorganic carbon results confirm that the plots represented the same initial soil type. The no-tillage plots were higher in organic carbon, which is a commonly reported result of multiple years of no-tillage (Carter 1992).

*Emergence Rate Index*

The Emergence Rate Index (ERI) is highest value for treatments whose plants emerged in entirety the fastest, while the lowest value describe treatments whose plants emerged the slowest. Within the no-tillage, the "Dry Workable" treatments emerged the slowest while the "Optimal" and "Wet Workable" had the same emergence rates, which were significantly different from the "Dry Workable" treatment. In the conventional tillage, the "Dry Workable" treatments emerged the slowest, followed by the "Optimal" treatments, and finally, the “Wet Workable” treatments emerged the fastest (Table 2.1). Although there is a positive trend between the ERI and soil moisture treatment, the “Optimal” treatment ERI is not significantly different from either the “Dry Workable” or the “Wet Workable” treatments; however, “Dry Workable” and “Wet Workable” are significantly different from each other. This positive trend between BTI and soil moisture content at planting is linear, $r^2 = 0.20$ (Fig 2.2). The results show that emergence is influenced by soil moisture and that soil moisture below 20% gravimetric water content can delay emergence.

Iqbal et al., (1998) reported results from a similar experiment, using a John Deere Max Emerge planter and in clay loam textured soils. Our results differ from Iqbal et al.’s (1998) first year of research, where a negative correlation between soil moisture and emergence rate was reported. The negative correlation was attributed to sidewall smearing and poor seed-to-soil contact. Iqbal et al., (1998) reported no significant differences between soil moisture treatments, whereas our data showed significant differences. The second year of the Iqbal work reported the intermediate moisture treatment emerging the fastest. The slower emergence in the dry soil moisture treatment was attributed to lack of water, while the slower emergence at the high soil moisture treatment was attributed to cloddy soils, poor furrow closure, poor seed-to-soil contact, and a smeared seed furrow sidewall. Iqbal’s soil moisture contents ranged from 15.8% to 28.9% on a dry basis and were very similar to the soil moisture ranges for this research.

**Table 2.1.** Mean Emergence Rate Index (ERI) and observed field emergence means (percent emerged) for Plantings 1 and 2.

| Blackland Trafficability Index | Growth chamber | Observed field emergence | |
|---|---|---|---|
| | Plantings 1 and 2 | Planting 1 | Planting 2 |
| | | ----plants $ha^{-1}$ (% emergence)---- | |
| | *No-tillage* | | |
| Dry Workable | 0.171[b] | 182,000 (98)[a] | 156,000 (85)[ns] |
| Optimal | 0.193[a] | 173,000 (94)[b] | 175,000 (95)[ns] |
| Wet Workable | 0.193[a] | 179,000 (96)[ab] | 163,000 (88)[ns] |
| LSD | 0.021 | 7100 | 32,500 |
| | *Conventional* | | |
| Dry Workable | 0.166[b] | 178,000 (96)[ns] | 105,000 (57)[ns] |
| Optimal | 0.182[ab] | 170,000 (92)[ns] | 139,000 (75)[ns] |
| Wet Workable | 0.196[a] | 177,000 (96)[ns] | 134,000 (73)[ns] |
| LSD | 0.028 | 37,600 | 73,300 |

*ns – Means are not significant between treatments.
**a, b, ab – Means followed by a different letter are statistically significant between treatments at a 0.05 significance level.

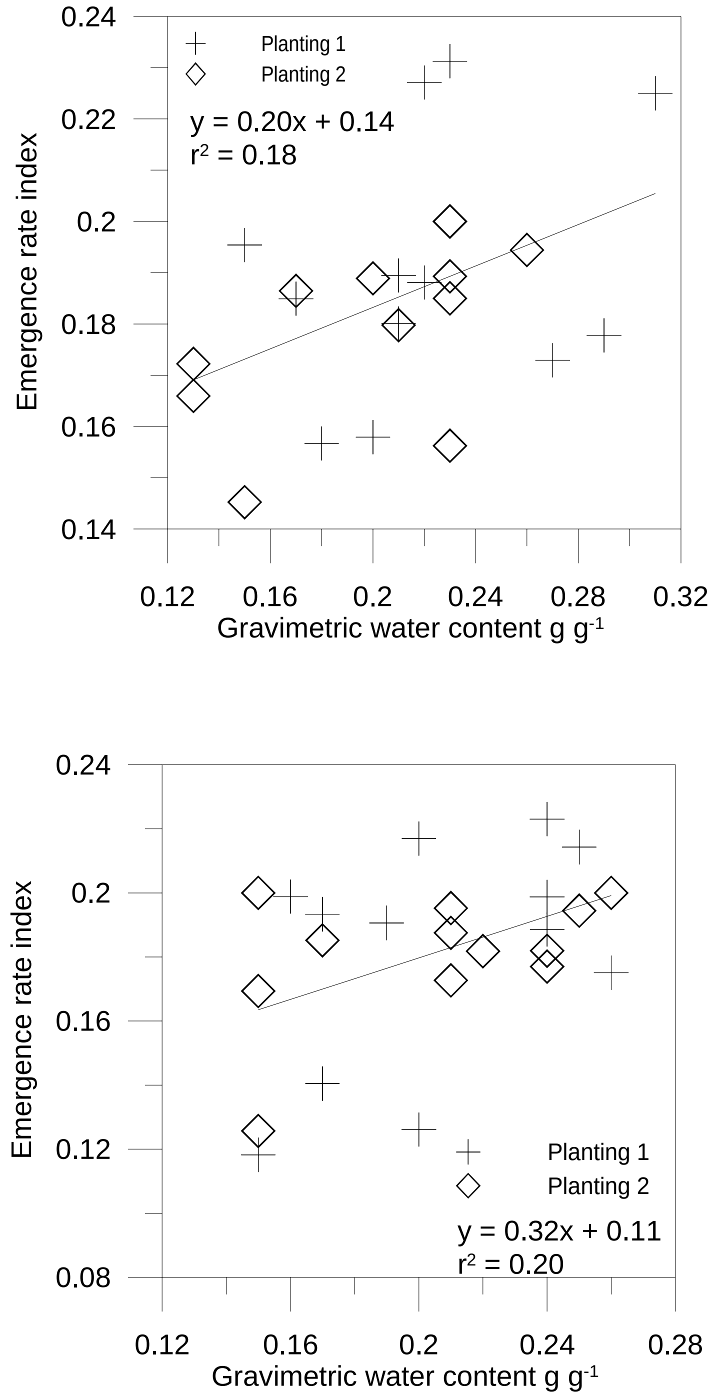



**Figure 2.2.** The relationship between gravimetric water content and the Emergence Rate Index for corn planting in no-tillage and conventional tillage.

The emergence values from the field showed more overall emergence in the no-tillage treatments than the conventional tillage treatments (Table 2.1). Higher overall emergence in no-tillage was unexpected because of the common perception that conventional tillage has better stand establishment than no-tillage. The higher soil organic carbon found in the no-tillage could have resulted in a stronger soil structure which allowed for better overall resistance to smearing, better soil moisture and aeration, all resulting in better seed-to-soil contact in a clay loam soil. Karunatilake et al. (2000) concluded that a lower soil moisture level, from increased air circulation and poor seed-to-soil contact in a cloddy surface layer, was the reason for reduced emergence in plowed versus no-tillage plots. A cloddy surface layer cannot be attributed to the lower stand count in this research, because the plots were cultivated with a two-row tiller which broke any large clods. Additionally, any clods that remained after tillage had disintegrated from heavy rainfalls and natural drying between the time of tillage in the spring and planting in August and November.

*Above and Below Ground Biomass*

The biomass values from Planting 1 and 2 were statistically different (p-value>0.05) could not be combined. The treatment means for Planting 1 were twice that of Planting 2; therefore, the two plantings could not be combined (Table 2.2). Although fertility tests were not made, it is possible that fewer nutrients were available in Planting 2 compared to Planting 1.

Though treatment differences were significant in only one case (no-tillage, Planting 2, shoot biomass), treatment means did increase with increasing soil moisture at planting. In the majority of cases, planting corn at “Wet Workable” soil moisture produced more above and below ground biomass. Biomass values reported in table 2.2 are similar to those reported in Karuntilake et al. (2000) and Maizlesh et al. (1980); they measured corn shoot biomasses of 0.118 g plant$^{-1}$ at 23 days after planting and 0.24 g plant$^{-1}$ at 17 days after emergence, respectively. These results are similar to the second year of research by Iqbal et al. (1998) who had shoot biomass means ranging from 0.389 g plant$^{-1}$ to 0.686 g plant$^{-1}$ and by Karuntilake et al. (2000) who had shoot biomass mean’s of 0.708 g plant$^{-1}$. In a growth chamber study, Tubeileh et al. (2003), using a growth medium consisting of a mixture of sand and a sandy loam, was packed to two bulk densities, 1.30 g cm$^{-3}$ and 1.45 g cm$^{-1}$, and the plants were then harvested 21 days after planting. They found a shoot biomass of 1.31 g plant$^{-1}$ in the lower bulk density and 1.05 g plant$^{-1}$ in the higher bulk density. The literature had similar results for no-tillage root biomass through Karuntilake et al. (2000) who had a mass of 0.208 g plant$^{-1}$

**Table 2.2.** Above and below ground biomass means and shoot-to-root ratios for no-tillage and conventional tillage treatments for Plantings 1 and 2, n = 8 where plantings are combined, otherwise, n = 4.

| BTI | Above ground biomass | | Below ground biomass | | Shoot-to-root ratio | | |
|---|---|---|---|---|---|---|---|
| | Planting 1 | Planting 2 | Planting 1 | Planting 2 | Planting 1 and 2 | Planting 1 | Planting 2 |
| | -------g plant$^{-1}$------- | | | | | | |
| | *No-tillage* | | | | | | |
| Dry workable | 0.50$^{ns}$ | 0.24$^{b}$ | 0.380$^{ns}$ | 0.183$^{ns}$ | 1.36$^{ns}$ | - | - |
| Optimal | 0.67$^{ns}$ | 0.29$^{ab}$ | 0.523$^{ns}$ | 0.208$^{ns}$ | 1.34$^{ns}$ | - | - |
| Wet workable | 0.73$^{ns}$ | 0.42$^{a}$ | 0.568$^{ns}$ | 0.265$^{ns}$ | 1.44$^{ns}$ | - | - |
| LSD | 0.375 | 0.152 | 0.255 | 0.299 | 0.304 | | |
| | *Conventional tillage* | | | | | | |
| Dry workable | 0.70$^{ns}$ | 0.42$^{ns}$ | 0.568$^{ns}$ | 0.305$^{ns}$ | - | 0.88$^{ns}$ | 1.35$^{ns}$ |
| Optimal | 0.86$^{ns}$ | 0.48$^{ns}$ | 0.622$^{ns}$ | 0.275$^{ns}$ | - | 1.23$^{ns}$ | 1.75$^{ns}$ |
| Wet workable | 1.00$^{ns}$ | 0.49$^{ns}$ | 0.783$^{ns}$ | 0.321$^{ns}$ | - | 1.31$^{ns}$ | 1.53$^{ns}$ |
| LSD | 0.369 | 0.349 | 0.371 | 0.411 | | 0.236 | 0.643 |

*ns – Means are not significant between treatments.
**a, b, ab – Means followed by a different letter are statistically significant between treatments at a 0.05 significance level.

at 35 days after planting. These data are much higher than data found in the literature which showed means of 0.309 g $plant^{-1}$ and 0.38 g $plant^{-1}$ ($2^{nd}$ year of research Iqbal et al. (1998) and Maizlesh et al. (1980) respectively).

