

## ABSTRACT

BROWN, JAMES GILBERT. Cultural Management of Cotton to Reduce the Effects of Herbicide-Resistant *Palmer amaranth*. (Under the direction of Dr. Gary Roberson)

Research was conducted to determine the best weed management practices to combat herbicide resistant *Palmer amaranth*, at three North Carolina State Research Stations, Central Crops Research Station (CCRS), Upper Coastal Plains Research Station (UCPRS) and Cherry Research Farm (CRF). Seed variety, pre-planting tillage and post emergence weed control were the factors for each of the trials. Weed densities in-row, between row and total, along with yields, were used to determine the best practices. In 2009, research conducted at UCPRS showed that plots that received more primary tillage soil disturbance showed higher weed densities. It was hypothesized that if soil disturbance was reduced, weed density would decrease. Overall CCRS showed the highest weed density, whereas CRF showed extremely low weed densities. The research conducted at the UCPRS in Rocky Mount, NC and the CCRS in Clayton, NC, both showed that in areas where herbicide resistant *Palmer amaranth* was present that mechanical cultivation was the best method to control *Palmer amaranth* between rows. Weed densities were so low at the Cherry Research Farm site, that it is difficult to conclude which post emergence weed control method was best for between row weed control. All plots showed that the best practice to combat in row weed density was herbicide application. This is due to the fact that mechanical cultivation cannot control weeds in row, without damaging the cotton plants. Yields for UCPRS and CCRS showed, as expected, that areas with higher weed densities, resulted in lower yields. CRF was an exception, in that there was no correlation between weed densities and yields. This could be attributed to the overall low weed densities for the site. Overall, the research from 2010 did not match the findings from 2009, in terms of the effects of soil disturbance on weed

proliferation. In some cases, especially UCPRS, the conservation tillage treatments showed much higher weed proliferation than the more aggressive tillage treatments.

Secondary research was conducted to originally help quantify the costs of the weed control practices used in the crop studies, discussed above. The goal of the research was to implement a tractor with an easy to use system that would continuously measure and record, fuel consumption, ground speed and draft load, as the tractor was moving. Previous research was done on each parameter individually, but not as a group. To measure the draft load, a three point hitch dynamometer was designed, fabricated, calibrated and tested. The tests were compared to estimates given in ASABE D497.7. Eight trials, using four different implements, were conducted. The comparison to the ASABE standard was inconclusive. Some of the implements were within 20% of the ASABE estimate draft, when the estimated variation was included, whereas some were off as much as 100%. A volumetric fuel flow meter with frequency output was installed on the research tractor. The output was compared to the data for the specific tractor from the Nebraska Tractor Test Data. It was determined that the fuel flow meter readings matched the Nebraska Tractor Data. A streamline data acquisition system, designed for race cars, was used to collect the dynamometer data and the fuel consumption data. The data acquisition system also had a built in GPS receiver, so it could record ground speed as well.

Cultural Management of Cotton to Reduce the Effects of Herbicide-Resistant *Palmer  
amaranth*

by  
James Gilbert Brown

A thesis submitted to the Graduate Faculty of  
North Carolina State University  
in partial fulfillment of the  
requirements for the Degree of  
Master of Science

Biological and Agricultural Engineering

Raleigh, North Carolina

2015

APPROVED BY:

---

Dr. Gary Roberson  
Committee Chair

---

Dr. David Jordan

---

Dr. Grant Ellington

## **DEDICATION**

To my family and friends, that never stopped encouraging me throughout this process.  
Especially my wife, Meredith Brown and our son, Davis.

## **BIOGRAPHY**

Gil began his life in the wee hours of August 7, 1987. His life started a little different than most, because he was born a twin. He and his brother were born a minute apart, which is one fact that has been used to his advantage numerous times in his life. He grew up in the small town of Pine Hall, which is located about 30 minutes north of Winston Salem in Stokes County, NC.

Stokes County is a rural, mainly tobacco producing county. Gil didn't grow up on a tobacco farm, but he helped extended family a few summers with their tobacco crop. As a child, he loved playing baseball, basketball, and golf. He also loved being outdoors. Later in life his favorite hobbies became hunting, fishing, golf and slow pitch softball.

He graduated from South Stokes High School in 2005. During high school he decided that he wanted to become some sort of engineer. He didn't know exactly what type of engineer, but once he got to college it became obvious that he wanted to become a biological and agricultural engineer. That discipline combined his love of the outdoors with his love for science. In 2009, he earned a Bachelor's of Science degree in Biological Systems Engineering from Virginia Tech.

While at Virginia Tech he was active in the student branch of the American Society of Agricultural and Biological Engineers. He was also one of the first members of the Virginia Tech chapter of Farmhouse Fraternity. During his senior year at Virginia Tech, Gil decided that he wanted to pursue a Master's of Science degree in Biological and Agricultural Engineering. Since his B.S. was mainly focused on environmental engineering, he wanted to focus his M.S. on a more traditional agricultural engineering degree.

Wanting to be close to home and wanting to attend a more traditional agricultural engineering department, he decided that N.C. State's Biological and Agricultural Engineering department was the best option. So he enrolled for the Fall semester in 2009. While at N.C. State, he joined the ASABE quarter scale tractor team. This experience helped him develop his knowledge of the mechanical design aspect of agricultural engineering. Also, while enrolled at N.C. State, he married his longtime girlfriend on July 10, 2010, Meredith Watts Brown. He and his wife had their first child May 21, 2013, Davis Trent Brown. They are expecting their second, December 2015.

Currently he and his family live in Walnut Cove, NC and he is a Process Development Manager for Unifi a leading manufacturer of multi filament polyester and nylon yarns.

## ACKNOWLEDGEMENTS

The author would like to thank the numerous people that helped with this research project. First, he would like to thank Dr. Gary Roberson, advisor, for always being willing to help. He would also like to thank Drs. David Jordan and Grant Ellington for their support and guidance as committee members.

The author would also like to thank the abundance of help from his friends of Weaver. He would like to give a special thanks to John Long, Ed Godfrey, Justin Rothrock, Bobby Vick, Michelle Mayer and Will Brown. They were the ones that no matter the problem or time of day were willing to help the best they could. Thanks to Ed, Michelle, Will and Justin for helping with the tedious task of picking cotton by hand. Thanks to Justin for all the help with the design and fabrication of the dynamometer. Thanks to Ed and John for always answering questions no matter how simple they seemed. Without their help, the project would have never been successful.

The author would like to thank Mr. Phil Harris and Mr. Barry Lineberger for their technical guidance with the dynamometer. Without their help, the dynamometer aspect of the research would never have been successful. The author would also like to thank the BAE research shop, especially Ken Coats and Steve Cameron, for all of their help with the dynamometer fabrication.

## TABLE OF CONTENTS

<b>LIST OF TABLES</b> .....	viii
<b>LIST OF FIGURES</b> .....	ix
<b>1.0 Introduction and Literature Review</b> .....	1
<b>1.1 Background</b> .....	1
<b>1.2 Why is Palmer amaranth a problem?</b> .....	4
<b>1.3 Mechanical Weed Control Options</b> .....	5
<b>1.4 Alternative Seed Type</b> .....	9
<b>1.5 Instrumentation to determine Fuel Use, Slippage and Draft Load</b> .....	10
<b>2.0 Research Objectives and Hypothesis</b> .....	12
<b>2.1 Project Goals</b> .....	12
<b>2.2 Hypotheses</b> .....	13
<i>2.3.1 Field Studies</i> .....	13
<i>2.3.2 Dynamometer</i> .....	13
<b>2.3 Objectives</b> .....	13
<b>3.0 Cotton Plots Methods</b> .....	14
<b>3.1 Central Crop Research Station</b> .....	14
<i>3.1.1 Tillage, Fertilizing and Weed Control</i> .....	14
<i>3.1.2 Weed Counts</i> .....	18
<i>3.1.3 Yield data collection</i> .....	19
<b>3.2 Upper Coastal Plain Research Station</b> .....	21
<i>3.2.1 Tillage, Fertilizing and Weed Control</i> .....	21
<i>3.2.2 Weed Counts</i> .....	24
<i>3.2.3 Yield data collection</i> .....	25
<b>3.3 Cherry Research Farm</b> .....	28
<i>3.3.1 Tillage, Fertilizing and Weed Control</i> .....	28
<i>3.3.2 Weed Counts</i> .....	31
<i>3.3.3 Yield data collection</i> .....	31
<b>4.0 Tractor Performance Methods</b> .....	32

<b>4.1 Fuel Flow Meter .....</b>	<b>32</b>
4.1.1 Installation.....	33
4.1.2 Calibration.....	34
4.1.3 Data Collection.....	35
<b>4.2 Dynamometer .....</b>	<b>35</b>
4.2.1 Design.....	35
4.2.2 Fabrication.....	38
4.2.3 Strain Gage and Signal Conditioner Installation.....	39
4.2.4 Calibration.....	41
4.2.5 Testing and Data Collection.....	46
<b>4.3 Data Acquisition System.....</b>	<b>49</b>
4.3.1 Installation.....	50
4.3.2 Software and Data Collection .....	50
<b>5.0 Results and Discussion.....</b>	<b>51</b>
<b>5.1 Cotton Field Studies.....</b>	<b>51</b>
5.1.1 Central Crops Research Station Results .....	51
5.1.2 Upper Coastal Plain Research Station Results .....	58
5.1.3 Cherry Research Farm Results.....	69
5.1.4 Field Study Conclusions .....	71
<b>5.2 Tractor Performance .....</b>	<b>72</b>
5.2.1 Dynamometer Results.....	72
5.2.2 Fuel Flow Meter and Data Acquisition Feasibility.....	76
<b>6.0 Future Research.....</b>	<b>77</b>
<b>7.0 Bibliography .....</b>	<b>78</b>

## LIST OF TABLES

<b>Table 1. Treatments for the field study conducted at the Central Crops Research Station in Clayton, NC.....</b>	<b>17</b>
<b>Table 2. Treatments for the field study conducted at the Upper Coastal Plain Research Station in Rocky Mount, NC.....</b>	<b>23</b>
<b>Table 3. Treatments for the field study conducted at the Cherry Research Farm in Goldsboro, NC.....</b>	<b>30</b>
<b>Table 4. Assumptions used to estimate the draft load of each of the four implements tested, using ASABE D497.7. ....</b>	<b>74</b>
<b>Table 5. Draft load for the four implements tested compared to the ASABE D497.7... </b>	<b>75</b>

## LIST OF FIGURES

<b>Figure 1. Percent of total cotton acreage in North Carolina that is Round-Up Ready only or gene stacked.....</b>	<b>2</b>
<b>Figure 2. The decline of acreage cultivated for weed control in North Carolina cotton. 2</b>	<b>2</b>
<b>Figure 3: Palmar Amaranth in an Agriculture Field .....</b>	<b>4</b>
<b>Figure 4: Sukup<sup>®</sup> Plow used for research completed in 2009.....</b>	<b>7</b>
<b>Figure 5. The typical setup for paratill subsoiler. (Bingham Brothers) .....</b>	<b>8</b>
<b>Figure 6. Plot map for the field study conducted at the Central Crops Research Station in Clayton, NC with the plot number in the lower left hand corner and the treatment number in the top center. ....</b>	<b>17</b>
<b>Figure 7. Diagram showing the areas in which the in row and between row weed counts were measured.....</b>	<b>19</b>
<b>Figure 8. Cotton being harvest and collected at Central Crops Research Station .....</b>	<b>20</b>
<b>Figure 9. A plot after being harvested at Central Crops Research Station.....</b>	<b>20</b>
<b>Figure 10. Plot map for the field study conducted at Upper Coastal Plain Research Station in Rocky Mount, NC with the plot number in the lower left hand corner and the treatment number in the top center. ....</b>	<b>24</b>
<b>Figure 11. Cotton harvester used at the Upper Coastal Plain Research Station. ....</b>	<b>26</b>
<b>Figure 12. The weighing apparatus on the rear of the cotton harvester used at the Upper Coastal Plain Research Station.....</b>	<b>27</b>
<b>Figure 13. Plot map for the field study conducted at the Cherry Research Farm in Goldsboro, NC with the treatment number in the top center.....</b>	<b>30</b>
<b>Figure 14. The dynamometer setup for use on a Category II hitch. ....</b>	<b>36</b>
<b>Figure 15. The dynamometer setup to be used on a Category III hitch. ....</b>	<b>37</b>
<b>Figure 16. The assembly of the three point hitch dynamometer, with the strain gage locations displayed. ....</b>	<b>39</b>
<b>Figure 17. Circuit diagram of a half Wheatstone Bridge circuit.....</b>	<b>40</b>
<b>Figure 18. Load cell calibration curve. ....</b>	<b>42</b>
<b>Figure 19. The setup used for horizontal force calibrations. The chain on the left is attached to the dynamometer and the tow strap on the right is attached to a tree. ....</b>	<b>43</b>
<b>Figure 20. Horizontal force profile for the calibration of the two bottom links. The force profile for the calibration of the top link was similar. ....</b>	<b>44</b>