The shoot-to-root ratio presents an index to compare the growth of the roots compared to the shoot. Changes in the shoot-to-root ratio between soil moisture treatments might present evidence of stress for developing root growth. Within the no-tillage treatments, the shoot-to-root ratio for Planting 1 and Planting 2 could be statistically combined, but the conventional treatments for Planting 1 and Planting 2 could not be combined.

The no-tillage shoot-to-root ratio showed a positive trend as compared to soil moisture, producing more biomass in the shoots than in the roots(Table 2.2). This is similar to the conventional tillage treatments where there was a positive trend associated with soil moisture and the shoot-to-root ratio (Table 2.2). The treatments planted at higher soil moistures in the conventional tillage produced greater shoot biomass than root biomass. The greater root biomass compared to shoot biomass in the no-tillage could be attributed to weak evidence of some sidewall compaction or less available water supplied by the soil for shoot growth. The greater shoot biomass in the conventional tillage could be a function of more adequate water supply; therefore the plant's energy was spent producing greater amounts of foliage.

Results in the literature provided a wide range of shoot-to-root ratios: Fageria (2002) had shoot-to-root ratios of 2.4; Iqbal et al. (first and second year of research respectively) had ratios of 0.115 and 0.309; Maizlesh (1980) had ratios of 0.63 (17 days after emergence (DAE, growth chamber), 1.5 at 12 DAE (field study), and 2.6 22 DAE (field study).

The root biomass means found in-furrow root zone 1, out-of-furrow root zone 2, and out-of-furrow root zone 3, all followed the trend of greater biomass at higher soil moisture at planting. The treatment means for Planting 1, no-tillage, were between 1.5 and 2.25 times greater than Planting 2. The treatment means for conventional tillage, Planting 1, were between 2 to 4.75 times greater than Planting 2. Although root zone means between the two planting were different, perhaps due to nitrogen availability, similar root biomasses have been reported by Iqbal et al., (1998). In-furrow roots of the Iqbal work had lower means for the first and second year of research, 0.065 and 0.041 g $plant^{-1}$ respectively. Iqbal et al. (1998) had similar out-of-furrow root results with 0.268 g $plant^{-1}$.

A Root Ratio (in-furrow root mass divided by out-of-furrow root mass) was calculated to help quantify any difference in root exploration between the soil moisture treatments. Essentially increases in the Root Ratio between treatments may indicate some restriction in root growth from sidewall compaction. No significant differences in Root Ratio were found between soil moisture treatments. In no-tillage, Plantings 1 and 2 had the largest Root Ratio in "Dry Workable" (Table 2.3). "Optimal" had the second largest Root Ratio. A regression between soil moisture and Root Ratio shows a negative correlation with a significant slope and a $r^2$ of 0.35, even though, there are no significant differences between treatments (Fig. 2.3).

In conventional tillage, Plantings 1 and 2 had the largest root ratio in "Optimal" (Table 2.3). Iqbal et al. (1998) had a similar in-furrow root to out-of-furrow root ratio of 1.3. The regression of soil moisture to Root Ratio was not significant for conventional tillage (data not shown).

**Table 2.3.** Normalized root biomass means, for in-furrow root zone 1, and out-of-furrow root zones 2 and 3 for Plantings 1 and 2, at three soil moistures from the Blackland Tillage Index (BTI), n = 4.

| BTI | Root zone 1 | | Root zone 2 | | Root zone 3 | | Root Ratio (Root zone 1 / (root zone 2+3)[1]) | |
|---|---|---|---|---|---|---|---|---|
| | Planting 1 | Planting 2 | Planting 1 | Planting 2 | Planting 1 | Planting 2 | Planting 1 | Planting 2 |
| | ----------------------------------------g plant$^{-1}$---------------------------------------- | | | | | | | |
| | | | | No-tillage | | | | |
| Dry Workable | 0.208$^{ns}$ | 0.095$^{b}$ | 0.058$^{ns}$ | 0.004$^{b}$ | 0.114$^{b}$ | 0.084$^{ns}$ | 1.32$^{ns}$ | 1.41$^{ns}$ |
| Optimal | 0.238$^{ns}$ | 0.104$^{ab}$ | 0.090$^{ns}$ | 0.016$^{a}$ | 0.195$^{a}$ | 0.088$^{ns}$ | 0.88$^{ns}$ | 1.30$^{ns}$ |
| Wet Workable | 0.236$^{ns}$ | 0.141$^{a}$ | 0.132$^{ns}$ | 0.015$^{a}$ | 0.200$^{a}$ | 0.109$^{ns}$ | 0.76$^{ns}$ | 1.22$^{ns}$ |
| LSD | 0.091 | 0.040 | 0.131 | 0.010 | 0.078 | 0.067 | 0.644 | 0.922 |
| | | | | Conventional tillage | | | | |
| Dry Workable | 0.228$^{ns}$ | 0.135$^{b}$ | 0.073$^{ns}$ | 0.046$^{b}$ | 0.267$^{ns}$ | 0.123$^{a}$ | 0.70$^{ns}$ | 1.15$^{ns}$ |
| Optimal | 0.274$^{ns}$ | 0.156$^{ab}$ | 0.075$^{ns}$ | 0.057$^{ab}$ | 0.273$^{ns}$ | 0.062$^{ab}$ | 1.14$^{ns}$ | 1.41$^{ns}$ |
| Wet Workable | 0.277$^{ns}$ | 0.169$^{a}$ | 0.124$^{ns}$ | 0.071$^{a}$ | 0.382$^{ns}$ | 0.081$^{b}$ | 0.62$^{ns}$ | 1.21$^{ns}$ |
| LSD | 0.069 | 0.032 | 0.083 | 0.024 | 0.304 | 0.125 | 0.814 | 1.37 |

*ns – Means are not significant between treatments.

**a, b, ab – Means followed by a different letter are statistically significant between treatments at a 0.05 significance level.

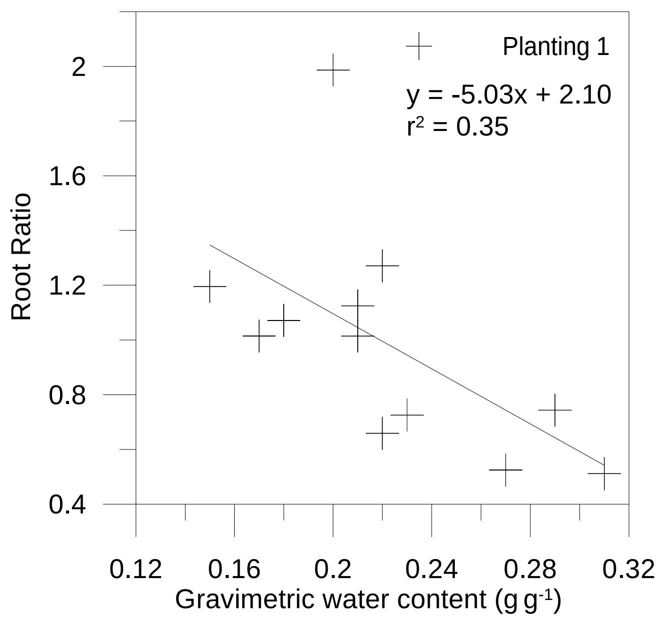



**Figure 2.3.** The relationship between gravimetric water content and the root ratio values for corn planting into no-tillage.

**Summary and Conclusions**

The development of the Blackland Trafficability Index has proven to be reliable guide for estimating the effects of planting corn on Texas Blacklands based upon soil moisture. In conventional tillage, the data showed that corn planted at the “Wet Workable” soil moisture content emerged faster than in soil moisture deemed “Optimal” by experienced producers on the Texas Blackland Prairie. In no-tillage, emergence was equally as fast in “Wet Workable as in “Optimal” soil moisture content. It should be noted that producers commented that corn planted at the “Dry Workable” soil moisture content are generally anticipating a rainfall event shortly after planting. The corn planted in this experiment did emerge at “Dry Workable” without adding water, but water was needed to prevent the plantlets from dying before harvesting the biomass.

Very few significant differences were found in corn root and shoot growth responses to planting a different soil moistures. The “Wet Workable” soil moisture content provided the greatest amount of above and below ground biomass. Although the “Wet Workable” soil moisture treatments had the greatest amount of in-furrow roots, they also had the greatest amount of out-of-furrow roots. If the soil density was increased in the seed furrow channel, due to smearing when planted at a high soil moisture content, conclusive evidence was not observed in this experiment. One variable eliminated from this experiment was wind. High winds after planting corn in the Texas Blackland Prairie (mid February through the beginning of March) can enhance evaporation which could facilitate soil cracking at the seed furrow channel and therefore expose the young roots. Based on Root Ratio values, roots were denser in-furrow under

“Dry Workable” soil moisture in no-tillage and in “Optimum” soil moisture in conventional tillage. Thus, these data show no evidence of a negative effect of planting at high soil moisture.

The quantification of soil moisture contents producers are willing to work their fields will be an important asset for developing a decision-aid tool for planting crops on the Texas Blackland Prairie. Results of this study suggest slight benefit to planting at “Wet Workable”, compared to “Optimal” soil moisture in the Blackland Prairie. However this study did not address long term compaction by equipment from planting at “Wet Workable”.

# CHAPTER III

# TESTING THE BLACKLAND TRAFFICABILITY INDEX FOR COTTON

## Introduction

Dryland cotton (*Gossypium hirsutum* L.) production on the Texas Blackland Prairie is an important economic component to Texas agriculture. From 1998 to 2006, annual cotton production on the Texas Blackland Prairie averaged over 130,000 acres planted annually. From 2007 to 2009, those numbers have average 73,000 acres planted. The increased price of other commodities such as corn and soybean has caused this decrease in production acres. (USDA NASS 2009).

The Texas Blackland Prairie provides a long growing season and the soils are classified as USDA prime farmland. The deep, fine-textured soils have very high water holding capacity and because of good soil structure, also have high plant-available water (USDA 2006). Water holding capacity and subsequent availability are an advantage in Texas dryland production because the soils have the potential to sustain a crop through dry-spells which are often experienced during a Texas summer. These fertile soils require experience to manage as they are often referred to as “noonday soils” – before noon they are too wet to work, and after noon they are too dry.

In conversations with Extension personnel, a potential problem with planting under wetter soil moisture conditions, in no-tillage, was identified. Producers and agronomists suspected that soil compaction in the side wall of the seed furrow opening was retarding root growth. In general, the suspect problem was that planting too wet caused local soil compaction, resulting in poor seed-to-soil contact and ultimately delayed emergence or seedling mortality (Iqbal, 1998; Abrameit, 2006).

This research aimed to test whether there is a measureable response in the cotton plant (shoot & root) to planting at three soil moistures identified by farmers as "optimal" or "workable" soil moistures. The Blackland Trafficability Index, discussed previously, was developed using experienced producers on the Texas Blackland Prairie to quantify in their expert opinion, on soil moisture contents that were "Dry Workable", "Optimal" and "Wet Workable" for cotton planting. This research collected was used to expand the precision agriculture and decision-aid instrument "toolbox" for producers. These tools can be used for management decisions when coupled with model simulations of the within-field and real-time temporal variability of soil moisture. The Precision Agricultural-Landscape Modeling System (PALMS), is one such model that can predict within field variability of soil moisture and thus provide a basis for management-specific decision aides. PALMS simulates key hydrologic and biophysical processes at a scale of physical realism and spatio-temporal detail (spatially, 10- to 20-m resolution) sufficient to evaluate the physical consequences of specific cropping, tillage, and fertilizer management strategies (Molling et al., 2005).

Differences in soil moisture and temperature regimes between no tillage and conventional tillage cropping systems is well documented (Stevens et al., 1992, Schwab et al., 2002, Triplett and Dick, 2008). Karamanos et al. (2004) noted that gravemetric water content was consistently higher in no-tillage plots and lowest in conventional tillage plots on a clay loam soil. The difference between no-tillage and conventional tillage gravimetric water content remained statistically significant between treatments throughout the experiment, 34 days after planting to harvest, and the maximum difference between soil moisture was measured at harvest. The higher soil water contents in no-tillage compared to conventional tillage fields will reduce soil temperatures, which will also cause a reduction in seedling emergence and growth of cotton (Stevens et al., 1992). Our experiment will hold soil temperature constant between tillage treatments and soil moisture at planting was varied. Nonetheless, no-tillage and conventional tillage treatments had identical soil moistures.

Producers and Natural Resources Conservation Service specialists have observed poor germination of seedlings and less vigorous seedlings in no-tillage operations as compared to conventional tillage practices in the Blackland Prairie (Nyakatawa and Reddy, 2000). Reduced germination in no tillage might be from temperature, soil moisture, or poor seedling-soil contact from planting too wet. In the literature, experiments by Nyakatawa and Reddy (2000) showed that no-tillage systems significantly emerged more plants than conventional tillage (Nyatakawa et al 2000; Boquet et al 2004). Cotton requires a soil temperature at planting depth to be at least 18° C for three consecutive days (Smith, 1995).

Delayed emergence causes potential problems to producers and can lead to delayed growth and maturity and may subsequently reduce lint yield (Nyakatawa and Reddy, 2000; Mert et al., 2006). Therefore, cultural and agronomic management practices promoting the establishment of early squares often result in better cotton yields (Nyakatawa et al., 2000). They also recorded no-tillage plants having 7-8 more squares per plant during flowering than did the conventional tillage treatment in both years of study. This increase in squares was attributed to a higher amount of soil moisture in the no-tillage plots. Malik et al. (1979) concluded that water deficit decreases shoot growth rate, plant height and yield. However, root growth was not as sensitive to drought as the shoot growth. These data are corroborated by Ball et al. (1994) who concluded root elongation of cotton plants was less sensitive to drought than the leaves. Ball et al. (1994) further concluded that smaller cotton roots are affected the most by drought, and as root size increased, less effect was noticed.

The overall objective of the research was to test the response of cotton to planting at three soil moistures identified in the Blackland Trafficability Index in both conventional and no-tillage systems. The hypothesis of the research was that planting at too high of a soil moisture in no-tillage would create side-wall compaction in the seed furrow that would impede cotton emergence in wet soil moisture conditions because of poor soil-seed contact or impeded root growth through local soil compaction. To test this hypothesis, crop emergence, shoot growth and root growth were measured 28 days after planting into conventional and no-tillage plots at three soil moistures.

**Materials and Methods**

To test the BTI, field plots were established at the Stiles Farm Foundation in Thrall, Texas on a Burleson Clay (Fine, smectitic, thermic Udic Haplustert; 30$^{o}$ 36’03.14” N 97$^{o}$ 18’08.35”W). The field is slightly terraced with 1-3% slopes in a cotton–grain sorghum rotation. The field has been involved in an ongoing tillage treatment study for the previous seven years with treatments of no tillage, strip tillage, and conventional tillage, which are applied to 16 rows on 96.5 cm centers by 366 m long, and replicated four times. Surface soil properties, including clay content, total carbon, bulk density, and inorganic carbon are tabulated in Appendix A and discussed in Chapter II.

Cotton was planted into no-tillage and conventional tillage at three moisture contents. The plot sizes were 3 $m^2$ and each soil moisture treatment was replicated four times. The three soil moisture treatments were chosen to represent the soil moisture rankings of Dry Workable, Optimum, and Wet Workable from the Blackland Trafficability Index. The moisture treatments were randomized within each 13-m wide by 40-m long strip under each tillage type.

Two days prior to planting the cotton (the plots received irrigation over a two day period), soil moisture in the top 10 cm in each plot was measured using the ThetaProbe moisture meter. According to the base moisture of each plot, the plots were irrigated, using water from the local well, to establish three moisture levels. The target moisture levels were identified by the BTI; Dry Workable ($\theta_2$ = 0.19 $m^3$ $m^{-3}$), Optimum ($\theta_3$ = 0.24 $m^3$ $m^{-3}$), and Wet Workable ($\theta_4$ = 0.28 $m^3$ $m^{-3}$). The irrigation system used Rain Bird R-13 Rotary Nozzles configured in a head-to-head design and covered a 4 $m^2$ area. The system required 19.72 L $min^{-1}$ and applied at a rate of 1.25 mm $min^{-1}$. The amount of water irrigated was monitored using a TM050-N electronic water meter (Great Plains Industries, Wichita, KS). The amount of water needed to reach the specified volumetric water content ($\theta_{BTI}$) to 100 mm deep was estimated by taking an initial soil moisture reading ($\theta_i$) using the ThetaProbe. Then the following equations were used,

$$\Delta\theta = \theta_{BTI} - \theta_{i,} \quad (3.1)$$

$$W_a = \Delta\theta \times 100 \text{ mm, and} \quad (3.2)$$

$$T = W_a/1.25, \quad (3.3)$$

where $W_a$ is the amount of water needed in mm; 1.25 is the rate at which the sprinklers were calibrated in mm min $^{-1}$; and t is the amount of time to irrigate for a desired BTI in min.

On the day of planting [June 2, 2008 (Planting 1) and June 3, 2008 (Planting 2)], a four row John Deere Max Emerge planter was adjusted for planting at a rate of 395,000 seeds ha$^{-1}$ at 2.5 cm deep using D&PL 445 RRBG1. The high planting rate was selected to insure the maximum number of plants per plot. The planter was adjusted separately for the conventional tillage and no-tillage plots to maintain the 2.5 cm planting depth. Plot layout as well as the stand count for the field plots can be found in Appendix C for the plantings events. Five days of weather data leading up to Planting 1 and Planting 2 is found in APPENDIX E.

After planting, 0.2-m wide x 0.15-m deep steel boxes for each moisture and tillage replicate were driven into the ground to collect 0.45 m of planted row. Before excavation, 2 soil cores, 7 cm dia. by 6 cm deep, were collected next to the steel planting boxes within the planting row. These cores were used to determine gravimetric water content, bulk density, and volumetric water content. The steel boxes were then excavated and placed into an enclosed trailer for transport to a green house.

Within 24 hours of excavating the boxes from the fields, the boxes were placed inside a greenhouse for 28 days. The daytime temperature reached an average daily maximum of 95$^o$ C and an average night temperature of 24$^o$ C. All plants received 1L of water, as needed, in the greenhouse to prevent plant death. Daily observations of plant emergence were made. Plant emergence rate was calculated using the Emergence Rate Index (ERI) which is summed from the first day after planting until no more emergence is observed,

$$ERI = \sum_{1}^{n} [np - (np-1)] / dap \qquad (3.4)$$

where np is percentage of plants emerged on day n, (np-1) is percentage of plants emerged on day n-1, and dap is number of days after planting Erbach (1982).

While in the greenhouse, Planting 1 was watered using 1L of distilled water 5, 16 and 23 days after planting with a final watering 27 days after planting. Planting 2 samples were watered using 1L of distilled water 5, 15, and 22 days after planting with a final water of 27 days after planting. After 28 days in the greenhouse, total plant emergence, mean plant height, and number of true leaves per plant were recorded. The planter boxes were then removed for processing for above-ground (shoot) and root biomass. The whole sample was soaked overnight in a Calgon soap solution and then destructively harvested by using a gentle water stream to remove the soil matrix from the roots. The soil was then carefully washed away from the roots. The above ground biomass was dried at 65 $^o$C for 24 hrs and weighed. Tap root diameter was measured at the soil surface and at 5 cm below the soil surface. Additional measurements were made of the diameter of the tap root, the occurrence of a curled tap root, and the depth at which a tap root curled. During the root washing process, we observed that tap roots in the no-tillage appeared to curl in contrast to growing directly into the soil. Therefore root curl measurements were made in an attempt and to quantify our observation. After root measurements were made the roots were dried at 65 $^{o}$C for 24 hrs and weighed. All root and shoot biomasses were divided by the number of plants in each box to normalize the treatments for statistical analysis.

For each measured variable, the means of Planting 1 and Planting 2 were first tested using an ANOVA table performed by SAS (2004). If Planting 1 was not significantly different from Planting 2, the data were combined, n = 8. Means between each BTI and within each tillage, no-tillage and conventional tillage, were compared using Fischer's Protected LSD at the 5% error level. Regression analysis was performed by plotting each variable as a function of the measured water content for each box. Regression lines were created within each tillage treatment.

## Results and Discussion

### *Emergence Rate Index*

Within no-tillage, the "Dry Workable" treatments emerged the slowest (Table 3.1). The "Optimal" treatment emerged slightly faster than the "Dry Workable", although they were not significantly different. The "Wet Workable" treatment emerged significantly faster than both the "Dry Workable" and "Optimal" treatments. In conventional tillage, "Dry Workable" emerged the slowest, followed by the "Optimal" treatments, and finally, the "Wet Workable" treatments emerged the fastest (Table 3.1).

Emergence rate trends were similar in the conventional tillage. However, there was a positive linear response, $r^2 = 0.35$ (Fig 3.1) between the ERI and soil moisture in the no-tillage treatments (Table 3.2). According to both no-tillage and conventional tillage regressions, emergence rates were influenced by soil moisture. In no-tillage soil moisture below 20% gravimetric water content at planting delayed emergence, and soil moisture below 22% gravimetric water content delayed emergence in conventional tillage. This data differs from similar work done in corn by Iqbal (1998) that showed a decrease in emergence as soil moisture increased.

The stand counts recorded in the field show that the no-tillage treatments emerged more plants per treatment compared to the conventional tillage (Table 3.1). The stand counts support the idea that planting at wetter soil moistures reduce stand counts and support the perception of "sidewall compaction" when planting at too high a soil moisture. The data shows that the "Dry Workable" treatments for both no-tillage and conventional tillage emerged more plants per field plot than did the "Optimal" and "Wet Workable" treatments. When compared between tillages, the "Optimal" treatment emerged significantly more plants in no-tillage than in conventional tillage.