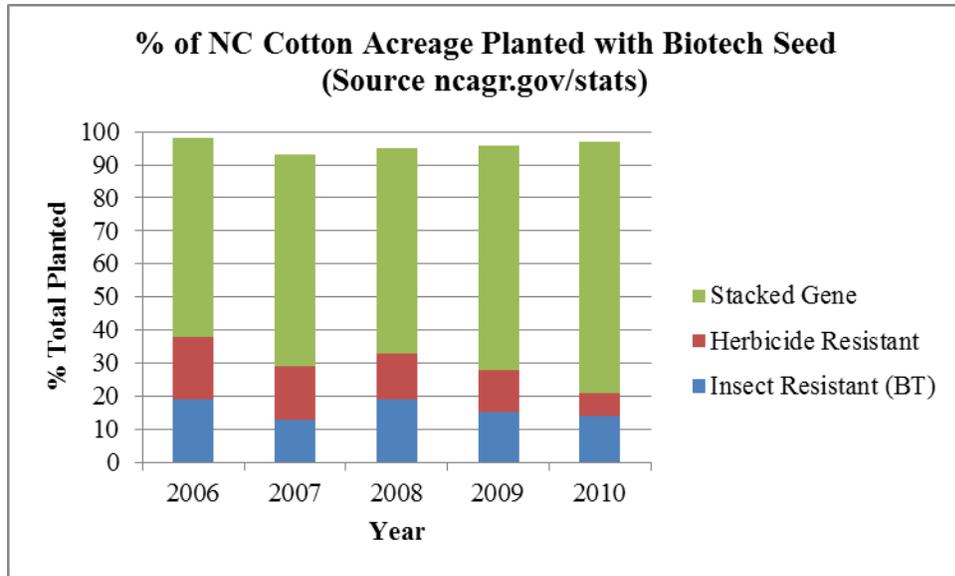
<b>Figure 21. Setup used for calibrating the vertical component of the dynamometer. ....</b>	<b>45</b>
<b>Figure 22. Vertical force profile for the calibration of the two bottom links. The force profile for the top link was similar. ....</b>	<b>46</b>
<b>Figure 23. The paratill used for the dynamometer research. ....</b>	<b>47</b>
<b>Figure 24. The Danish tine row cultivator being pulled through the test plot. ....</b>	<b>48</b>
<b>Figure 25. The chisel plow being lowered into the test plot. ....</b>	<b>48</b>
<b>Figure 26. The field cultivator used for the research. ....</b>	<b>49</b>
<b>Figure 27. Average weed density values for each treatment type at the Central Crops Research Station for the 2010 Cotton season. ....</b>	<b>52</b>
<b>Figure 28. Cotton yield values at the Central Crops Research Station for the 2010 Cotton season.....</b>	<b>53</b>
<b>Figure 29. ANOVA analysis Minitab output of in row weed densities with main effects of seed type, tillage, and post emergence weed management strategy. ....</b>	<b>54</b>
<b>Figure 30. Main effects plot for the post emergence weed control factor for in-row weed density. ....</b>	<b>55</b>
<b>Figure 31. ANOVA analysis Minitab output of Between Row Weed Densities with main effects of seed type, tillage, and post emergence weed management strategy. ....</b>	<b>56</b>
<b>Figure 32. Main effects plot for post emergence weed control factors on between row weed density.....</b>	<b>56</b>
<b>Figure 33. ANOVA Analysis Minitab Output of Total Weed Density with main effects of seed type, tillage, and weed management strategy .....</b>	<b>57</b>
<b>Figure 34. ANOVA Analysis Minitab Output of Total Weed Density for effect of Treatment Only .....</b>	<b>57</b>
<b>Figure 35. Weed density values at the Upper Coastal Plains Research Station for the 2009 Cotton season.....</b>	<b>59</b>
<b>Figure 36. Weed density values at the Upper Coastal Research Station for the 2010 Cotton season.....</b>	<b>60</b>
<b>Figure 37. ANOVA Analysis Minitab Output of In-Row Weed Density with main effects of seed type, tillage, and weed management strategy .....</b>	<b>62</b>
<b>Figure 38. Interaction plot for in row weed density for the pre-plant tillage and post emergence weed control factors.....</b>	<b>63</b>
<b>Figure 39. ANOVA Analysis Minitab Output of Between-Row Weed Density with main effects of seed type, tillage, and weed management strategy. ....</b>	<b>64</b>

<b>Figure 40. Main effects plot for the post emergence weed control factor for between row weed density.....</b>	<b>65</b>
<b>Figure 41. ANOVA Analysis Minitab Output of Total Weed Density with main effects of seed type, tillage, and weed management strategy. ....</b>	<b>66</b>
<b>Figure 42. Interaction plot for total weed density for the pre plant tillage and post emergence weed control factors.....</b>	<b>67</b>
<b>Figure 43. Yields for Upper Coastal Plains Research Station. ....</b>	<b>68</b>
<b>Figure 44. Weed census for the field studies at Cherry Research Farm. ....</b>	<b>69</b>
<b>Figure 45. Yield analysis for Cherry Research Farm.....</b>	<b>70</b>
<b>Figure 46. Calibration curve used for the left side bottom link of the three point hitch dynamometer.....</b>	<b>73</b>
<b>Figure 47. Example output from the data acquisition system. ....</b>	<b>76</b>

## **1.0 Introduction and Literature Review**

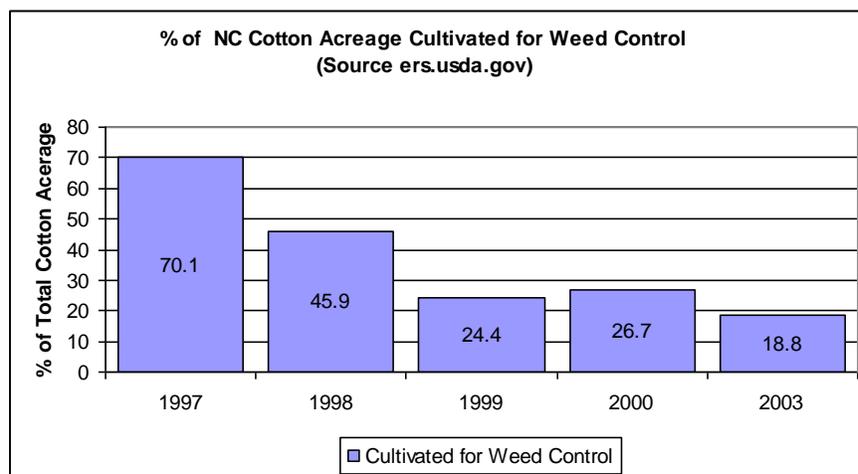
### **1.1 Background**

Cotton has consistently been one of North Carolina's top cash crops. In 2007, North Carolina's cotton crop was valued at approximately \$206,000,000 (USDA 2008). Due to increased fuel and fertilizer prices, along with the push for farmers to implement more environmentally conscious practices, a majority of farmers have begun using conservation tillage equipment. Conservation tillage equipment, such as no-till and strip-till planters, has been proven to save farmers substantial amounts of money in fuel costs. The USDA Energy Calculator shows that a farmer in eastern North Carolina could likely see a fuel savings of approximately 41-46% if he were to grow 1000 acres of cotton using conservation tillage equipment (USDA 2008). Since the release of Roundup Ready Cotton<sup>®</sup> seed in 1997, most farmers using conservation tillage techniques have relied solely on chemical herbicides as a means of controlling weeds (Monsanto). As Figure 1 shows, approximately 80 percent of the cotton planted in North Carolina is a Roundup Ready Cotton<sup>®</sup> cultivar (USDA 2008).



**Figure 1. Percent of total cotton acreage in North Carolina that is Round-Up Ready only or gene stacked.**

With the heavy use of chemical herbicides there has been a substantial decrease in cultivation for weed control. Figure 2 displays the decrease in cultivation from 1997-2003 (USDA 2008).



**Figure 2. The decline of acreage cultivated for weed control in North Carolina cotton.**

The herbicides that have been the most widely used in cotton production are glyphosate based products, such as Roundup<sup>®</sup>. With the repeated application of the same herbicide, many weeds have shown significant resistance to glyphosates. *Palmer amaranth* is one weed that has developed this resistance. The development of this resistance has led many farmers to question their future in the cotton production industry. Virginia Cooperative Extension (2009) states that one *Palmer amaranth* plant per 9.14 meters of row can reduce cotton yield by 6-12%.

Cotton production in the United States has dramatically declined over the last few years. In North Carolina alone, cotton production dropped from 865,000 acres to 490,000 acres from 2006 to 2007 (USDA 2008). This drop in production may be attributed to the increased prices for other commodities, or it may be related to the problems farmers encounter while trying to control weeds. A majority of the recent research that has been done to develop a way to combat the glyphosate resistant weeds in cotton has been focused on alternative herbicides and different herbicide application strategies. Due to the strict requirements herbicide developing companies must adhere to, this research will not have an immediate impact. A minimum tillage system that can effectively control weeds and maintain low fuel consumption must be developed. Research that compares weed densities in conventional tillage systems and in conservation tillage systems must be done to determine if the higher fuel requirements in the conventional systems offset the yield losses due to weed proliferation found in conservation tillage systems. The *Palmer amaranth* control associated with winter cover crops must also be determined. The optimum system will most likely include a pre-plant mechanical tillage system combined with a post emergence chemical herbicide application.

## 1.2 Why is Palmer amaranth a problem?

*Palmer amaranth* is a summer annual weed that can grow to 3-4 m. It is a tap-rooted weed that uses the C<sub>4</sub> photosynthetic pathway, so it competes well for water, light and nutrients (Ehleringer, 1983). Figure 3 shows a typical *Palmar Amaranth* plant in an agricultural field.



**Figure 3: Palmar Amaranth in an Agriculture Field**

As found by Currie et. al. (2001), *Palmer amaranth* can produce 200,000-600,000 seeds per plant, which gives it the ability to spread rapidly. It also has the ability to cross with other *Amarathus* species, which allows it to adapt to or resist herbicides more rapidly than most weeds. Burgos et. al. (2006) documented that *Palmer amaranth* is resistant to two modes of actions, ALS inhibitors and EPSPS Synthase inhibitors. Glyphosate is an EPSPS Synthase

inhibitor. Brown et. al. (2006) found that *Palmer amaranth* that was 5-13 cm tall required 12 times the normal rate of glyphosate to obtain 82% control of the weed.

Yield reduction due to *Palmer amaranth* has been documented in many of the major crops in the United States. It has been shown that 10 *Palmer amaranth* plants per meter of row can reduce soybean yields by 68% and eight *Palmer amaranth* plants per meter of row can reduce corn yields by 91% (Currie et. al. 2001). In cotton, one plant per 9.14 meters of row can reduce yield by 6-12% (Virginia Cooperative Extension). With documented evidence that *Palmer amaranth* can cause detrimental yield reduction, the agriculture industry is becoming concerned. Since the weed has become resistant to herbicides, farmers may need to revert back to using mechanical tillage, even though conservation tillage methods are more beneficial to the environment.

### **1.3 Mechanical Weed Control Options**

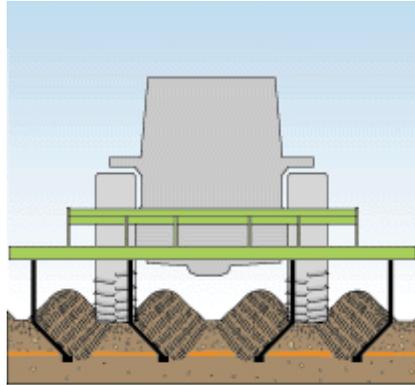
Research has proven that no-till and strip-till systems are beneficial cropping systems (Pollock and Reeder, 2010). It has been concluded that conservation tillage systems can reduce erosion caused by wind and water, improve soil moisture retention and increase soil organic matter. A possible downfall for conservation tillage systems is the exclusive reliance on chemical herbicides. Weed density reduction is directly related to how well the herbicide application performs. Since *Palmer amaranth* has shown resistance to herbicides, mechanical removal of the weed is likely the best way to control the weed. Unlike conventional tillage methods, conservation tillage systems do not offer a mechanical means of removing weeds. Mechanical removal of weeds is a proven method to reduce weed

stands, due to the process of physically extracting weeds from the soil bed. Although mechanical removal of the weeds has proven effective, it still must be considered that the fuel requirements are higher in conventional systems compared to conservation tillage systems. Conventional tillage methods usually include using a chisel plow to break the soil and then a disk harrow to break the soil into finer particles and level the soil for easier planting. Some farmers have different methods for pre-plant tillage in conventional systems. Conventional systems require many passes through a single field, one for chemical burndown, one for chisel plowing, one for disking, one for planting and a varying number of passes through the field for spraying. Conservation tillage systems require fewer passes through a single field, one for chemical burndown, one for planting and varying passes for cultivation or spraying. The additional passes through a field contributes to the higher fuel requirements for conventional systems. As mentioned above, there are numerous techniques and types of equipment for conventional tillage systems. One pre-plant tillage tool that is commonly used in a conventional tillage system to create row beds is the Sukup® ripper bedder. The Sukup® plow is an aggressive tillage tool that leads to significant above ground soil disturbance. From preliminary research, conducted in the 2009 growing season, it was found that the Sukup® plow resulted in the highest weed incidence when compared to no-till and strip-till, Figure 34. The Sukup® plow that was used for the 2009 research project can be seen in Figure 4. It was concluded, from the 2009 growing season, that soil surface disturbance that was introduced during the pre-plant tillage activities was the largest contributor to higher weed densities and subsequently lower yields (Personal Communication, Matthew Veal 2010).