Although the stand counts appear much greater for the “Dry Workable” treatment in no-tillage compared to conventional tillage, the numbers are not statistically significant due to a high coefficient of variation, cv = 24.50%. Cotton seedling emergence counts recorded by Nyakatawa & Reddy (2000) were significantly greater in no-tillage than in conventional tillage systems. The increased field emergence in the no-tillage could have been due to an increase in soil moisture as compared to the conventional tillage (Karamanos et al., 2004).

*Above Ground Plant Response*

The above ground variables measured, shoot mass, plant height and number of true leaves, all followed the same trend; the “Wet Workable” treatment produced the most above-ground biomass, the tallest plants and the most number of true leaves. The “Optimal” treatments produced the next greatest amount (Table 3.3). Highly significant positive linear responses ($p < 0.001$) within no-tillage for shoot mass (Fig 3.2) and height (Fig 3.3) were recorded, $r^2 = 0.55$ and 0.44, respectively (Table 3.2).

**Table 3.1.** Mean values for the Emergence Rate Index and field emergence for combined cotton plantings, n = 8 at soil moistures for the Blackland Trafficability Index.

| Blackland Trafficability Index | Greenhouse ERI | Field stand counts |
|---|---|---|
| | *no-tillage* | |
| Dry Workable | $0.197^{A,b*}$ | $207{,}000^{A,a}$ |
| Optimal | $0.216^{A,b}$ | $215{,}000^{A,a}$ |
| Wet Workable | $0.272^{A,a}$ | $184{,}000^{A,a}$ |
| LSD | 0.036 | 37,101 |
| | *conventional tillage* | |
| Dry Workable | $0.208^{A,a}$ | $182{,}000^{A,a}$ |
| Optimal | $0.213^{A,a}$ | $173{,}000^{B,a}$ |
| Wet Workable | $0.249^{A,a}$ | $179{,}000^{A,a}$ |
| LSD | 0.045 | 45,331 |

*means followed by a different uppercase letter are statistically different between tillage treatments; means followed by a different lowercase letter are statistically significant between moisture treatments, p-value <0.05.

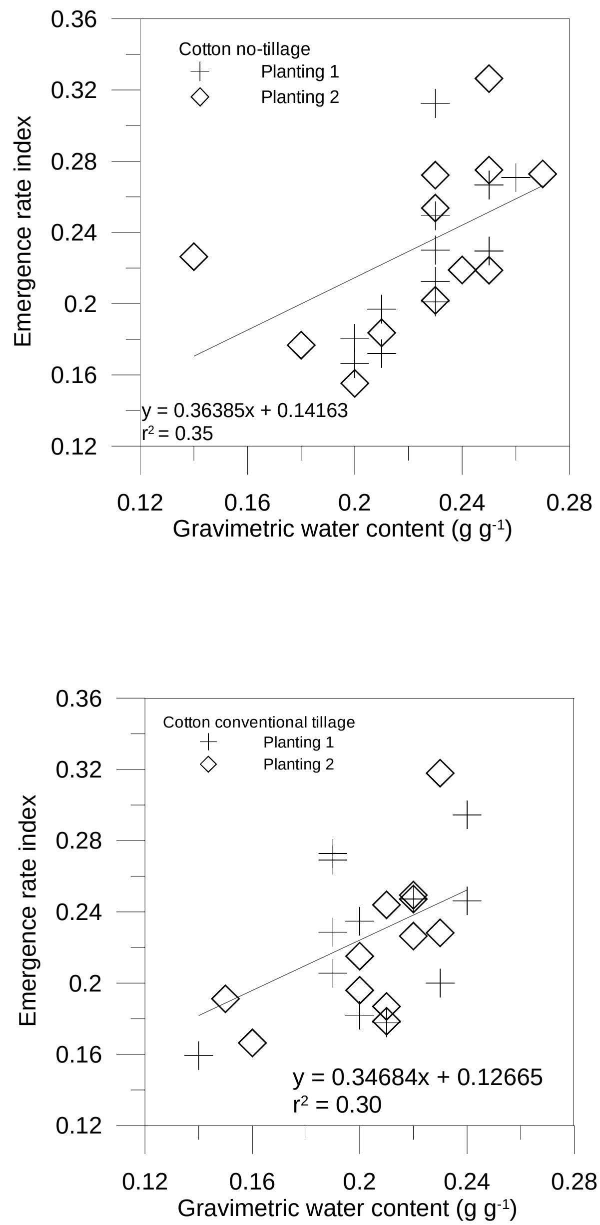



**Figure 3.1.** The relationship between gravimetric water content and the Emergence Rate Index for cotton planting in no-tillage and conventional tillage.

**Table 3.2** Regression results for crop response variables presented as a function of gravimetric water content in g $g^{-1}$. These regression lines correspond to Figures 3.1 through 3.6. Corresponding plots not shown for weak correlations.

| Dependent variable | Equation | $r^2$ |
|---|---|---|
| | *no-tillage* | |
| Emergence Rate Index | 0.36385x + 0.14163** | 0.35 |
| Root mass per plant | 0.14606x + 0.19610* | 0.16 |
| Shoot mass per plant | 0.15540x + 0.15593*** | 0.55 |
| Shoot-to-root-ratio | 0.00356x + $0.21544^{ns}$ | 0.02 |
| Height | 0.00743x + 0.12794*** | 0.44 |
| True leaves | 0.01650x + 0.18333* | 0.14 |
| Tap root diameter 0cm below ground level | 0.06861x + 0.05282*** | 0.41 |
| Tap root diameter 5cm below ground level | 0.06239x + 0.14805*** | 0.40 |
| Depth of observed root curl | 0.02117x + 0.16055* | 0.12 |
| Percent roots with observed curl | 0.01002x + $0.21664^{ns}$ | 0.00 |
| | *conventional tillage* | |
| Emergence Rate Index | 0.34684x + 0.12665* | 0.30 |
| Root mass per plant | 0.13208x + $0.18980^{ns}$ | 0.06 |
| Shoot mass per plant | 0.08398x + 0.17035** | 0.29 |
| Shoot-to-root ratio | 0.00631x + $0.17910^{ns}$ | 0.08 |
| Height | 0.00690x + 0.12221** | 0.36 |
| True leaves | 0.01809x + 0.16649** | 0.16 |
| Tap root diameter 0cm below ground level | 0.04119x + 0.10484** | 0.21 |
| Tap root diameter 5cm below ground level | 0.03867x + 0.16289** | 0.23 |
| Depth of observed root curl | 0.01754x + 0.15510* | 0.12 |
| Percent roots with observed curl | 0.01420x + $0.19336^{ns}$ | 0.0125 |

*, **, *** have p-values less than 0.10, 0.05, and 0.001, respectively; ns - slope of regression equation is non-significant

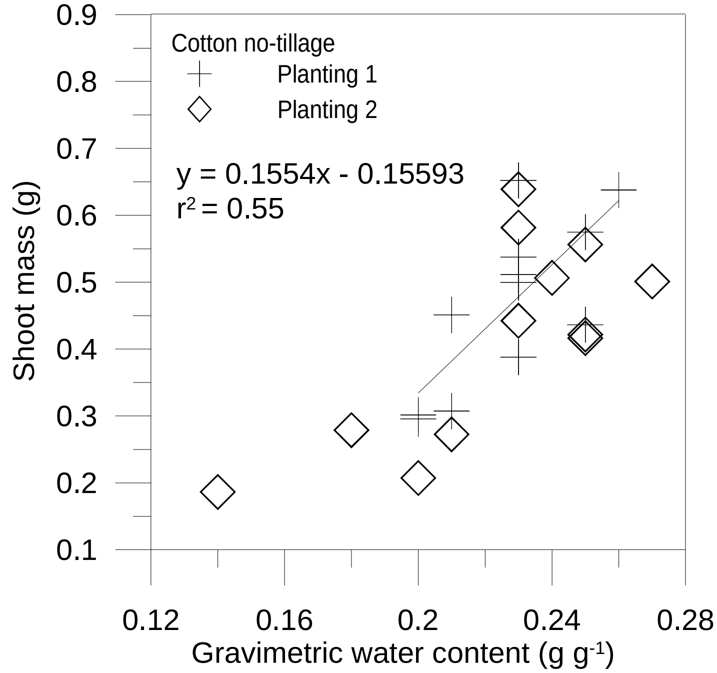
The conventional tillage treatments also had a significant positive linear response ($p < 0.05$) for shoot mass, height and number of true leaves (Fig 3.4) , with corresponding $r^2 =$ 0.29, 0.36, and 0.16, respectively. These results clearly indicate that within the moisture range studied; greater soil moisture at planting provided water for greater above-ground biomass. Significant differences between tillages were only observed for the true leaves variable for the "Dry Workable" treatment, although the coefficient for this moisture treatment was higher than the ones for "Optimal" and "Wet Workable", 23.52, 21.05 and 19.05, respectively.

In a two year study, Nyakatawa et al. (2000) observed that cotton grown under no-tillage reached flowering 1 to 4 days earlier than those under conventional tillage. In one of the two years of the same study, cotton plants were taller in the no-tillage as compared to the conventional tillage. Nyakatawa et al. also concluded that no-tillage significantly increased the growth parameters and subsequent yield of cotton. Ball et al. (1994) found that the rate of expansion for the youngest leaf of a cotton plant was highly sensitive to water stress and impacted the leaf negatively.

**Table 3.3.** Above ground biomass, plant height and true leaf means for cotton Plantings 1 and 2, n =8 for the Blackland Trafficability Index (BTI).

| BTI | Above ground biomass | Plant height | True leaves |
|---|---|---|---|
| | -------g $plant^{-1}$------- | -------cm------- | |
| | *no-tillage* | | |
| Dry Workable | 0.357[A,b*] | 11.25[A,b] | 2.13[A,b] |
| Optimal | 0.458[A,ab] | 13.13[A,ab] | 2.50[A,ab] |
| Wet Workable | 0.510[A,a] | 14.63[A,a] | 2.87[A,a] |
| LSD | 0.124 | 2.44 | 0.665 |
| | *conventional tillage* | | |
| Dry Workable | 0.284[A,b] | 10.25[A,c] | 1.63[B,b] |
| Optimal | 0.429[A,a] | 11.88[A,b] | 2.25[A,a] |
| Wet Workable | 0.496[A,a] | 13.50[A,a] | 2.38[A,a] |
| LSD | 0.106 | 1.49 | 0.343 |

*means followed by a different uppercase letter are statistically different between tillage treatments; means followed by a different lowercase letter are statistically significant between moisture treatments, p-value <0.05.



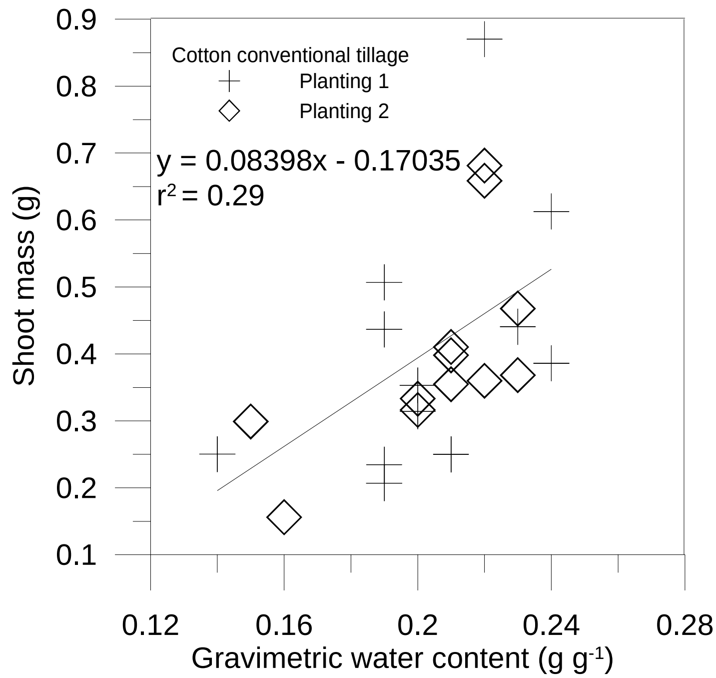




**Figure 3.2.** The relationship between gravimetric water content and shoot mass for cotton planting in no-tillage and conventional tillage.

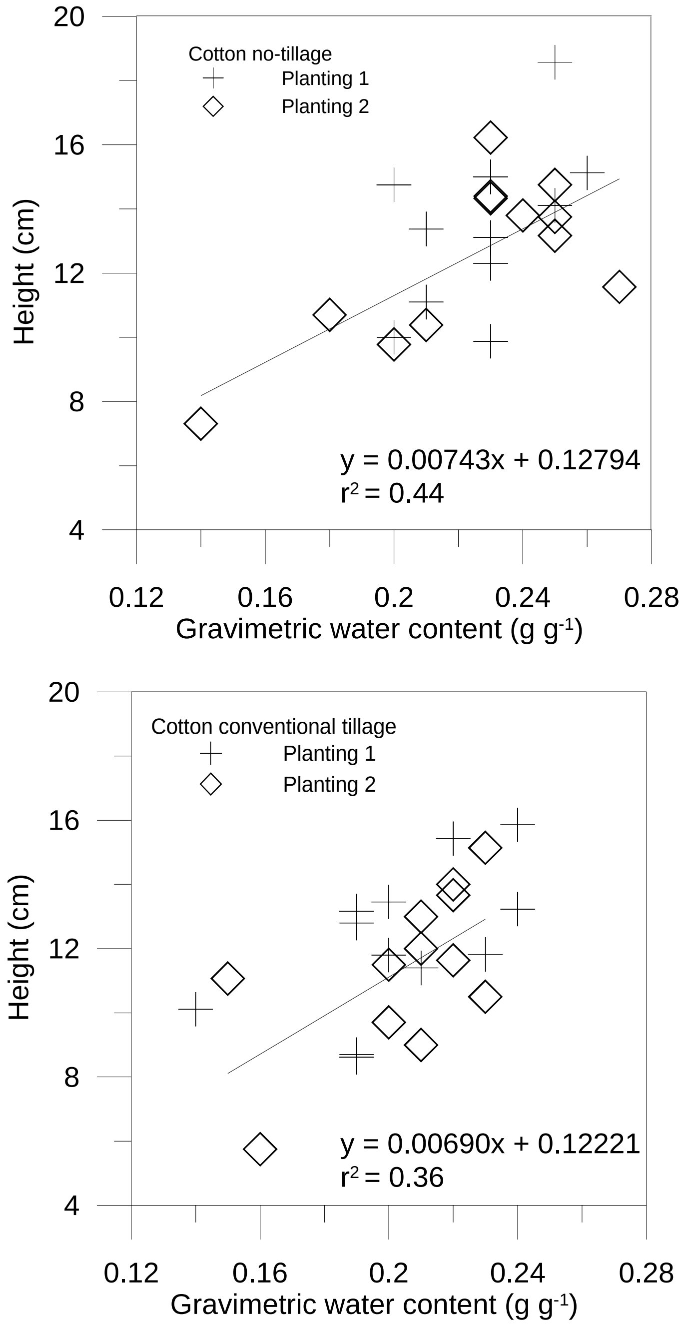



Figure 3.3. The relationship between gravimetric water content and plant height for cotton planting in no-tillage and conventional tillage.

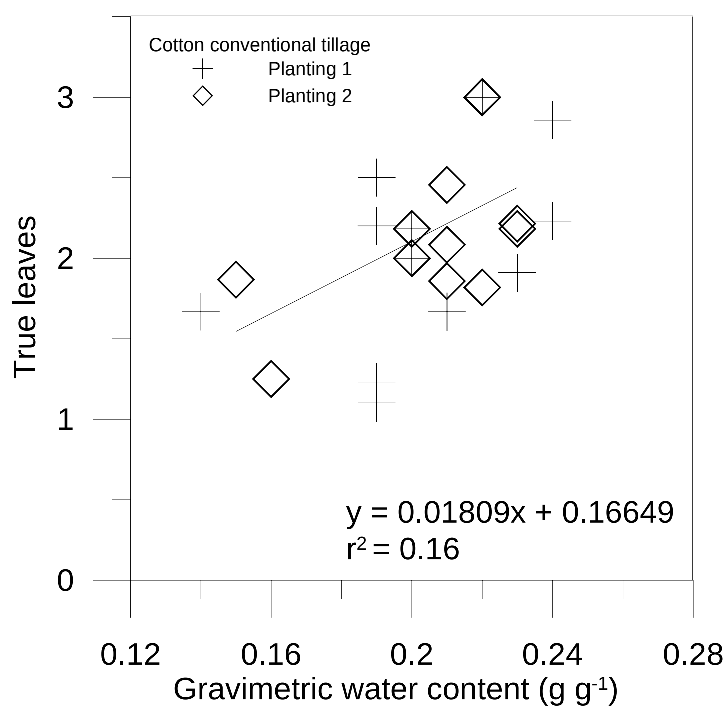



**Figure 3.4.** The relationship between gravimetric water content and true leaves for cotton planting in conventional tillage.

*Below Ground Plant Response*

The below ground biomass data for no-tillage showed a trend of the “Optimal” soil moisture treatments creating the most below ground biomass while the “Dry Workable” produced the least. The conventional tillage treatments showed similar trends, with the “Dry Workable” soil moisture treatment producing the least amount of below ground biomass (Table 3.4). For planting 1, significantly higher root biomass was observed in the no-tillage between the “Dry Workable” and “Optimal” moisture treatments. For planting 2, significantly higher biomass was observed in no-tillage for the “Optimal” and “Wet Workable” moisture treatments.

The no-tillage tap root diameter at 0 cm below the soil surface had no significant differences between soil moisture treatments based on ANOVA results (Table 3.4). However, there was a significant positive trend between soil moisture and tap root diameter, $r^2 = 0.41$ (Fig 3.5, Table 3.2). Similarly in conventional tillage, there was an

**Table 3.4.** Mean values for total root biomass, tap root diameter at the soil surface, and tap root diameter 5 cm below the soil surface. Where values are missing, planting 1 and 2 are combined; therefore, n=8, otherwise n=4.

| BTI | Below ground biomass | | Tap root diameter 0cm below soil surface | | Tap root diameter 5cm below soil surface |
|---|---|---|---|---|---|
| | Planting 1 | Planting 2 | Planting 1 | Planting 2 | Plantings 1 & 2 |
| | -------g plant$^{-1}$------- | | ---------------------------- mm | ---------------------------- | |
| | | | *no-tillage* | | |
| Dry Workable | $0.111^{A,b*}$ | $0.152^{A,b}$ | $2.38^{A,a}$ | - | $1.17^{A,a}$ |
| Optimal | $0.221^{A,ab}$ | $0.285^{A,a}$ | $2.52^{A,a}$ | - | $1.20^{A,a}$ |
| Wet Workable | $0.161^{A,ab}$ | $0.241^{A,ab}$ | $2.61^{A,a}$ | - | $1.32^{A,a}$ |
| LSD | 0.080 | 0.104 | 0.286 | | 0.307 |
| | | | *conventional tillage* | | |
| Dry Workable | $0.057^{B,b}$ | $0.090^{A,b}$ | $2.07^{A,b}$ | $2.43^{A,a}$ | $0.88^{A,b}$ |
| Optimal | $0.171^{B,a}$ | $0.101^{B,ab}$ | $2.42^{A,a}$ | $2.47^{A,a}$ | $1.07^{A,ab}$ |
| Wet Workable | $0.109^{A,ab}$ | $0.124^{B,a}$ | $2.47^{A,a}$ | $2.61^{A,a}$ | $1.25^{A,a}$ |
| LSD | 0.074 | 0.029 | 0.325 | 0.218 | 0.291 |

* means followed by a different uppercase letter are statistically different between tillage treatments; means followed by a different lowercase letter are statistically significant between moisture treatments, p-value <0.05.

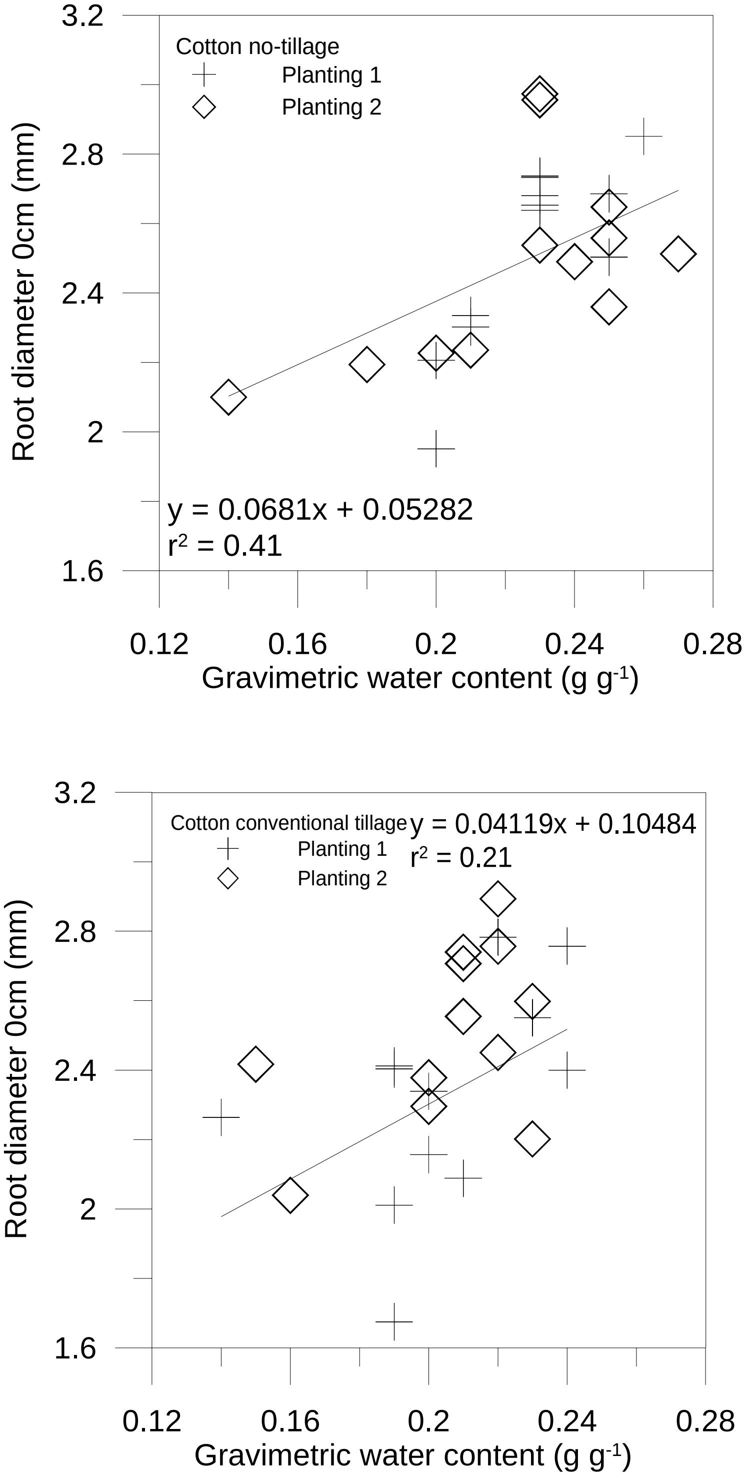



**Figure 3.5.** The relationship between gravimetric water content and the tap root diameter at the soil surface for cotton planting in no-tillage and conventional tillage.