**Figure 4: Sukup® Plow used for research completed in 2009.**

Another tillage tool that some include in a conventional tillage system is an inter-row sub-soiling. Bernier et. al. (1989) found that sub-soiling is an effective means of reducing compaction, which in turn improves infiltration and ultimately improves yield. The fact that inter-row sub-soiling does not introduce significant soil surface disturbance, makes it a viable option to replace the Sukup® plow in a conventional tillage system that relies on the Sukup® plow for row bedding. The Tye Paratill™ is one of numerous sub-soiling implements available on the market today. It is a four row, category III three-point-hitch soil loosener (Alberta Farm Machinery Research Centre, 1991). It has four shanks that have a 45 degree angle. Figure 5 displays a typical Paratill apparatus.



**Figure 5. The typical setup for paratill subsoiler. (Bingham Brothers)**

The purpose of the Paratill is to disturb soil horizons below the surface while only cutting the soil surface in one place. It is thought that the Tye Paratill™ can disturb the soil directly below where the seed is planted, which would destroy the roots of weeds present immediately prior to planting, without disturbing the surface as much as conventional tillage does. An evaluation conducted by the Alberta Farm Machinery Research Centre (1991) showed that the Tye Paratill™ caused very little soil surface disturbance when it was used in untilled soils. The evaluation also concluded that moist soils and previously tilled soils caused the soil fracture depth to decrease. These conclusions demonstrate that the Tye Paratill™ would be an effective way to disturb the root of a *Palmer amaranth* plant in untilled soils without disturbing much of the soil surface. The negative aspect of the four row Tye Paratill™ is that it requires a tractor with a PTO power rating of 18.8 kW per meter of implement width (Alberta Farm Machinery Research Centre, 1991). This estimate is based on a tillage depth of 25.4 cm, a minimum shatter plate angle and a ground speed of 7.2 km/h (Alberta Farm Machinery Research Centre, 1991). Since the Tye Paratill™ requires a fairly large tractor, it will cost the farmer more to use the Tye Paratill™ than it will to use other tillage tools. It is estimated that the total cost (fuel, repair, etc...) to use a four row Tye

Paratill™ that had 0.76 m between each shank would be \$44.04/ha (Mississippi State University Dept. of Ag. Econ., 2009), whereas it would only cost \$16.87/ha to use a 4.88 m chisel plow (Mississippi State University Dept. of Ag. Econ., 2009). This one example shows the economic impact of using the Paratill™. The largest contributor to higher total cost is the fuel cost. For the above example the fuel cost for the Paratill (\$14.38/ha) is almost 3 times the fuel cost for operating the chisel plow (\$4.71/ha) (Mississippi State University Dept. of Ag. Econ., 2009). Although the Tye Paratill™ has been proven to be effective in alleviating the effects of soil compaction, there is limited research on its effectiveness in controlling weeds. It needs to be determined if the Tye Paratill™ is an effective way of controlling *Palmer amaranth* before farmers will be willing to use the more expensive tillage tool.

One inexpensive method farmers can try and use to reduce *Palmer amaranth* pressure is using an herbicide or combination of herbicides that have a different mode of action than glyphosate and ALS inhibitors. For farmers to be able to use different types of post emergence weed control chemicals, seeds that have a the appropriate seed treatment must be used.

#### **1.4 Alternative Seed Type**

In 2004, Bayer CropScience released FiberMax® Liberty Link® cotton seed (Bayer CropScience). This seed is similar to the Roundup Ready® varieties in that it can withstand an over the top application of an herbicide. The Liberty Link® seed were developed to withstand the application of Ignite®. Ignite® is an herbicide that uses glufosinate-

ammonium as the active ingredient. It is a glutamine synthetase inhibitor, so it has a different mode of action than Roundup® (Bayer CropScience). Since Liberty Link® cotton is a relatively new cotton variety, it has not been researched as much as the Roundup Ready® varieties. Since Liberty Link® varieties can be sprayed post emergence, they do yield themselves to being a viable competitor in conservation tillage systems (Bayer CropScience). These seeds can be planted in traditional conventional tillage and conservation tillage systems, just like Roundup Ready® varieties, but the appropriate post emergence herbicide should be applied.

### **1.5 Instrumentation to determine Fuel Use, Slippage and Draft Load**

Although there are numerous proposed methods of combating *Palmer amaranth*, the one that has the lowest cost will be the optimum choice. From the previously mentioned items, it can be noted that fuel consumption is a significant factor when deciding upon which management strategy to use to combat *Palmar Amaranth*. Fuel consumption can be influenced by an increase in the number of passes through a field or the increased fuel consumption due to tillage equipment type. Draft load of a specific implement is directly related to the fuel consumption of a tractor. The lower the draft load on the tractor, the lower the amount of power is required to pull the implement at a given ground speed. Lowering the power required will ultimately reduce fuel consumption. There are many ways to instrument a tractor to determine the draft load of different implements. All of the instruments are either affixed to the tractor's linkage or to a frame that is attached to the three-point-hitch on the tractor. These instruments are referred to as three-point-hitch dynamometers. There has been numerous research conducted on both forms of the dynamometer. It was found that

instruments attached to the tractor itself caused less disruption of the tractor but they are not interchangeable between different tractors (Palmer, A.L., 1992). The instruments that are built into frames between the tractors and implement have been found to easily obtain horizontal, vertical and lateral forces along with their respective moments (Palmer, A.L., 1992). Most dynamometers are instrumented with strain gages (Bowers et al. 1989 and Upadhyaya et al. 1985) , but draft force has also been determined by using transducers (Garner et al 1988, Johnson and Vorhees 1979, Bandy et al. 1986 and Zoerb et al. 1983), load sensing pins (Bandy et al. 1936) and load cells (Chaplin et al. 1987).

Slippage is another measurement that helps determine the efficiency of a tractor. Wheel slippage is the difference between the peripheral speed at the drive wheels of a tractor and the tractors actual forward speed. The equation for slippage is below, where  $v_t$  = theoretical velocity and  $v_a$  = actual speed:

$$\mathbf{Slippage} = \frac{v_t - v_a}{v_t}$$

There are a number of ways to determine slippage. Every method uses the same concept. There must be one instrument to determine the speed of the rear axle. A common method to determine actual wheel speed uses a proximity sensor to count the number of gear teeth that passes a fixed location. If the number of teeth on a particular gear is known, then the gear revolutions can be calculated by dividing the number of teeth counted by the sensor by the number of teeth on the gear. By using the ratio of gear size to tire size, the actual wheel speed can be calculated. There also must be an instrument that can calculate actual forward speed. Forward speed can be found by using radar or GPS technologies. From the actual forward speed and the revolutions of the rear axle one can calculate the amount of slippage the tractor is experiencing while pulling a certain implement.

Reducing fuel consumption is one of the most important aspects to consider when determining which tillage implement is optimum. Fuel consumption can be estimated by using tractor operating conditions, but measuring fuel consumption, which would show a more absolute value, requires a fuel flow meter. Many companies manufacture fuel flow meters. They all measure the volume of fuel through a known cross sectional area for a given amount of time, but may be instrumented differently.

## **2.0 Research Objectives and Hypothesis**

### **2.1 Project Goals**

There were two primary goals of this research:

1. Investigate the interaction of seed type, tillage, cultivation, and herbicide application on cotton production parameters.
2. Quantify tractor draft load and fuel consumption while implementing various tillage tools.

The success of the first objective was based on cotton yield for each treatment and how well the treatments suppressed *Palmer amaranth* populations. The success of the second objective was based on how closely the draft load data matched that of ASABE D497.7. As a result of this study, North Carolina cotton producers will be able to make informed decisions about management practices needed to combat glyphosate resistant *Palmer amaranth*.

## **2.2 Hypotheses**

### *2.3.1 Field Studies*

1. The Tye Paratill™ would show lower weed densities than the Sukup® plow.
2. The FiberMax® Liberty Link® cotton seed type would have lower weed densities than the Genuity® Bollgard II® with Roundup Ready® Flex seed type.

### *2.3.2 Dynamometer*

1. The strain gage pair on the front of the U-shaped beam would be best at predicting horizontal forces.
2. The strain gage pair on the top of the U-shaped beam would be best at predicting vertical forces.
3. The dynamometer results would be similar to the ASABE tillage data.

## **2.3 Objectives**

To accomplish the project goals and test the hypotheses, the following objectives were established:

1. Design and conduct a field study at three different North Carolina research farms, using various management practices.
2. Design, instrument and implement a three point hitch dynamometer to quantify draft load for various tillage tools.
3. Instrument an agricultural tractor in order to quantify ground speed and fuel consumption.

4. Instrument an agricultural tractor so that it can record, with little operator effort, all of the fuel consumption, ground speed and dynamometer data onto one memory card. This data would then be used to help quantify the cost of using different weed management practices.

### **3.0 Cotton Plots Methods**

Three research plots were established in Eastern North Carolina. One each at Central Crops Research Station (CCRS) in Clayton, NC, the Upper Coastal Plain Research Station (UCPRS) in Rocky Mount, NC, and the Cherry Research Farm (CRF) in Goldsboro, NC. Central Crops Research Station is owned and operated by North Carolina State University. The Upper Coastal Plain Research Station and the Cherry Research Farm are owned and operated by the North Carolina Department of Agriculture and Consumer Sciences. The plots located at CCRS and UCPRS were established in fields that were known to contain glyphosate-resistant *Palmer amaranth* throughout. The plot located at CRF was established in a field that has recently showed glyphosate-resistant *Palmer amaranth* in isolated areas.

#### **3.1 Central Crop Research Station**

##### *3.1.1 Tillage, Fertilizing and Weed Control*

At the Central Crops Research Station, eight treatments were replicated at least 3 times to total 32 plots. The plots also included a control plot. One replication of treatments 2, 3, 6, and 8 were dropped to accommodate the control plots. Each plot measured 7.62 m by

15.24 m, with a 15.24 m alley between the replications. Each plot contained eight rows of cotton, which yielded the four middle rows for data collection and two buffer rows on each side to reduce the influence of the adjacent plots. The eight treatments included two different seed varieties, two primary tillage treatments and two post emergence weed control methods. The treatments can be found in Table 1 and the plot layout can be found in Figure 6.

The two seed varieties used were FiberMax® LibertyLink® from Bayer CropScience and Genuity® Bollgard II® with Roundup Ready® Flex from Monsanto. The FiberMax® LibertyLink® seed are tolerant of glufosonate ammonium, also known by the common name Ignite®. The Roundup Ready® Flex seed are tolerant of glyphosate, also known by the common name Roundup®.

All of the plots received the same preplant herbicide treatment, also known as burndown. Glystar® was applied at a rate of 2.34 L/ha on April 16, 2010. In early June 2010 the two pre-plant tillage treatments were administered to the predetermined plots. The two primary tillage systems used were a conventional tillage system and a strip-till system. The conventional tillage system consisted of chisel plowing followed by a heavy disking. Then a rolling reel, which is a finishing tool, was used to level the ground before planting. The strip-till system consisted of a strip-till unit, that cut a strip approximately 20.3 cm wide, where the cotton seed was planted. Once the tillage systems had been implemented a 6-8-46 fertilizer was broadcasted at a rate of 449.1 kg/ha. The two seed varieties were planted in mid-June, after the broadcast fertilizer application, rather than the usual planting time period of mid-May (late planting was due to weather).