increase of tap root diameter with an increase in soil moisture, with a significant positive response, $r^2 = 0.21$ (Fig 3.5, Table 3.2). The increased tap root diameter as a response to soil moisture was again observed at 5cm below ground level in both no-tillage and conventional tillage, with the "Wet Workable" soil moisture treatments producing the thickest roots while the "Dry Workable" soil moisture treatment produced the thinnest roots. Regression analysis for the tap root diameter 5 cm below ground level showed a positive response when plotted against gravimetric soil water content for no-tillage, $r^2 = 0.40$, p-value $<0.001$, and for conventional tillage treatments, $r^2 = 0.23$, p-value $<0.05$ (Fig 3.6). The amount of below ground biomass and the root thickness of were also a function of soil moisture at the time of planting.

Root curl measurements indicated there was no association between root curling or the depth of root curling (Table 3.5). Malik at al. (1979) concluded that that a water deficit decreased shoot growth rate, plant height and yield, but root growth was less sensitive to water stress than above ground parameters. Drought stressed cotton showed some increase in root length but a reduced diameter (Pace et al., 1999). Though our research was not designed to measure root length, Ball et al. (1994) and Prior et al. (1995) reported that inadequate soil moisture reduced cotton root lengths. Ball et al. also found that small roots were more sensitive to drought than those of a larger size, and those small roots generally stopped growing several days before the larger counterparts stopped growth. Even though the smaller roots recovered to grow to diameters equivalent to the control when water was added, this work provides evidence that larger root diameters have some advantage over smaller root diameters.

**Table 3.5.** Mean values for percent roots with root curl and the root curl depth for cotton Plantings 1 and 2. Where values are missing, Planting 1 and 2 are combined; therefore, n=8, otherwise n=4.

| Blackland Trafficability Index | Percent roots with observed curl | | Depth of observed root curl |
|---|---|---|---|
| | Planting 1 | Planting 2 | Plantings 1 & 2 |
| | | | -------mm------ |
| | *no-tillage* | | |
| Dry Workable | $0.64^{A,a}$ | $0.89^{A,a}$ | $3.06^{A,a}$ |
| Optimal | $0.72^{A,a}$ | $0.87^{A,a}$ | $2.86^{A,a}$ |
| Wet Workable | $0.79^{A,a}$ | $0.85^{A,a}$ | $3.16^{A,a}$ |
| LSD | 0.270 | 0.247 | 0.598 |
| | *conventional tillage* | | |
| Dry Workable | $0.66^{A,a}$ | - | $2.65^{A,a}$ |
| Optimal | $0.83^{A,a}$ | - | $2.85^{A,a}$ |
| Wet Workable | $0.78^{A,a}$ | - | $2.90^{A,a}$ |
| LSD | 0.214 | | 0.527 |

* means followed by a different uppercase letter are statistically different between tillage treatments; means followed by a different lowercase letter are statistically significant between moisture treatments, p-value <0.05.

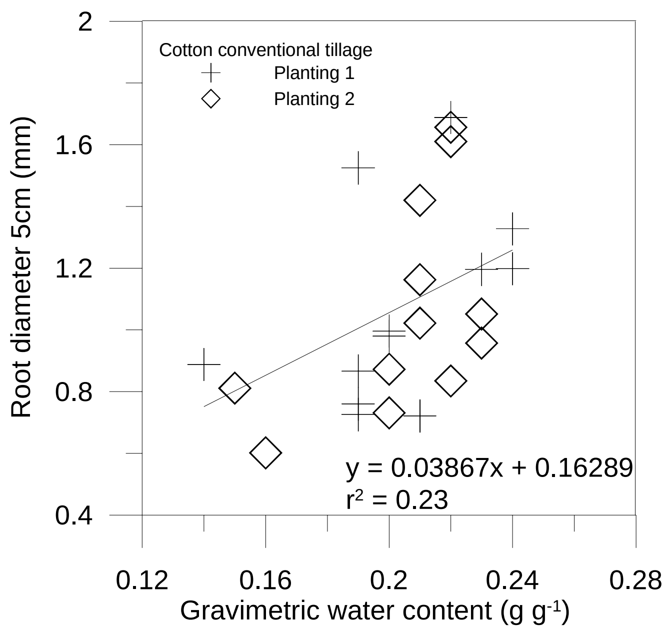



**Figure 3.6.** The relationship between gravimetric water content and the tap root diameter 5 cm below the soil surface for cotton planting in conventional tillage.

**Summary and Conclusions**

The Blackland Trafficability Index proved its usefulness as a decision-aid tool for this experiment. Agronomically, cotton's above ground response to planting at different soil moisture contents is evident; the greater the soil moisture at planting, the more biomass the plant put on from planting to 28 days after planting. Likewise for the below ground parameters, increased soil moisture at planting provided greater root mass and an increase in the diameter of tap root diameters-both advantageous for a competitive cotton plant. One variable eliminated from this experiment was wind. High winds after planting cotton in the Texas Blackland Prairie can cause evaporation which may facilitae soil cracking of the seed furrow channel, and therefore expose the young roots. Regression analysis showed the positive linear response for biomass when plotted against gravimetric water content.

Logistically, the different workable moisture regimes derived from producer input provided robust break points for taking equipment to the field. During planting, the "Wet Workable" conventional tillage treatments tended to gum up the planter and which lead to physical destruction of same areas of the planting bed. Seeds were left exposed to the air in some cases. However, this was not a problem in the no-tillage treatments. The residual organic matter, increased soil structure and strength, did not cause a problem for the planter with the "Wet Workable" soil moisture treatments. The means for the different variables were generally greater in the no-tillage treatment as compared to the conventional tillage treatment, and were probably due to the robust soil structure, increased soil organic carbon and a higher soil water holding capacity, since temperature was held constant therefore testing soil moisture between two tillage types.

# CHAPTER IV

# CONCLUSIONS

Collaborating with experienced producers on the Texas Blackland Prairie was crucial in establishing quantifiable, repeatable soil moisture contents for the planting establishment of corn and cotton across multiple tillage practices. The development of the Blackland Trafficability Index has proven to be reliable guide for estimating the effects of planting corn and cotton in Texas Blacklands based upon soil moisture. Planting at a higher soil moisture produced more above and below ground biomass than planting at a lower soil moisture in both corn and cotton. The effects of seed furrow sidewall compaction could not be quantified in this study, perhaps due to a lack of wind in the controlled growth environment. Logistically, the different workable moisture regimes derived from producer input provided robust break points for taking equipment to the field. The quantification of soil moisture contents producers are willing to work their fields will be an important asset for developing a decision-aid tool for planting crops in the Texas Blackland Prairie.

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# APPENDIX A

Laboratory characterization of field plots at the Stiles Farm in Thrall, TX.

| Tillage | Surface texture | Sand | Clay | Organic carbon | Inorganic carbon |
|---|---|---|---|---|---|
| | | ----%---- | | -----------g $kg^{-1}$---------- | |
| No-tillage | clay loam | 24.7 | 32.9 | 1.50[a] | 0.41[ns] |
| Conventional tillage | clay loam | 24.7 | 32.9 | 1.02[b] | 0.45[ns] |

# APPENDIX B

Corn Plantings 1 and 2 plot designs with observed field emergences in parentheses. In the plot designs, numbers 2, 3, and 4 represent Blackland Trafficability Indexes and the letters a, b, c, and d, represent replicates.

a). Planting 1

| Conventional plots (Emerged plants per 1.5m) | No-tillage plots (Emerged plants per 1.5m) |
|---|---|
| 3a (22) | 2a (26) |
| 4a (27) | 2b (28) |
| 2a (25) | 4a (26) |
| 2b (28) | 3a (26) |
| 3b (29) | 2c (27) |
| 4b (22) | 3b (26) |
| 4c (28) | 4b (27) |
| 3c (22) | 2d (26) |
| 3d (27) | 4c (26) |
| 4d (27) | 3c (26) |
| 2c (27) | 3d (24) |
| 2d (25) | 4d (26) |

b) Planting 2

| Conventional plots (Emerged plants per 1.5m) | No-tillage plots (Emerged plants per 1.5m) |
|---|---|
| 3a (20) | 3a (26) |
| 4a (21) | 2a (24) |
| 4b (22) | 4a (25) |
| 2a (3) | 4b (24) |
| 3b (25) | 3b (30) |
| 4c (17) | 2b (22) |
| 2b (22) | 3c (20) |
| 3c (18) | 2c (24) |
| 4d (19) | 4c (24) |
| 2c (10) | 4d (23) |
| 3d (19) | 3d (27) |
| 2d (27) | 2d (22) |

**APPENDIX C**

Cotton Plantings 1 and 2 plot designs with observed field emergences in parentheses. In the plot designs, numbers 2, 3, and 4 represent Blackland Trafficability Indexes and the letters a, b, c, and d, represent replicates.

Planting 1

| Conventional plots | No-tillage plots |
|---|---|
| ---emerged plants per 1.5 m--- | |
| 2a (22) | 3a (27) |
| 4a (18) | 2a (32) |
| 3a (10) | 2b (29) |
| 3b (25) | 3b (29) |
| 3c (29) | 4a (30) |
| 4b (27) | 4b (25) |
| 2b (30) | 4c (26) |
| 2c (24) | 3c (35) |
| 2d (27) | 4d (30) |
| 4c (17) | 2c (30) |
| 3d (29) | 3d (32) |
| 4d (22) | 2d (23) |

Planting 2

| Conventional plots | No-tillage plots |
|---|---|
| ---emerged plants per 1.5 m--- | |
| 2a (25) | 4a (16) |
| 3a (21) | 2a (27) |
| 4a (34) | 3a (25) |
| 4b (29) | 2b (23) |
| 2b (26) | 4b (31) |
| 4c (23) | 3b (28) |
| 4d (38) | 4c (25) |
| 2c (18) | 3c (36) |
| 3b (19) | 4d (30) |
| 2d (39) | 2c (39) |
| 3c (25) | 2d (37) |
| 3d (42) | 3d (37) |

# APPENDIX D

## Soil Aggregate Stability

Fifty grams of air-dry soil were used to determine aggregate stability using a wet-sieve shaker, in which composite samples for each BTI were collected from corn Planting 1 and 2 from the top 6cm of soil and then passed through a 1.27 cm sieve. The samples were then sorted through a stack of progressively smaller sieves (i.e., 4-, 2-, 1-, 0.5-, and 0.25-mm) (Yoder, 1936). After the 50-g sub-sample of soil was placed atop the stack of sieves, the sieve stack was then plunged repeatedly in a water bath at 130 cycles per minute for 5 min (Yoder, 1936). After wet sieving, aggregates retained on each sieve (the entire 50-g sub-sample was not recovered as some soil material passed through the 0.25 mm sieve) were quantitatively transferred to a drying tray, dried at 105$^{o}$ C for 24 h, and weighed (Yoder, 1936).

| Tillage | Planting | BTI | Sieve size | rep | grams |
|---|---|---|---|---|---|
| conventional tillage | 1 | 2 | 4 | 1 | 2.85 |
| conventional tillage | 1 | 2 | 4 | 2 | 2.23 |
| conventional tillage | 1 | 2 | 4 | 3 | 0 |
| conventional tillage | 1 | 2 | 4 | 4 | 1.2 |
| conventional tillage | 1 | 3 | 4 | 1 | 3.15 |
| conventional tillage | 1 | 3 | 4 | 2 | 0 |
| conventional tillage | 1 | 3 | 4 | 3 | 0.12 |
| conventional tillage | 1 | 3 | 4 | 4 | 0.39 |
| conventional tillage | 1 | 4 | 4 | 1 | 5.33 |
| conventional tillage | 1 | 4 | 4 | 2 | 0 |
| conventional | 1 | 4 | 4 | 3 | 2.02 |

| | | | | | |
|---|---|---|---|---|---|
| tillage | | | | | |
| conventional tillage | 1 | 4 | 4 | 4 | 1.15 |
| conventional tillage | 1 | 2 | 2 | 1 | 1.02 |
| conventional tillage | 1 | 2 | 2 | 2 | 0.7 |
| conventional tillage | 1 | 2 | 2 | 3 | 1.69 |
| conventional tillage | 1 | 2 | 2 | 4 | 0.9 |
| conventional tillage | 1 | 3 | 2 | 1 | 1.46 |
| conventional tillage | 1 | 3 | 2 | 2 | 0.22 |
| conventional tillage | 1 | 3 | 2 | 3 | 0.54 |
| conventional tillage | 1 | 3 | 2 | 4 | 0.25 |
| conventional tillage | 1 | 4 | 2 | 1 | 2.04 |
| conventional tillage | 1 | 4 | 2 | 2 | 0 |
| conventional tillage | 1 | 4 | 2 | 3 | 0.98 |
| conventional tillage | 1 | 4 | 2 | 4 | 0.56 |
| conventional tillage | 1 | 2 | 1 | 1 | 2.3 |
| conventional tillage | 1 | 2 | 1 | 2 | 1.63 |
| conventional tillage | 1 | 2 | 1 | 3 | 1.22 |
| conventional tillage | 1 | 2 | 1 | 4 | 1.29 |
| conventional tillage | 1 | 3 | 1 | 1 | 1.97 |
| conventional tillage | 1 | 3 | 1 | 2 | 0.73 |
| conventional tillage | 1 | 3 | 1 | 3 | 0.95 |
| conventional tillage | 1 | 3 | 1 | 4 | 0.79 |
| conventional tillage | 1 | 4 | 1 | 1 | 1.43 |
| conventional tillage | 1 | 4 | 1 | 2 | 0.78 |
| conventional tillage | 1 | 4 | 1 | 3 | 1.1 |
| conventional tillage | 1 | 4 | 1 | 4 | 0.96 |
| conventional tillage | 1 | 2 | 0.5 | 1 | 9.73 |

| | | | | | |
|---|---|---|---|---|---|
| conventional tillage | 1 | 2 | 0.5 | 2 | 6.79 |
| conventional tillage | 1 | 2 | 0.5 | 3 | 7.31 |
| conventional tillage | 1 | 2 | 0.5 | 4 | 5.95 |
| conventional tillage | 1 | 3 | 0.5 | 1 | 8.04 |
| conventional tillage | 1 | 3 | 0.5 | 2 | 3.49 |
| conventional tillage | 1 | 3 | 0.5 | 3 | 4.68 |
| conventional tillage | 1 | 3 | 0.5 | 4 | 4.31 |
| conventional tillage | 1 | 4 | 0.5 | 1 | 5.38 |
| conventional tillage | 1 | 4 | 0.5 | 2 | 3.06 |
| conventional tillage | 1 | 4 | 0.5 | 3 | 4.82 |
| conventional tillage | 1 | 4 | 0.5 | 4 | 4.57 |
| conventional tillage | 1 | 2 | 0.25 | 1 | 19.99 |
| conventional tillage | 1 | 2 | 0.25 | 2 | 18.45 |
| conventional tillage | 1 | 2 | 0.25 | 3 | 19.38 |
| conventional tillage | 1 | 2 | 0.25 | 4 | 13.3 |
| conventional tillage | 1 | 3 | 0.25 | 1 | 18.18 |
| conventional tillage | 1 | 3 | 0.25 | 2 | 12.02 |
| conventional tillage | 1 | 3 | 0.25 | 3 | 15.85 |
| conventional tillage | 1 | 3 | 0.25 | 4 | 14.21 |
| conventional tillage | 1 | 4 | 0.25 | 1 | 13.73 |
| conventional tillage | 1 | 4 | 0.25 | 2 | 13.42 |
| conventional tillage | 1 | 4 | 0.25 | 3 | 16.05 |
| conventional tillage | 1 | 4 | 0.25 | 4 | 17.11 |
| conventional tillage | 2 | 2 | 4 | 1 | 3.12 |
| conventional tillage | 2 | 2 | 4 | 2 | 0.35 |
| conventional tillage | 2 | 2 | 4 | 3 | 2.8 |
| conventional | 2 | 2 | 4 | 4 | 0.33 |

| | | | | | |
|---|---|---|---|---|---|
| tillage | | | | | |
| conventional tillage | 2 | 3 | 4 | 1 | 2.15 |
| conventional tillage | 2 | 3 | 4 | 2 | 0.95 |
| conventional tillage | 2 | 3 | 4 | 3 | 0.73 |
| conventional tillage | 2 | 3 | 4 | 4 | 1.08 |
| conventional tillage | 2 | 4 | 4 | 1 | 6.37 |
| conventional tillage | 2 | 4 | 4 | 2 | 4.18 |
| conventional tillage | 2 | 4 | 4 | 3 | 4.53 |
| conventional tillage | 2 | 4 | 4 | 4 | 3.14 |
| conventional tillage | 2 | 2 | 2 | 1 | 0.73 |
| conventional tillage | 2 | 2 | 2 | 2 | 0.33 |
| conventional tillage | 2 | 2 | 2 | 3 | 1.06 |
| conventional tillage | 2 | 2 | 2 | 4 | 0.88 |
| conventional tillage | 2 | 3 | 2 | 1 | 2.09 |
| conventional tillage | 2 | 3 | 2 | 2 | 0.53 |
| conventional tillage | 2 | 3 | 2 | 3 | 0.53 |
| conventional tillage | 2 | 3 | 2 | 4 | 0.69 |
| conventional tillage | 2 | 4 | 2 | 1 | 2.11 |
| conventional tillage | 2 | 4 | 2 | 2 | 0.82 |
| conventional tillage | 2 | 4 | 2 | 3 | 1.01 |
| conventional tillage | 2 | 4 | 2 | 4 | 1.32 |
| conventional tillage | 2 | 2 | 1 | 1 | 0.86 |
| conventional tillage | 2 | 2 | 1 | 2 | 1.13 |
| conventional tillage | 2 | 2 | 1 | 3 | 1.21 |
| conventional tillage | 2 | 2 | 1 | 4 | 0.96 |
| conventional tillage | 2 | 3 | 1 | 1 | 1.77 |
| conventional tillage | 2 | 3 | 1 | 2 | 0.88 |

| | | | | | |
|---|---|---|---|---|---|
| conventional tillage | 2 | 3 | 1 | 3 | 0.81 |
| conventional tillage | 2 | 3 | 1 | 4 | 1.01 |
| conventional tillage | 2 | 4 | 1 | 1 | 1.17 |
| conventional tillage | 2 | 4 | 1 | 2 | 0.95 |
| conventional tillage | 2 | 4 | 1 | 3 | 1.15 |
| conventional tillage | 2 | 4 | 1 | 4 | 1.1 |
| conventional tillage | 2 | 2 | 0.5 | 1 | 4.27 |
| conventional tillage | 2 | 2 | 0.5 | 2 | 4.6 |
| conventional tillage | 2 | 2 | 0.5 | 3 | 6.07 |
| conventional tillage | 2 | 2 | 0.5 | 4 | 5.1 |
| conventional tillage | 2 | 3 | 0.5 | 1 | 6.56 |
| conventional tillage | 2 | 3 | 0.5 | 2 | 4.02 |
| conventional tillage | 2 | 3 | 0.5 | 3 | 4.56 |
| conventional tillage | 2 | 3 | 0.5 | 4 | 5.23 |
| conventional tillage | 2 | 4 | 0.5 | 1 | 4.89 |
| conventional tillage | 2 | 4 | 0.5 | 2 | 3.81 |
| conventional tillage | 2 | 4 | 0.5 | 3 | 5.27 |
| conventional tillage | 2 | 4 | 0.5 | 4 | 4.71 |
| conventional tillage | 2 | 2 | 0.25 | 1 | 15.92 |
| conventional tillage | 2 | 2 | 0.25 | 2 | 18.2 |
| conventional tillage | 2 | 2 | 0.25 | 3 | 18.02 |
| conventional tillage | 2 | 2 | 0.25 | 4 | 17.45 |
| conventional tillage | 2 | 3 | 0.25 | 1 | 17.46 |
| conventional tillage | 2 | 3 | 0.25 | 2 | 17.62 |
| conventional tillage | 2 | 3 | 0.25 | 3 | 17.71 |
| conventional tillage | 2 | 3 | 0.25 | 4 | 13.46 |