At planting, each plot received an in furrow application of Temik 15G and Ridomil Gold PCGR at a rate of 6.4 kg/ha and 8.98 kg/ha respectively. After planting, on June 22,

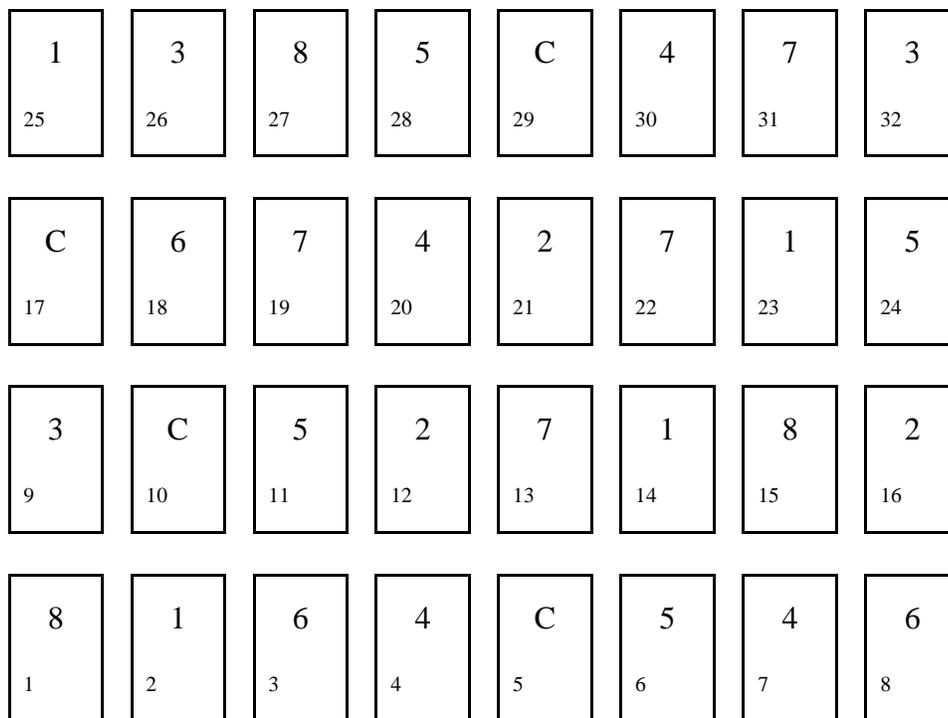
2010, all plots received a side dress application of liquid nitrogen fertilizer at a rate of 112.3 L/ha. The plots also received an additional application of liquid nitrogen fertilizer at a rate of 112.3 L/ha at layby, July 7, 2010.

For post emergence weed control, two treatments were used. One treatment was the use of mechanical cultivation in the form of a Danish tine cultivator. The other treatment was an over-the-top chemical application. Roundup PowerMAX® was applied on June 23, July 7, July 20, and July 30, 2010 at a rate of 2.34 L/ha to the plots that contained the Genuity® Bollgard II® with Roundup Ready® seed. Ignite® was applied on June 23 and July 20, 2010 at a rate of 3.14 L/ha to the plots that contained the FiberMax® LibertyLink® seed. The Danish tine was used on the plots that were to receive mechanical cultivation every time the Roundup PowerMAX® was applied. This difference between the pesticide application timings and amounts were due to the different application recommendations of the pesticide labels.

Due to the late planting, a defoliant was never applied. The cotton was naturally defoliated by the first frost. The alley ways between the replications were mowed three times and were sprayed with Roundup® twice during the season to allow for easier access to the plots. Control plots received none of the above mentioned treatments. They were established to set a baseline for the worst case scenario that could occur in the particular field that was used.

**Table 1. Treatments for the field study conducted at the Central Crops Research Station in Clayton, NC.**

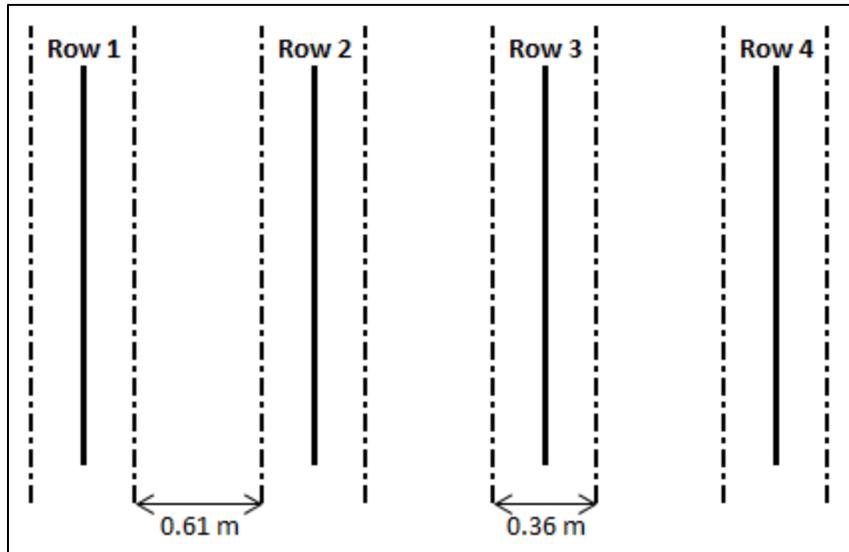
SEED	TILLAGE TREATMENT	POST-EMERGENCE CONTROL	TREATMENT LABEL	TREATMENT NUMBER (on plot map)
FiberMax® LibertyLink®	Conventional	Chemical	LL_Conv_Chem	1
	Conventional	Tillage*	LL_Conv_Till	2
	Strip-Till	Chemical	LL_ST_Chem	3
	Strip-Till	Tillage*	LL_ST_Till	4
Genuity® Bollgard II® with Roundup Ready® Flex	Conventional	Chemical	RR_Conv_Chem	5
	Conventional	Tillage*	RR_Conv_Till	6
	Strip-Till	Chemical	RR_ST_Chem	7
	Strip-Till	Tillage*	RR_ST_Till	8
None	None	None	Control	C



**Figure 6. Plot map for the field study conducted at the Central Crops Research Station in Clayton, NC with the plot number in the lower left hand corner and the treatment number in the top center.**

### 3.1.2 Weed Counts

Weed counts were conducted two times during the season. The counts focused on the occurrence of *Palmer amaranth* in and between the four middle rows of cotton of each plot. The four middle rows were chosen to get a representative sample and to reduce the effects of adjacent plots. The counts were done by walking the length of the plot and counting the number of *Palmer amaranth* plants observed in rows 3, 4, 5, 6 and between rows 3 and 4, 4 and 5, and 5 and 6. In row weed counts were conducted in the 0.36 m strip, Figure 7, centered about the established cotton row. Between row weed counts came from the 0.61m strip, Figure 7, centered about the midpoint between two rows of established cotton. Weed density was calculated by dividing weed count by the area from which the weed count was taken. This allowed the weed counts to be compared in a fairer manner, since in row and between row weed counts were conducted over different areas. Averages were established for the in row counts and for the between the row counts for each treatment. These averages were then analyzed graphically. An ANOVA analysis was conducted, using weed densities from individual plots, to determine if there was any significance between the factors.



**Figure 7. Diagram showing the areas in which the in row and between row weed counts were measured.**

### 3.1.3 Yield data collection

Due to high weed incidence, some of the plots only developed small unopened bolls, so they were deemed non-harvestable. These plots included 1, 3, 4, 5, 7, 10, 12, 15, 16, 17, 18, 20, 21, 25, 27, 29, 30, and 31. The plots that were harvestable had such a high incidence of *Palmer amaranth* that it was concluded that a traditional cotton harvester could not be used because the risk of damaging the spindles in the head of the harvester was too high. So all yield data was collected by hand picking the lint, plus seed, from the middle two rows of each plot. Figure 8 shows the cotton being handpicked and collected in bags and Figure 9 shows what the plots looked like after harvesting. The lint was collected in bags and weighed. Averages across the four replications were established for each treatment. A basic statistical analysis was conducted to determine if there was any significance between the treatment yields. A more in depth analysis could not be completed due to not being able to harvest some plots.



**Figure 8. Cotton being harvest and collected at Central Crops Research Station**



**Figure 9. A plot after being harvested at Central Crops Research Station.**

## 3.2 Upper Coastal Plain Research Station

### 3.2.1 Tillage, Fertilizing and Weed Control

At the Upper Coastal Plain Research Station, 17 treatments, including a control, were replicated three times to total 51 plots. The plots included a control treatment. Each plot measured 7.62 m by 15.24 m, with a 15.24 m alley between the replications. Each plot contained eight rows of cotton, which yielded the four middle rows for data collection and two buffer rows on each side to reduce the influence of the adjacent plots. The 16 treatments, not including the control, included two different seed varieties, four preplant tillage treatments and two post emergence weed control methods. The treatments can be found in

Table 2 and the plot layout can be found in Figure 10.

The two seed varieties used were FiberMax® LibertyLink® from Bayer CropScience and Genuity® Bollgard II® with Roundup Ready® Flex from Monsanto. The FiberMax® LibertyLink® seed are tolerant of glufosonate ammonium, also known by the common name Ignite®. The Roundup Ready® Flex seed are tolerant of glyphosate, also known by the common name Roundup®.

All of the plots received the same burndown treatment. Glystar® was applied at a rate of 2.34 L/ha in late April 2010. In early June 2010 the four pre-plant tillage treatments were administered to the predetermined plots. The four tillage systems used were a conventional tillage system, a strip-till system, a no-till system and a tillage system utilizing a Sukup® plow. The conventional tillage system consisted of chisel plowing followed by a heavy disking. Then a rolling reel was used to level the ground before planting. With the no-till system, the cotton seed was planted directly into undisturbed soil by a no-till planter.

The strip-till system consisted of a strip-till unit, cutting a strip approximately 20.3 cm wide, where the cotton seed was planted. The Sukup® plow system utilized a Sukup® plow as the only primary tillage tool. A rolling reel was then used to level the seed bed. Once the tillage systems had been implemented a 6-8-46 fertilizer was broadcast at a rate of 449.1 kg/ha. The two seed varieties were then planted in mid-June (planting was delayed due to weather).

At planting, each plot received an in furrow application of Temik 15G and Ridomil Gold PCGR at a rate of 6.4 kg/ha and 8.98 kg/ha respectively. After planting, all plots received a side dress application of liquid nitrogen fertilizer, with added Sulfur, at a rate of 112.3 L/ha. The plots also received an additional application of liquid nitrogen fertilizer at a rate of 112.3 L/ha at layby.

For post emergence weed control, two treatments were used. One treatment was the use of mechanical cultivation in the form of a Danish tine cultivator. The other treatment was an over-the-top chemical application. Roundup PowerMAX® was applied four times throughout the season; once, a week after planting and then once every other week to total four applications, at a rate of 2.34 L/ha to the plots that contained the Genuity® Bollgard II® with Roundup Ready® seed. Ignite® was applied twice throughout the season at a rate of 3.14 L/ha to the plots that contained the FiberMax® LibertyLink® seed. The Danish tine was used on the plots that were to receive mechanical cultivation every time the Roundup PowerMAX® was applied.

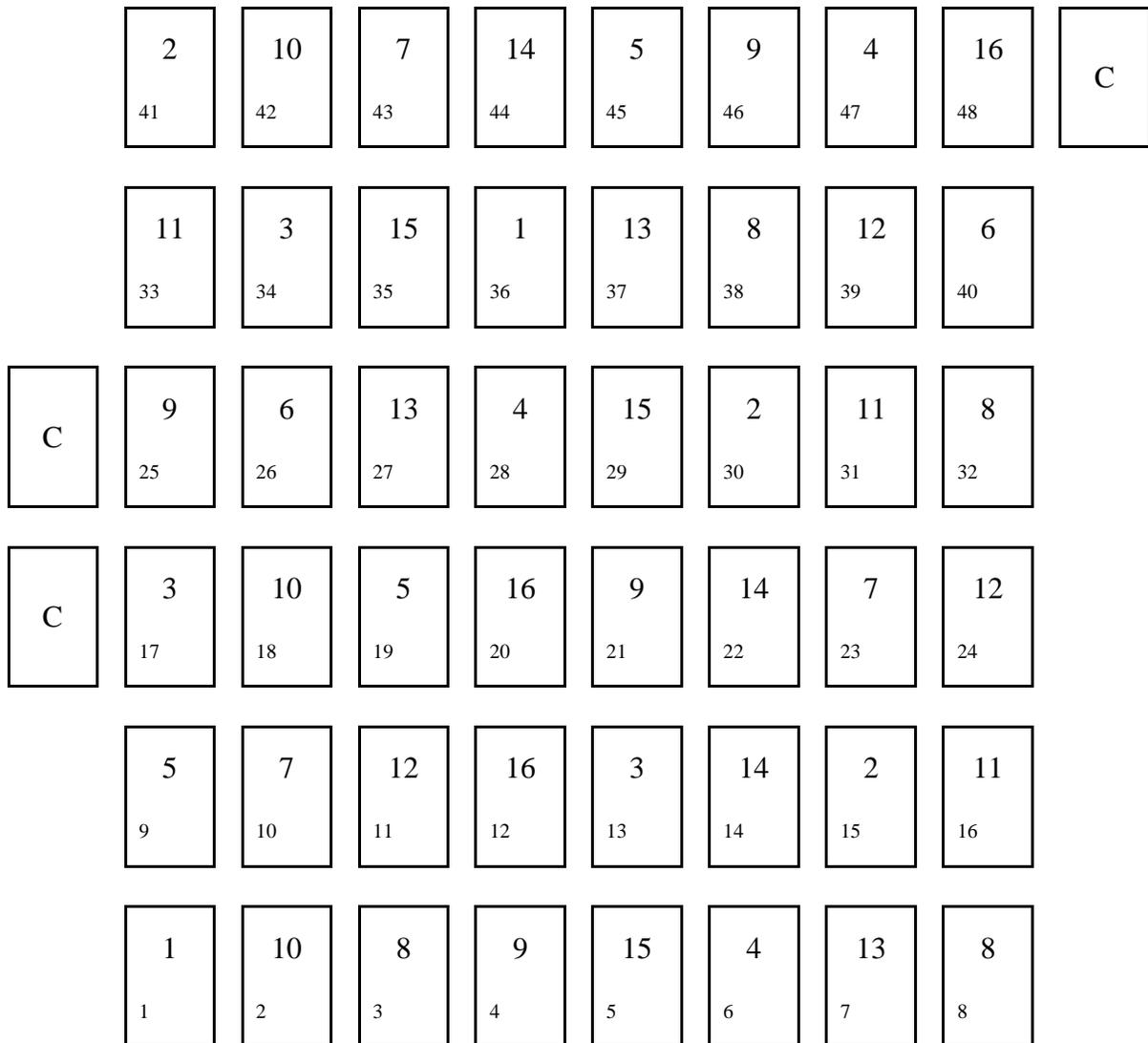
Similar to CCRS a defoliant was never applied, due to late maturity caused by the delayed planting. Since a defoliant was never used, the first frost served as a natural defoliant. The alley ways between the replications were mowed, and sprayed with Roundup® routinely during the season to allow for easier access to the plots. Control plots received

none of the above mentioned treatments. They were established to set a baseline for the worst case scenario that could occur in the particular field that was used.

**Table 2. Treatments for the field study conducted at the Upper Coastal Plain Research Station in Rocky Mount, NC.**

SEED	TILLAGE TREATMENT	POST-EMERGENCE CONTROL	TREATMENT LABEL	TREATMENT NUMBER (on plot map)
FiberMax® LibertyLink®	Conventional	Chemical	LL_Conv_Chem	1
	Conventional	Tillage*	LL_Conv_Till	2
	Sukup® Plow	Chemical	LL_SP_Chem	3
	Sukup® Plow	Tillage*	LL_SP_Till	4
	Strip-Till	Chemical	LL_ST_Chem	5
	Strip-Till	Tillage*	LL_ST_Till	6
	No-Till	Chemical	LL_NT_Chem	7
	No-Till	Tillage*	LL_NT_Till	8
Genuity® Bollgard II® with Roundup Ready® Flex	Conventional	Chemical	RR_Conv_Chem	9
	Conventional	Tillage*	RR_Conv_Till	10
	Sukup® Plow	Chemical	RR_SP_Chem	11
	Sukup® Plow	Tillage*	RR_SP_Till	12
	Strip-Till	Chemical	RR_ST_Chem	13
	Strip-Till	Tillage*	RR_ST_Till	14
	No-Till	Chemical	RR_NT_Chem	15
	No-Till	Tillage*	RR_NT_Till	16
None	None	None	Control	C

\*Row Cultivator for post-emergence tillage control



**Figure 10. Plot map for the field study conducted at Upper Coastal Plain Research Station in Rocky Mount, NC with the plot number in the lower left hand corner and the treatment number in the top center.**

### 3.2.2 Weed Counts

Weed counts were conducted three times during the season. The counts focused on the occurrence of *Palmer amaranth* in and between the four middle rows of cotton of each plot. The four middle rows were chosen to get a representative sample and to reduce the effects of adjacent plots. The counts were done by walking the length of the plot and

counting the number of *Palmer amaranth* plants observed in rows 3, 4, 5, 6 and between rows 3 and 4, 4 and 5, and 5 and 6. In row weed counts were conducted in the 0.36 m strip centered about the established cotton row. Between row weed counts came from the 0.61m strip centered about the midpoint between two rows of established cotton. Weed density was calculated by dividing weed count by the area from which the weed count was taken. This allowed the weed counts to be compared in a fairer manner, since in row and between row weed counts were conducted over different areas. Averages were established for the in row counts and for the between the row counts for each treatment. These averages were then analyzed graphically. An ANOVA analysis was conducted, using weed densities from individual plots, to determine if there was any significance between the factors.

### 3.2.3 Yield data collection

Due to high weed incidence, some of the plots were deemed non-harvestable. These non-harvestable plots had such a high incidence of *Palmer amaranth* that it was concluded that the cotton harvester could not be used because the risk of damaging the spindles in the head of the harvester was too high. These plots included 3, 12, 20, 25, 32, 38 and 45. The plots that were harvestable were harvested using a two row cotton harvester designed for research applications. The harvester was implemented with a weighing mechanism that would weigh the cotton from each plot. The machine operator had to input when the plots changed, and the harvester would record the weight. The output was a list of weights for each plot. The lint from the middle two rows of each plot was the only lint harvested. Figure 11 and Figure 12 show the cotton harvester used to collect yield data. Averages across the three replications were established for each treatment. A basic statistical analysis was

conducted to determine if there was any significance between the treatment yields. A more in depth analysis could not be completed due to not being able to harvest some plots.



**Figure 11. Cotton harvester used at the Upper Coastal Plain Research Station.**



**Figure 12. The weighing apparatus on the rear of the cotton harvester used at the Upper Coastal Plain Research Station.**

### 3.3 Cherry Research Farm

#### 3.3.1 Tillage, Fertilizing and Weed Control

At the Cherry Research Farm, 6 treatments, not including the control treatment, were replicated one time to total 6 plots. Bad weather at time of planting and difficulties related to logistics of moving the desired equipment are the reasons for only one replication. Even though higher level statistical analysis could not be done on this data set, the plots were still managed, so that the performance of the Paratill could still be seen. Three control plots were also established. Each plot measured 7.62 m by 30.48 m. Each plot contained eight rows of cotton, which yielded the four middle rows for data collection and two buffer rows on each side to reduce the influence of the adjacent plots. The 6 treatments included two different seed varieties, three pre-plant tillage treatments and one post emergence weed control method. The treatments can be found in

Table 3 and the plot layout can be found in Figure 13.

The two seed varieties used were FiberMax® LibertyLink® from Bayer CropScience and Genuity® Bollgard II® with Roundup Ready® Flex from Monsanto. The FiberMax® LibertyLink® seed are tolerant of glufosinate ammonium, also known by the common name Ignite®. The Roundup Ready® Flex seed are tolerant of glyphosate, also known by the common name Roundup®.

All of the plots received the same burndown treatment. Glystar® was applied at a rate of 2.34 L/ha in late April 2010. In early June 2010 the three pre-plant tillage treatments were administered to the predetermined plots. The three tillage systems used were a strip-till system, a no-till system and a tillage system utilizing a Tye® Paratill plow. With the no-till system, the cotton seed was planted directly into undisturbed soil by a no-till planter. The strip-till system consisted of a strip-till unit, that cut a strip approximately 20.3 cm wide,

where the cotton seed was planted. The paratill plow system utilized a two row Tye® Paratill plow as the only primary tillage tool. A rolling reel was used to level the seed bed. Once the tillage systems had been implemented a 6-8-46 fertilizer was broadcasted at a rate of 449.1 kg/ha. The two seed varieties were planted in late-June (planting was delayed due to weather).

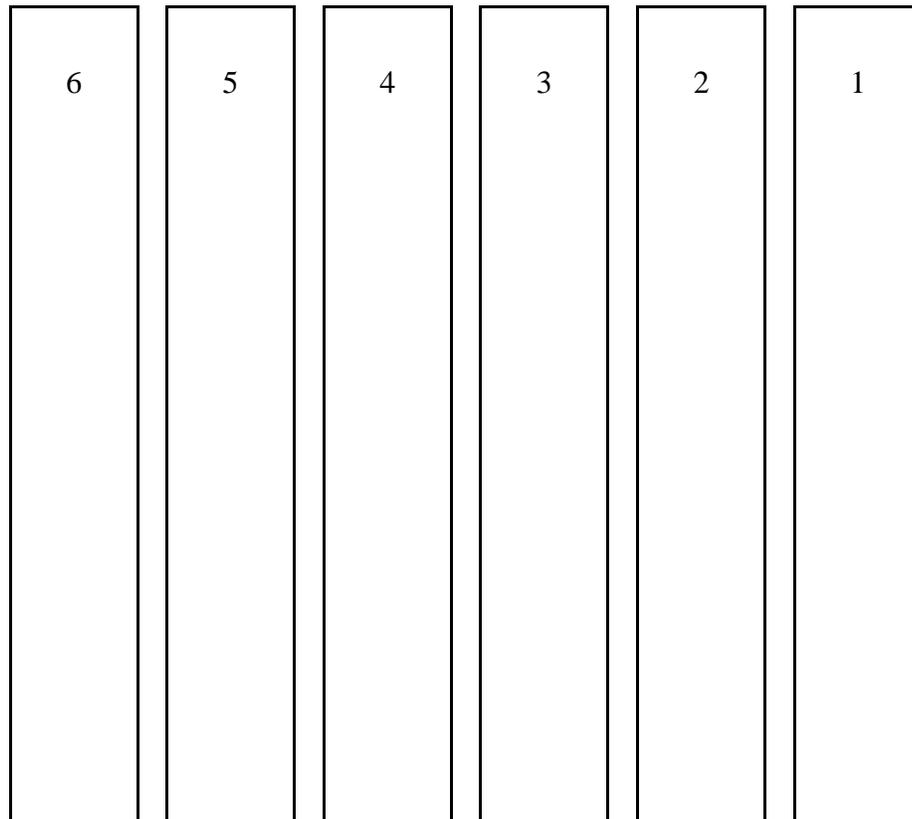
At planting, each plot received an in furrow application of Temik 15G and Ridomil Gold PCGR at a rate of 6.4 kg/ha and 8.98 kg/ha respectively. After planting, all plots received a side dress application of liquid nitrogen fertilizer at a rate of 112.3 L/ha. The plots also received an additional application of liquid nitrogen fertilizer at a rate of 112.3 L/ha at layby.

For post emergence weed control, one treatment was used. The treatment was an over-the-top chemical application. Roundup PowerMAX® was applied four times throughout the season; once, a week after planting and then once every other week to total four applications, at a rate of 2.34 L/ha to the plots that contained the Genuity® Bollgard II® with Roundup Ready® seed. Ignite® was applied every other time the Roundup PowerMAX® was applied at a rate of 3.14 L/ha to the plots that contained the FiberMax® LibertyLink® seed.

Due to the late planting, a defoliant was never applied. The cotton was naturally defoliated by the first frost. Control plots received none of the above mentioned treatments. The control plots were located adjacent to plot 6, opposite of plot 5. They were established to set a baseline for the worst case scenario that could occur in the particular field that was used.

**Table 3. Treatments for the field study conducted at the Cherry Research Farm in Goldsboro, NC.**

SEED	TILLAGE TREATMENT	POST-EMERGENCE CONTROL	TREATMENT LABEL	TREATMENT NUMBER (on plot map)
FiberMax® LiberyLink®	Strip-Till	Chemical	LL_ST_Chem	1
	Paratill	Chemical	LL_PT_Chem	2
	No-Till	Chemical	LL_NT_Chem	3
Genuity® Bollgard II® with Roundup Ready® Flex	Strip-Till	Chemical	RR_ST_Chem	4
	Paratill	Chemical	RR_PT_Chem	5
	No-Till	Chemical	RR_NT_Chem	6
None	None	None	Control	C



**Figure 13. Plot map for the field study conducted at the Cherry Research Farm in Goldsboro, NC with the treatment number in the top center.**

### 3.3.2 Weed Counts

Weed counts were conducted one time during the season. The counts focused on the occurrence of *Palmer amaranth* in and between the four middle rows of cotton of each plot. The four middle rows were chosen to get a representative sample and to reduce the effects of adjacent plots. The counts were done by walking the length of the plot and counting the number of *Palmer amaranth* plants observed in rows 3, 4, 5, 6 and between rows 3 and 4, 4 and 5, and 5 and 6. In row weed counts were conducted in the 0.36 m strip centered about the established cotton row. Between row weed counts came from the 0.61 m strip centered about the midpoint between two rows of established cotton. Weed density was calculated by dividing weed count by the area from which the weed count was taken. This allowed the weed counts to be compared in a fair manner, since in row and between row weed counts were conducted over different areas. Averages were established for the in row counts and for the between the row counts for each treatment. These averages were then summarized graphically. No conclusions will be made from this data, due to only including one replication.