| | | | | | |
|---|---|---|---|---|---|
| conventional tillage | 2 | 4 | 0.25 | 1 | 16.43 |
| conventional tillage | 2 | 4 | 0.25 | 2 | 15.63 |
| conventional tillage | 2 | 4 | 0.25 | 3 | 18.53 |
| conventional tillage | 2 | 4 | 0.25 | 4 | 16.16 |
| no-tillage | 1 | 2 | 4 | 1 | 0.53 |
| no-tillage | 1 | 2 | 4 | 2 | 0 |
| no-tillage | 1 | 2 | 4 | 3 | 0.13 |
| no-tillage | 1 | 2 | 4 | 4 | 1.63 |
| no-tillage | 1 | 3 | 4 | 1 | 0.19 |
| no-tillage | 1 | 3 | 4 | 2 | 0.42 |
| no-tillage | 1 | 3 | 4 | 3 | 0.97 |
| no-tillage | 1 | 3 | 4 | 4 | 0.24 |
| no-tillage | 1 | 4 | 4 | 1 | 0 |
| no-tillage | 1 | 4 | 4 | 2 | 0.61 |
| no-tillage | 1 | 4 | 4 | 3 | 1.35 |
| no-tillage | 1 | 4 | 4 | 4 | 0.27 |
| no-tillage | 1 | 2 | 2 | 1 | 0.80 |
| no-tillage | 1 | 2 | 2 | 2 | 0.26 |
| no-tillage | 1 | 2 | 2 | 3 | 0.82 |
| no-tillage | 1 | 2 | 2 | 4 | 1.03 |
| no-tillage | 1 | 3 | 2 | 1 | 0.43 |
| no-tillage | 1 | 3 | 2 | 2 | 0.47 |
| no-tillage | 1 | 3 | 2 | 3 | 0.67 |
| no-tillage | 1 | 3 | 2 | 4 | 0.64 |
| no-tillage | 1 | 4 | 2 | 1 | 0.4 |
| no-tillage | 1 | 4 | 2 | 2 | 0.83 |
| no-tillage | 1 | 4 | 2 | 3 | 0.79 |
| no-tillage | 1 | 4 | 2 | 4 | 0.49 |
| no-tillage | 1 | 2 | 1 | 1 | 2.87 |
| no-tillage | 1 | 2 | 1 | 2 | 1.76 |
| no-tillage | 1 | 2 | 1 | 3 | 3.42 |
| no-tillage | 1 | 2 | 1 | 4 | 2.86 |
| no-tillage | 1 | 3 | 1 | 1 | 1.86 |
| no-tillage | 1 | 3 | 1 | 2 | 1.82 |
| no-tillage | 1 | 3 | 1 | 3 | 2.1 |
| no-tillage | 1 | 3 | 1 | 4 | 2.42 |
| no-tillage | 1 | 4 | 1 | 1 | 1.46 |
| no-tillage | 1 | 4 | 1 | 2 | 2.32 |
| no-tillage | 1 | 4 | 1 | 3 | 1.84 |
| no-tillage | 1 | 4 | 1 | 4 | 1.3 |
| no-tillage | 1 | 2 | 0.5 | 1 | 9.20 |
| no-tillage | 1 | 2 | 0.5 | 2 | 10.52 |
| no-tillage | 1 | 2 | 0.5 | 3 | 9.46 |

| | | | | | |
|---|---|---|---|---|---|
| no-tillage | 1 | 2 | 0.5 | 4 | 7.64 |
| no-tillage | 1 | 3 | 0.5 | 1 | 7.31 |
| no-tillage | 1 | 3 | 0.5 | 2 | 6.28 |
| no-tillage | 1 | 3 | 0.5 | 3 | 7.24 |
| no-tillage | 1 | 3 | 0.5 | 4 | 6.94 |
| no-tillage | 1 | 4 | 0.5 | 1 | 4.83 |
| no-tillage | 1 | 4 | 0.5 | 2 | 7.39 |
| no-tillage | 1 | 4 | 0.5 | 3 | 5.67 |
| no-tillage | 1 | 4 | 0.5 | 4 | 5.1 |
| no-tillage | 1 | 2 | 0.25 | 1 | 17.52 |
| no-tillage | 1 | 2 | 0.25 | 2 | 18.71 |
| no-tillage | 1 | 2 | 0.25 | 3 | 16.83 |
| no-tillage | 1 | 2 | 0.25 | 4 | 15.38 |
| no-tillage | 1 | 3 | 0.25 | 1 | 15.57 |
| no-tillage | 1 | 3 | 0.25 | 2 | 16.17 |
| no-tillage | 1 | 3 | 0.25 | 3 | 15.81 |
| no-tillage | 1 | 3 | 0.25 | 4 | 16.69 |
| no-tillage | 1 | 4 | 0.25 | 1 | 13.27 |
| no-tillage | 1 | 4 | 0.25 | 2 | 15.8 |
| no-tillage | 1 | 4 | 0.25 | 3 | 13.65 |
| no-tillage | 1 | 4 | 0.25 | 4 | 14.54 |
| no-tillage | 2 | 2 | 4 | 1 | 0.99 |
| no-tillage | 2 | 2 | 4 | 2 | 0 |
| no-tillage | 2 | 2 | 4 | 3 | 0.63 |
| no-tillage | 2 | 2 | 4 | 4 | 0.56 |
| no-tillage | 2 | 3 | 4 | 1 | 1.43 |
| no-tillage | 2 | 3 | 4 | 2 | 0.54 |
| no-tillage | 2 | 3 | 4 | 3 | 1.74 |
| no-tillage | 2 | 3 | 4 | 4 | 3.09 |
| no-tillage | 2 | 4 | 4 | 1 | 6.72 |
| no-tillage | 2 | 4 | 4 | 2 | 0.69 |
| no-tillage | 2 | 4 | 4 | 3 | 1.2 |
| no-tillage | 2 | 4 | 4 | 4 | 1.79 |
| no-tillage | 2 | 2 | 2 | 1 | 1.27 |
| no-tillage | 2 | 2 | 2 | 2 | 0.88 |
| no-tillage | 2 | 2 | 2 | 3 | 0.63 |
| no-tillage | 2 | 2 | 2 | 4 | 0.32 |
| no-tillage | 2 | 3 | 2 | 1 | 0.75 |
| no-tillage | 2 | 3 | 2 | 2 | 0.79 |
| no-tillage | 2 | 3 | 2 | 3 | 0.41 |
| no-tillage | 2 | 3 | 2 | 4 | 0.55 |
| no-tillage | 2 | 4 | 2 | 1 | 1.14 |
| no-tillage | 2 | 4 | 2 | 2 | 0.89 |
| no-tillage | 2 | 4 | 2 | 3 | 1.08 |
| no-tillage | 2 | 4 | 2 | 4 | 1.11 |
| no-tillage | 2 | 2 | 1 | 1 | 2.4 |
| no-tillage | 2 | 2 | 1 | 2 | 2.16 |
| no-tillage | 2 | 2 | 1 | 3 | 1.3 |

| | | | | | |
|---|---|---|---|---|---|
| no-tillage | 2 | 2 | 1 | 4 | 1.43 |
| no-tillage | 2 | 3 | 1 | 1 | 1.47 |
| no-tillage | 2 | 3 | 1 | 2 | 1.05 |
| no-tillage | 2 | 3 | 1 | 3 | 0.85 |
| no-tillage | 2 | 3 | 1 | 4 | 1.01 |
| no-tillage | 2 | 4 | 1 | 1 | 1.92 |
| no-tillage | 2 | 4 | 1 | 2 | 2.23 |
| no-tillage | 2 | 4 | 1 | 3 | 1.48 |
| no-tillage | 2 | 4 | 1 | 4 | 1.18 |
| no-tillage | 2 | 2 | 0.5 | 1 | 8.76 |
| no-tillage | 2 | 2 | 0.5 | 2 | 8.19 |
| no-tillage | 2 | 2 | 0.5 | 3 | 5.89 |
| no-tillage | 2 | 2 | 0.5 | 4 | 6.01 |
| no-tillage | 2 | 3 | 0.5 | 1 | 5.27 |
| no-tillage | 2 | 3 | 0.5 | 2 | 5.44 |
| no-tillage | 2 | 3 | 0.5 | 3 | 4.88 |
| no-tillage | 2 | 3 | 0.5 | 4 | 4.71 |
| no-tillage | 2 | 4 | 0.5 | 1 | 5.55 |
| no-tillage | 2 | 4 | 0.5 | 2 | 6.47 |
| no-tillage | 2 | 4 | 0.5 | 3 | 4.72 |
| no-tillage | 2 | 4 | 0.5 | 4 | 4.77 |
| no-tillage | 2 | 2 | 0.25 | 1 | 18.04 |
| no-tillage | 2 | 2 | 0.25 | 2 | 19.32 |
| no-tillage | 2 | 2 | 0.25 | 3 | 15.98 |
| no-tillage | 2 | 2 | 0.25 | 4 | 17.05 |
| no-tillage | 2 | 3 | 0.25 | 1 | 16.82 |
| no-tillage | 2 | 3 | 0.25 | 2 | 18.25 |
| no-tillage | 2 | 3 | 0.25 | 3 | 16.7 |
| no-tillage | 2 | 3 | 0.25 | 4 | 15.37 |
| no-tillage | 2 | 4 | 0.25 | 1 | 14.09 |
| no-tillage | 2 | 4 | 0.25 | 2 | 14.95 |
| no-tillage | 2 | 4 | 0.25 | 3 | 16.29 |
| no-tillage | 2 | 4 | 0.25 | 4 | 17.41 |

**APPENDIX E**

Five days of preceding weather data before each planting date.

| Date | Day of Year | Temperature maximum | Temperature minimum | Temperature Average | Relative Humidity (%) | Soil Temperature 1" | Soil Temperature 3" |
|---|---|---|---|---|---|---|---|
| 8/26/2007 | 238 | 93.3 | 72.1 | 82.1 | 86.2 | 92.5 | 98.3 |
| 8/27/2007 | 239 | 93.6 | 70.9 | 80.6 | 88.4 | 91.4 | 95.4 |
| 8/28/2007 | 240 | 92.2 | 69.1 | 79.5 | 89.8 | 89.7 | 94.3 |
| 8/29/2007 | 241 | 93.3 | 72 | 79.5 | 90.9 | 89.4 | 93.3 |
| 8/30/2007 | 242 | 91.3 | 70.9 | 80 | 90.5 | 90.2 | 95.3 |
| 8/31/2007 | 243 | 91.1 | 71.4 | 78.5 | 92.1 | 87.8 | 91.4 |
| 11/4/2007 | 308 | 81.9 | 56.1 | 67.6 | 85.3 | 66.8 | 69.7 |
| 11/5/2007 | 309 | 83.7 | 58.9 | 69.4 | 88.7 | 68.1 | 71.4 |
| 11/6/2007 | 310 | 66.8 | 54.8 | 58.9 | 64.5 | 61.7 | 58.1 |
| 11/7/2007 | 311 | 67.9 | 51.4 | 59 | 57.1 | 62.5 | 63.1 |
| 11/8/2007 | 312 | 76.8 | 47.8 | 62.7 | 90.8 | 64 | 63.8 |
| 11/9/2007 | 313 | 83.3 | 63.2 | 70.9 | 88.1 | 68.8 | 72.7 |
| 5/28/2008 | 149 | 89.5 | 67 | 77.6 | 88.3 | 88.6 | 87.4 |
| 5/29/2008 | 150 | 89.1 | 69.8 | 78.6 | 88.9 | 89.4 | 88.2 |
| 5/30/2008 | 151 | 89.8 | 66.2 | 78.1 | 83.8 | 88.7 | 85.7 |
| 5/31/2008 | 152 | 92.4 | 69.5 | 80.7 | 86.2 | 89.3 | 87.4 |
| 6/1/2008 | 153 | 93 | 71.9 | 81.4 | 83.4 | 89.9 | 88 |
| 6/2/2008 | 154 | 94.4 | 72.4 | 82.3 | 83.6 | 90.1 | 87.9 |
| 6/3/2008 | 155 | 94.6 | 75.1 | 83.1 | 82 | 89.7 | 88.2 |

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