### 3.3.3 Yield data collection

Due to high weed occurrence and late planting, none of the plots had open bolls. So, a method used by crop insurance adjusters was used to estimate the yield of each plot. Hand harvesting was not used because the bolls had not opened, so using fiber weight to estimate yield would have not been accurate. The method required a boll count per 3.05 m of row. The centers of the two middle rows from each plot were used for yield estimation. The boll count was then used, along with established coefficients to estimate yield on a bales per acre basis. The bales per acre estimate was then converted to kilogram per ha basis, while

assuming a bale weight of 226.8 kg. A graph was created to summarize the difference between treatments, in terms of cotton yield.

## **4.0 Tractor Performance Methods**

A secondary goal of this research was to develop a set of methods that could be used to quantify tractor performance parameters. Those parameters were draft load requirements for different tillage implements, which included vertical and horizontal forces, and fuel consumption values while operating the different tillage implements. These parameters would allow a cost analysis to be done on each tillage practice. To quantify draft load for the different implements a strain gage instrumented three point hitch dynamometer was fabricated and installed on an Allis Chalmers 8010. To quantify fuel consumption a volumetric fuel flow meter was installed on the same tractor. The signals from both instruments were conditioned appropriately and routed to a data acquisition system.

The tractor used for the research was a two-wheel-drive, early 1980s model, Allis Chalmers 8010. The tractor included a cab, which yielded a cool, dust free space to install the required instruments. The tractor PTO is rated at 80.70 kW. It has a static weight distribution of 30% and 70% on the front and rear axles, respectively.

### **4.1 Fuel Flow Meter**

The fuel flow meter used, was manufactured by FloScan Instrument Co., Inc. The system used included a digital LCD unit that displayed instantaneous gallons per hour,

cumulative gallons consumed, a resettable gallon consumed and machine hours. A momentary switch was included to reset the gallons consumed display. Also included in the package were two fuel flow sensors and pulsation dampers, one each for the supply and return fuel lines, along with the necessary mounting hardware. The fuel flow metering system required a return fuel cooling apparatus. It was purchased separately.

#### *4.1.1 Installation*

Prior to installation, the sensors were attached to the pulsation dampers, which were attached to the provided mounting brackets. The factory installed fuel lines were then removed from the Allis Chalmers 8010. With the fuel lines out of the way, the two fuel flow sensors were attached to the tractor frame and the fuel cooling apparatus was installed directly in front of the tractor's radiator. The sensor for the supply fuel line was installed on the left hand side of the tractor, just after the primary fuel filter and before the secondary fuel filter. The return fuel sensor was installed on the right hand side of the tractor after the fuel cooling apparatus and before the point the excess fuel returned to the existing fuel tank. Additional fuel line was then installed to connect all of the components. When possible, the original fuel line was salvaged and reused.

After installing the sensors into the fuel system, they were connected to the display. The display was mounted on the side of the tractor's instrument panel, so it could be visible to the operator and easy to reach. A 16-pin wiring harness, which connected to the back of the LCD display, was included in the kit. To connect the sensors to the wiring harness, 18 AWG stranded wire was used, along with Weather Pack™ connectors. Weather Pack™ connectors were used to simplify the disconnect of the sensors and because the sensors were

mounted to the outside of the tractor and could be exposed to different types of weather. The tractor's 12V battery system was used as the power supply. Once the system was fully installed, the injectors on the tractor had to be bled. This was done to eliminate any air that entered into the fuel lines during installation.

#### *4.1.2 Calibration*

After installing the fuel flow sensor system, a hydraulic power take off (PTO) dynamometer, which is a tool that applies a controlled load on the tractor engine so that the tractor PTO horsepower can be measured, was used to create a fuel consumption calibration curve that yielded a comparison between horsepower and actual fuel consumption. The Allis Chalmers 8010 was connected to the dynamometer and the throttle was adjusted so that the engine speed was 2300 revolutions per minute (RPM), the rated engine speed designated on the Nebraska Tractor Test Data (Tractor Museum). The dynamometer was adjusted so that the tractor was delivering maximum PTO horsepower and the instantaneous fuel consumption was recorded for the load levels described. The dynamometer was then adjusted so that the tractor was operating at zero load and the instantaneous fuel consumption was recorded. Likewise, the dynamometer was adjusted so that the tractor was operating at 10% and 25% of the maximum horsepower and the instantaneous fuel consumption values were recorded. The four values recorded were compared to the results from the Nebraska Tractor Test Data for the Allis Chalmers 8010 to insure that the fuel values were within 10% of that data. Differences in fuel consumption values could be attributed to the lack of a digital tachometer and the fact that the test conducted in this research yielded a maximum power that was 7.46 kW greater than the Nebraska Tractor Test results. It was concluded that the fuel flow sensors were working properly and displaying the correct values.

#### *4.1.3 Data Collection*

The fuel flow sensor kit that was used, allowed the data collected to not only be displayed on the LCD screen provided, but also provided an output frequency signal. This frequency signal was routed to the data acquisition system that was also collecting the three point hitch dynamometer data. A 10 K $\Omega$  resistor was added between the output signal and the 12V power source to insure the circuit has a set default value, even when it is not receiving a signal, which in turn produced a cleaner signal.

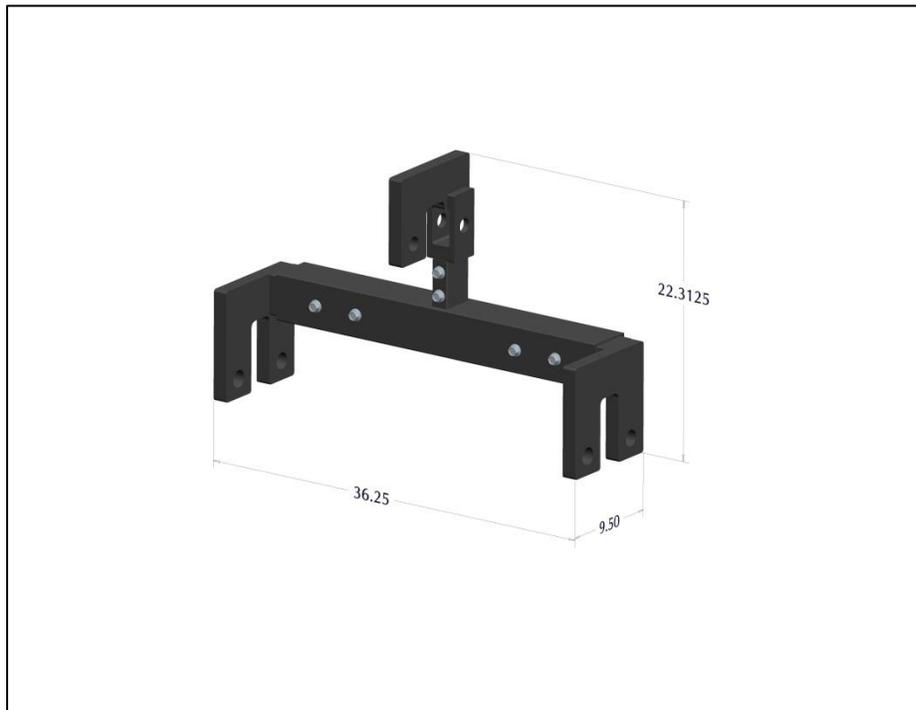
## **4.2 Dynamometer**

It was decided that a strain gage instrumented three point hitch dynamometer would be used to measure draft load of the implements tested. The dynamometer was designed to meet two main criteria beyond its obvious utility. The first constraint was to design the dynamometer in such a way that it could be used with any Category II or III hitch. The second constraint was to design it so that it could be easily mounted and dismounted from the tractor and implement.

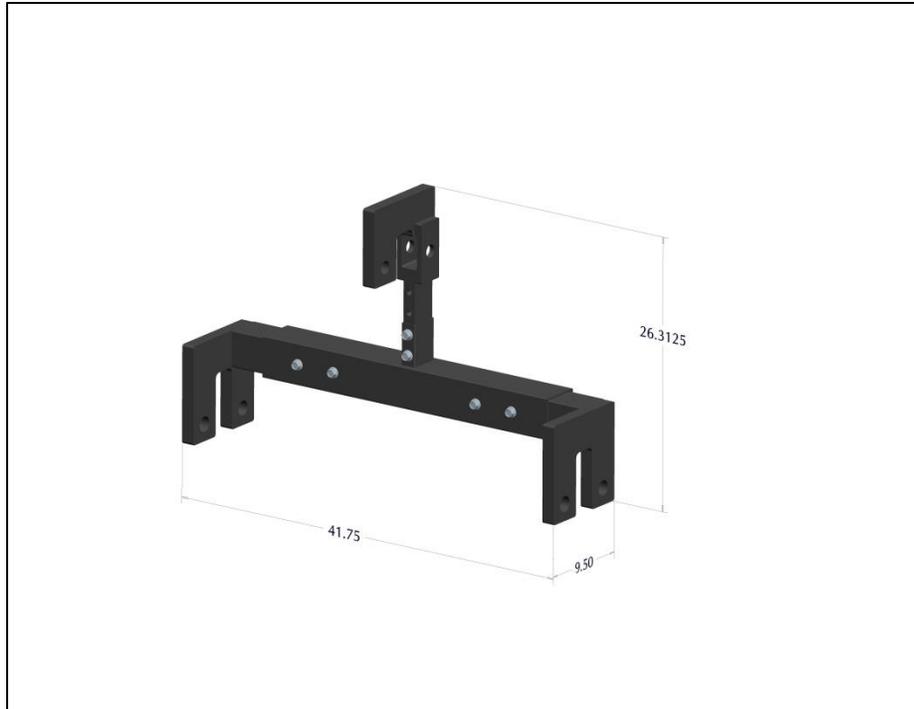
#### *4.2.1 Design*

The dynamometer design used was similar to the one developed by Bowers in 1989. Like Bowers (1989) dynamometer, the dynamometer utilizes three strain gage instrumented U-shaped cantilever beams. The main difference in the two designs was the data acquisition system used. As mentioned previously, one of the design constraints was to fabricate the dynamometer so that it could be used on Category II and Category III hitches. The bottom links on a Category II hitch are narrower than a Category III hitch. The top link of a

Category II hitch is lower, in reference to the bottom links, than a Category III hitch. The differences can be seen in Figures 14 and 15. Adjustability was accomplished by using two different sizes of square tubing so one can fit inside the other. Holes were drilled in both pieces to provide the needed adjustment, and to provide a method to rigidly position the members for both hitch categories. The two different sized square tubing allowed for the lower links to be adjusted horizontally and the top link to be adjusted vertically as needed. Once in position, two bolts held the pieces in place. Figure 14 shows the dynamometer in position to be used on a Category II hitch and Figure 15 shows the dynamometer in position to be used on a Category III hitch. The dimensions used came from ASABE Standard S278.7 (ASABE, 2003).



**Figure 14. The dynamometer setup for use on a Category II hitch.**



**Figure 15. The dynamometer setup to be used on a Category III hitch.**

Each of the U-shaped beams included four strain gages, for a total of 12 on the dynamometer. Figure 16 displays the placement of the strain gages. On each U-shaped beam a gage was placed on the front and top faces. Two other strain gages were placed on the opposite faces of the same sections of the beam. All of the strain gages used were 120  $\Omega$  unidirectional strain gages purchased from Omega Engineering. All of the gages, except those on the underside of the U-shaped beam, were 2.54 cm long. The ones on the underside of the U-shaped beam were 1.27 cm long. Strain gage pairs were used to reduce the effects of temperature.

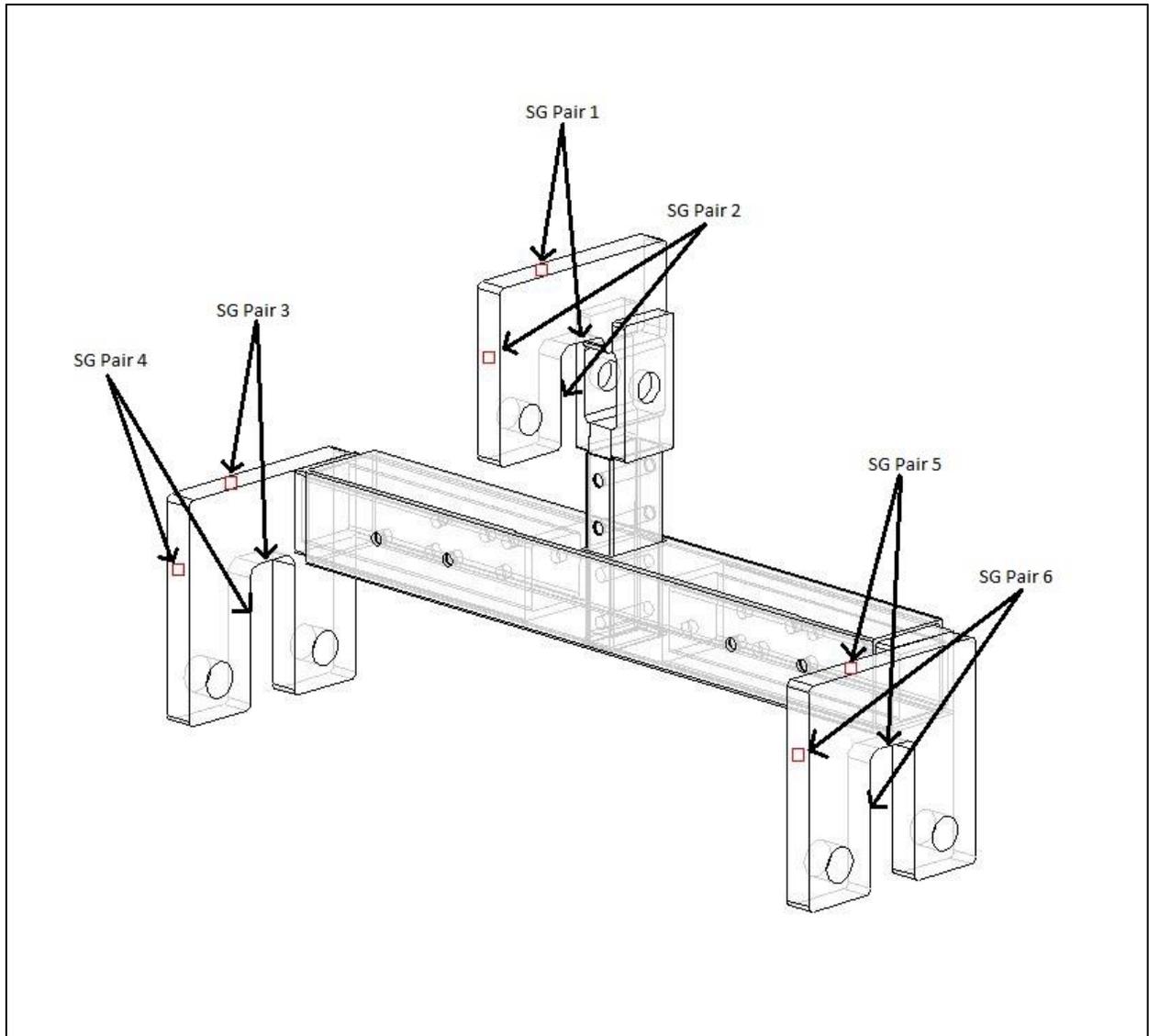
It was hypothesized that strain gage pairs 1, 3 and 5 would be best for predicting the vertical load whereas pairs 2, 4 and 6 would be best to predict the horizontal load. The pairs were wired into a 120  $\Omega$  Wheatstone half bridge configurations. The circuits, which included two 120  $\Omega$  bridge completion resistors, were mounted in sealed electrical junction boxes on

the side of each U-shaped beam. The circuits were wired to separate signal conditioners that were mounted in the cab of the tractor. The signal conditioners provided adjustment of the excitation voltage and zero points.

The dynamometer was designed in PRO-Engineer software. The finite element analysis software within PRO-Engineer was used to determine the placement location of the 12 strain gages. Estimates of the loads the dynamometer may encounter were applied and the areas with the highest deformation were chosen as the points in which to install the strain gages.

#### *4.2.2 Fabrication*

The 3.175 cm steel plates, used for the three U-shaped beams, were rough cut from a 1.22 m x 2.44 m steel plate. The rough cut pieces were then outsourced to be cut by a precision laser. The steel pieces located where the top link of the tractor connects to the dynamometer were CNC machined in the BAE research shop at NCSU. All of the required welding and drilling were also done in the BAE research shop at NCSU. The final assembly of the dynamometer can be seen in Figure 166. Once the dynamometer was assembled, the strain gages were installed.

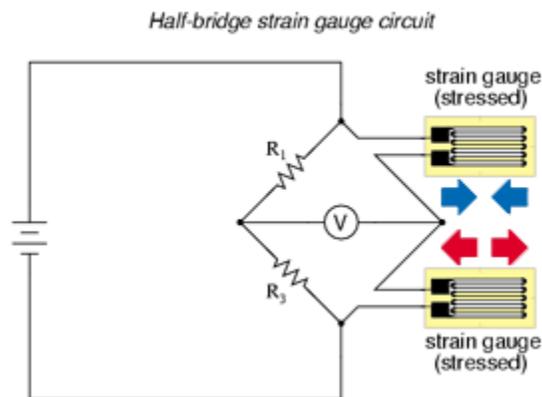


**Figure 16. The assembly of the three point hitch dynamometer, with the strain gage locations displayed.**

#### *4.2.3 Strain Gage and Signal Conditioner Installation*

As mentioned previously, the strain gage locations were based on using finite element analysis. The areas chosen were then smoothed using a grinder. A rough grinding was done first, followed by a fine grinding to reach a glass like finish. The ground areas were cleaned with a degreaser and a neutralizer. Once the areas were clean, the strain gages were installed using a strain gage adhesive purchased from Omega Engineering.

To reach a Wheatstone half-bridge for each pair of strain gages, three circuit boards were attached to the dynamometer. Each circuit board had two circuits, that way two pairs of strain gages could be attached to each one. Each circuit included two 120  $\Omega$  bridge completion resistors. The Wheatstone half bridge circuit diagram can be seen in Figure 17. The circuit boards were placed in electrical junction boxes and attached to each U-shaped beam, using a clear silicone adhesive.



**Figure 17. Circuit diagram of a Wheatstone Half - Bridge circuit.**

Lead wires were then soldered to the strain gages. These wires were then attached to the circuit boards. Each circuit was then wired to its own signal conditioning module, using four stranded signal conditioner wire. There were two strands for the excitation voltage and two strands for the signal.

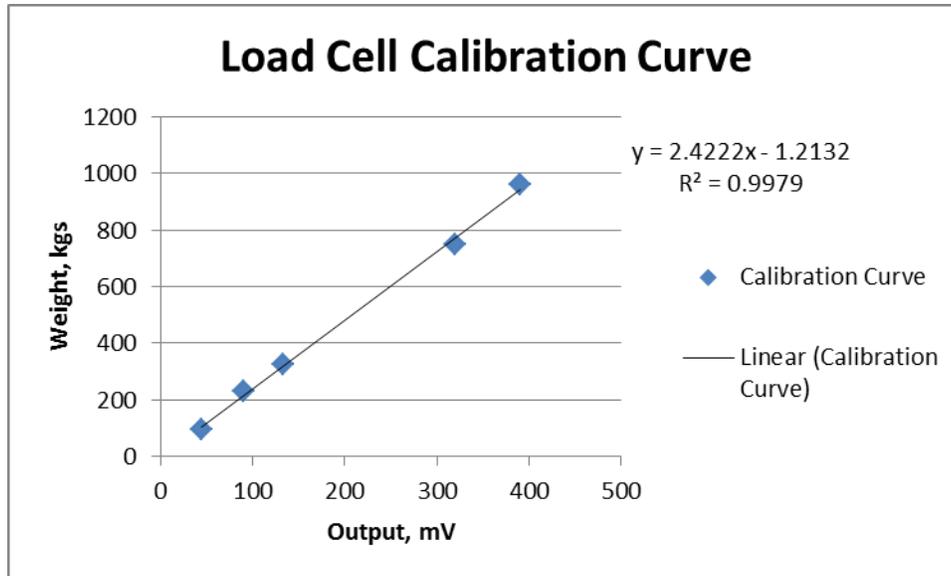
The signal conditioners, purchased from ICP DAS, were installed inside a sealed electrical junction box in the tractor cab. There were a total of seven signal conditioners, one for each strain gage pair and one for the load cell used for calibration. The signal conditioners were mounted on a DIN rail inside the junction box, so they could be removed with relative ease. They were powered by the tractors 12V battery system. An automotive

style cigarette socket and plug were used to allow the signal conditioners to be disconnected from the power supply. Each conditioner had internal configuration switches that allow the user to adjust the input and output ranges. They also included three adjustable pins on the front for excitation, zero and span.

Once the signal conditioners were installed and the Wheatstone half-bridges were wired, the signal conditioners were adjusted. The internal configuration pins were set to allow for a  $\pm 10$  mV input signal and a 0-10V output signal. The excitation was set to 2.5 V for all of the Wheatstone half-bridges. The excitation voltage was set at 2.5 V because the signal conditioners were rated at 20 mA. As a result, the 120  $\Omega$  bridges with a 2.5 V excitation the signal conditioners were exposed to maximum amperage. The zero was set to 5 V, that way compression ( $<5$ ) and tension ( $>5$ ) could be observed.

#### *4.2.4 Calibration*

Once the strain gages were installed the dynamometer was calibrated. To calibrate the dynamometer a 22,680 kg load cell was used. The load cell used had a clevis on each end, so that it could read tensile forces. To calibrate the load cell, it was attached to a chain hoist and known weights of 95, 230, 325, 750, and 960 kg were hung from it and the readings were recorded for each weight. A five volt excitation voltage was used. The calibration curve for the load cell can be seen in Figure 18.



**Figure 18. Load cell calibration curve.**

It was concluded from the calibration curve that the load cell responds linearly with the amount of weight applied, as was expected.

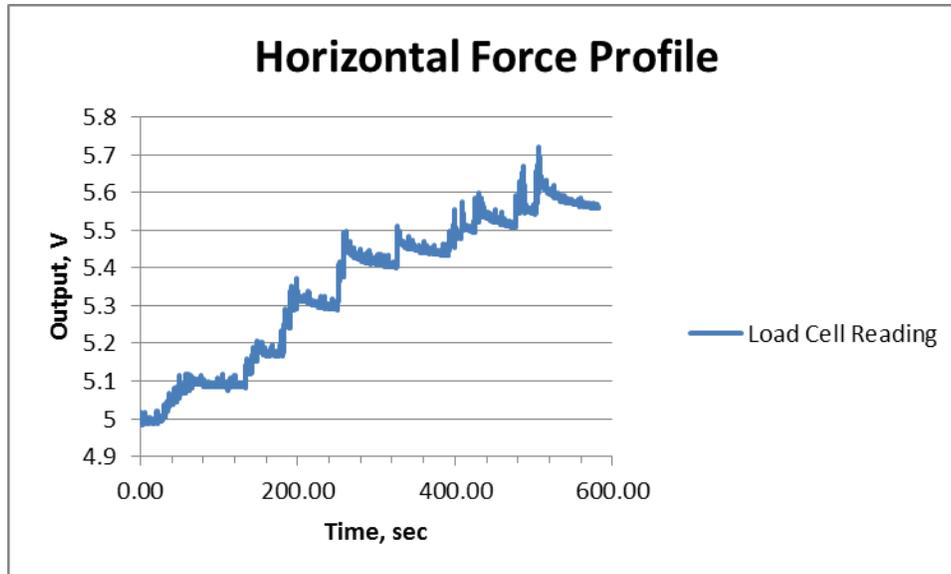
Once the load cell was calibrated, the dynamometer could be calibrated. To calibrate the dynamometer a vertical and horizontal force were applied to the two bottom links and the top link. The two bottom links were calibrated simultaneously and independent of the top link. To apply the horizontal force to the bottom links, the dynamometer was attached to the tractor and a chain was hooked between the two bottom links and one end of a 3629 kg rated come-along. The come-along was attached to one of the clevis' on the load cell. The other clevis on the load cell was attached to a tow strap that was wrapped around a tree. A bubble level was used to insure that the force being applied by the come-along was horizontal.

Figure 19 shows the setup for the horizontal force calibrations.



**Figure 19. The setup used for horizontal force calibrations. The chain on the left is attached to the dynamometer and the tow strap on the right is attached to a tree.**

Once everything was setup, the tractor was placed in Park and the come-along was used to apply the force. Data were collected continuously throughout the calibration. The force was increased in increments to produce a step function force profile. This step function force profile can be seen in Figure 20. A similar procedure was used to develop a horizontal calibration curve for the top link. The only difference was that only the top link was attached to the come-along.

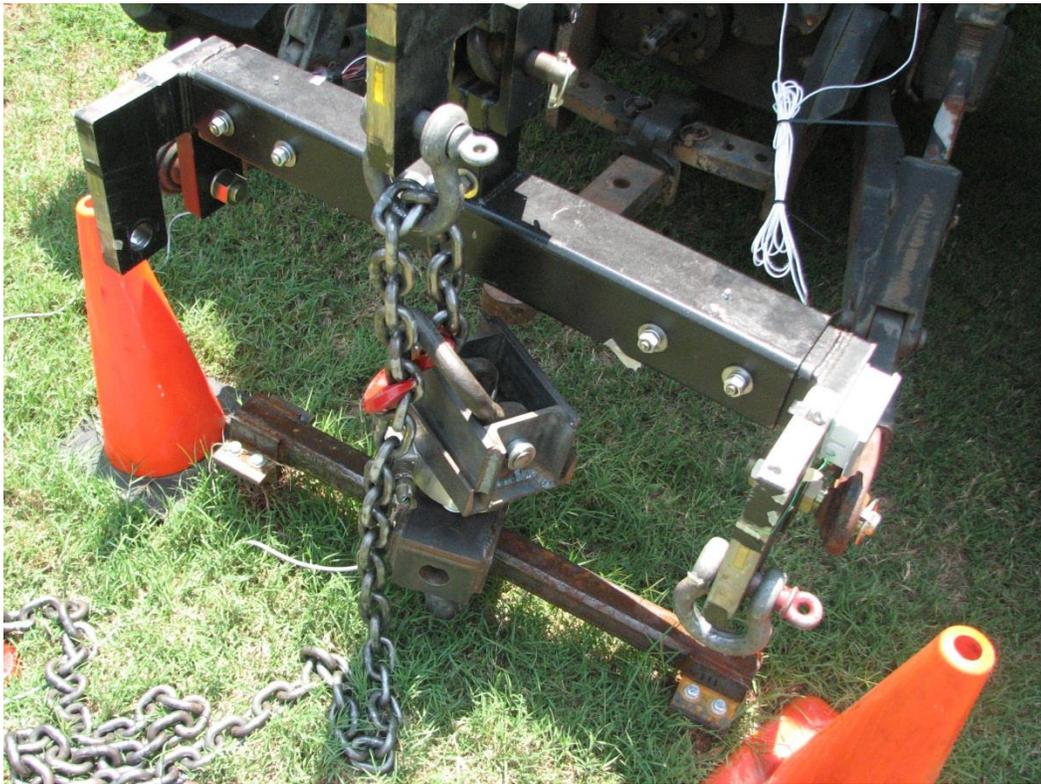


**Figure 20. Horizontal force profile for the calibration of the two bottom links. The force profile for the calibration of the top link was similar.**

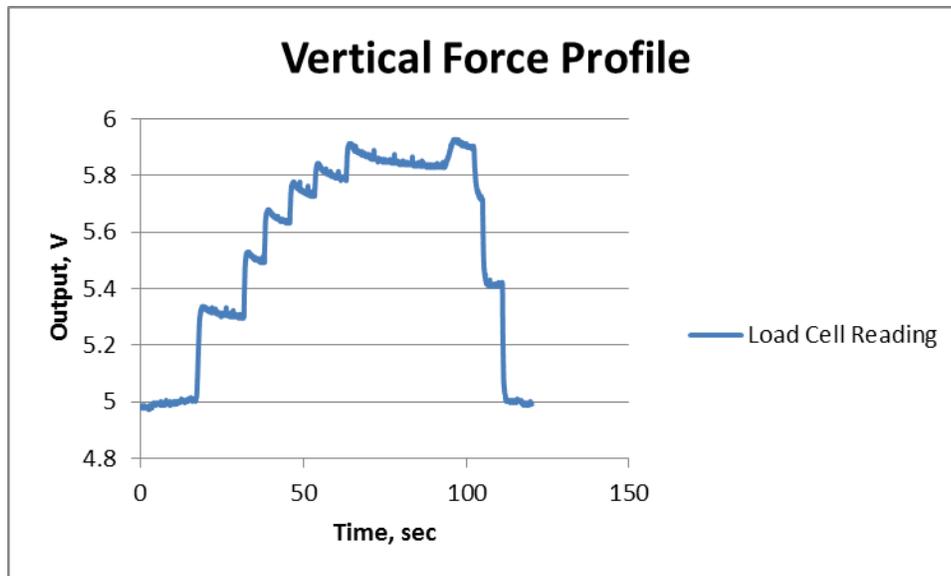
To develop the vertical force calibration curves, a different setup was used. Two mobile home anchors, rated up to 1134 kgs, were installed in the front lawn of Weaver Labs at North Carolina State University. The anchors were installed in a way so that a piece of 3.81 cm square tubing could be bolted between them. By doing this, it yielded a single anchor point to which the dynamometer could be attached.

Once the anchors were in place, one of the clevis' on the load cell was attached to the square tubing. The tractor, with the dynamometer attached, was positioned so that the dynamometer was directly over the load cell. The other clevis on the load cell was then attached, by chain, to the two bottom links of the dynamometer. Figure 21 shows the setup used for vertical calibration. The hydraulic lift arms of the tractor were used to apply force. The lift arms were gradually raised, so that the load cell and strain gages would not encounter drastic changes in force. Figure 22 shows the vertical force profile for the bottom link

calibration. The same methods were used to develop the vertical calibration curve for the top link, except that only the top link was attached to the load cell.



**Figure 21. Setup used for calibrating the vertical component of the dynamometer.**



**Figure 22. Vertical force profile for the calibration of the two bottom links. The force profile for the top link was similar.**

#### 4.2.5 Testing and Data Collection

The output signals were routed to the same data acquisition system used for the fuel flow sensors. The signals from the dynamometer were analog so they had to be routed to certain pins in the data acquisition systems wiring harness. All of the draft data was collected on a CompactFlash Type I memory card.

Four implements were tested. They included a paratill subsoiler, a Danish tine row cultivator, a chisel plow and a field cultivator with rolling reel levelers. The paratill subsoiler used, which is shown in Figure 23, had a 4.5 m toolbar that had two shanks attached. The Danish tine row cultivator used, which can be seen in Figure 24, had a 4.2 m toolbar with 21 tines attached. It was setup to cultivate four, 0.91 m rows. The chisel plow had a 2.74 m toolbar with nine tines attached, and the field cultivator had a 3.96 m toolbar with 25 tines attached. The chisel plow and field cultivator used for the research can be seen in Figure 25 and Figure 26, respectively.

All of the implements were tested at Lake Wheeler Road Field Laboratory in a field that previously had been planted in corn. The field had a minor slope, so each implement was tested twice, once uphill and once downhill. The paratill was pulled in low range, 2<sup>nd</sup> gear, and powershift low range setting. The chisel plow and the Danish tine cultivator were pulled in high range, 1<sup>st</sup> gear, and high range on the powershift. The field cultivator was pulled in low range, 3<sup>rd</sup> gear and powershift low range. The ground speeds for each implement can be found in Table 4.



**Figure 23. The paratill used for the dynamometer research.**



**Figure 24. The Danish tine row cultivator being pulled through the test plot.**



**Figure 25. The chisel plow being lowered into the test plot.**



**Figure 26. The field cultivator used for the research.**

### **4.3 Data Acquisition System**

The data acquisition system used to collect data from the fuel flow sensors and the three point hitch dynamometer was the DL1 Data Logger by Race Technology Ltd. Although the data logger is intended for use in the racing industry, it worked well for this research. The system can receive and collect data from 8 different analog signal sources and 4 frequency signal sources. With this research, there were 7 analog signals, one each from the six pairs of strain gages and load cell, and one frequency signal, from the fuel flow sensors. It also came with a GPS antenna, which was needed to collect ground speed. Ground speed data was collected externally to the 12 input signals, by the data acquisition system. The system included an empty plug, that could be custom configured, that fit in the back of the housing. Once the wires were routed from the signal conditioners, load cell and fuel flow sensors into the plug, it could be easily plugged in and the system was ready to start

collecting data. The system was powered by the tractors 12V battery. An automotive cigarette socket and plug were used so that the power could be interrupted between the battery and the data acquisition system, for normal operation.

The logger recorded data on a CompactFlash Type I mass storage device. Also, on the back of the data logger's main housing, there was a 9-pin serial port. This port was used to view the data being collected in real-time on a portable computer. The serial port was mainly used for initial setup and calibration.

#### *4.3.1 Installation*

The main housing of the data logger was installed on the side of the tractor console. It was mounted directly below the display screen for the fuel flow sensors. By mounting the two instruments close to each other, it only requires the operator to look in one place to determine if all of the instruments are working properly. The placement of the instruments, along with single button operation, made this system more ergonomic than previous efforts. The data logger came with sliding mounting brackets, so the housing could be removed and adjusted without using tools.

#### *4.3.2 Software and Data Collection*

The data logger came with its own software package. The package included an analysis program and three different levels of monitoring programs. The normal monitoring program was used to look at the data being collected in real time. The analysis software was used to observe the data after it had been collected. The analysis software was mainly used as a way to export the data into Microsoft Excel.

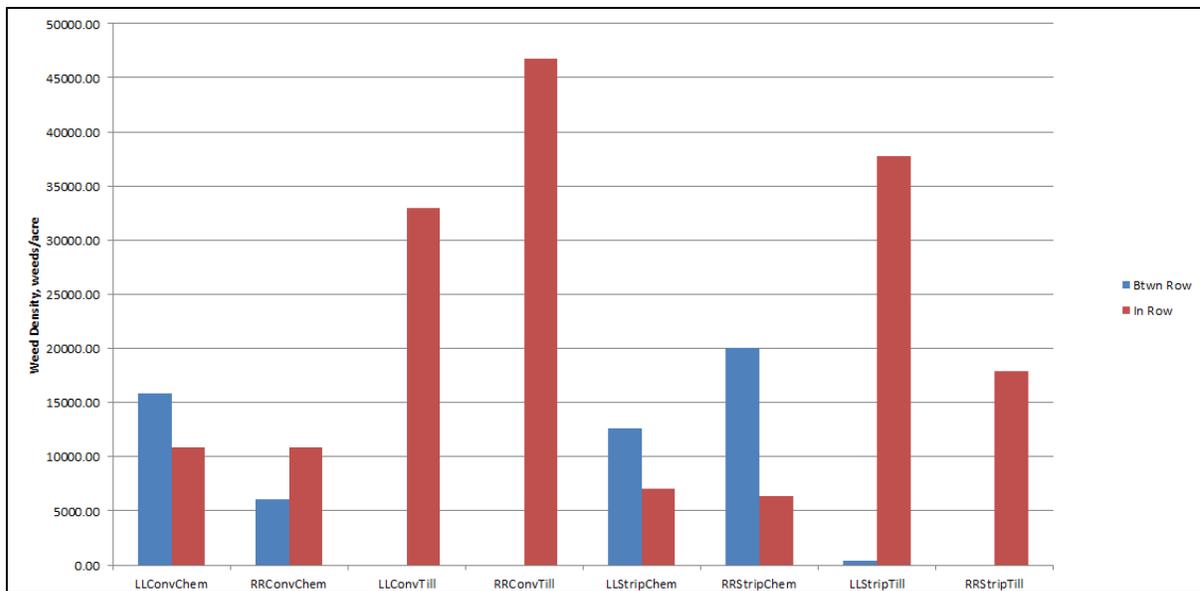
All of the data was written by the data logger to a CompactFlash drive. The operator had to push one button on the front of the data logger for it to begin collecting data, then the button had to be pushed again to stop data collection. The CompactFlash drive was then removed from the data logger and downloaded to a PC. The analysis software included with the data logger was used to convert the data to Microsoft Excel. Microsoft Excel was then used to analyze the data.

## **5.0 Results and Discussion**

### **5.1 Cotton Field Studies**

#### *5.1.1 Central Crops Research Station Results*

The results of the Palmer amaranth census from CCRS are provided in Figure 27. Figure 27. Average weed density values for each treatment type at the Central Crops Research Station for the 2010 Cotton season.. The figure provides the weed density of each of the treatments which was developed by calculating a weed count per acre value. This was done by dividing the number of *Palmer amaranth* plants between rows and in row by their respective areas. Analysis was also conducted using raw weed counts and a log transformation of the weed counts to see if the different data forms would show any other significant interactions. The analysis of weed count and the log transformations did not yield differing results.

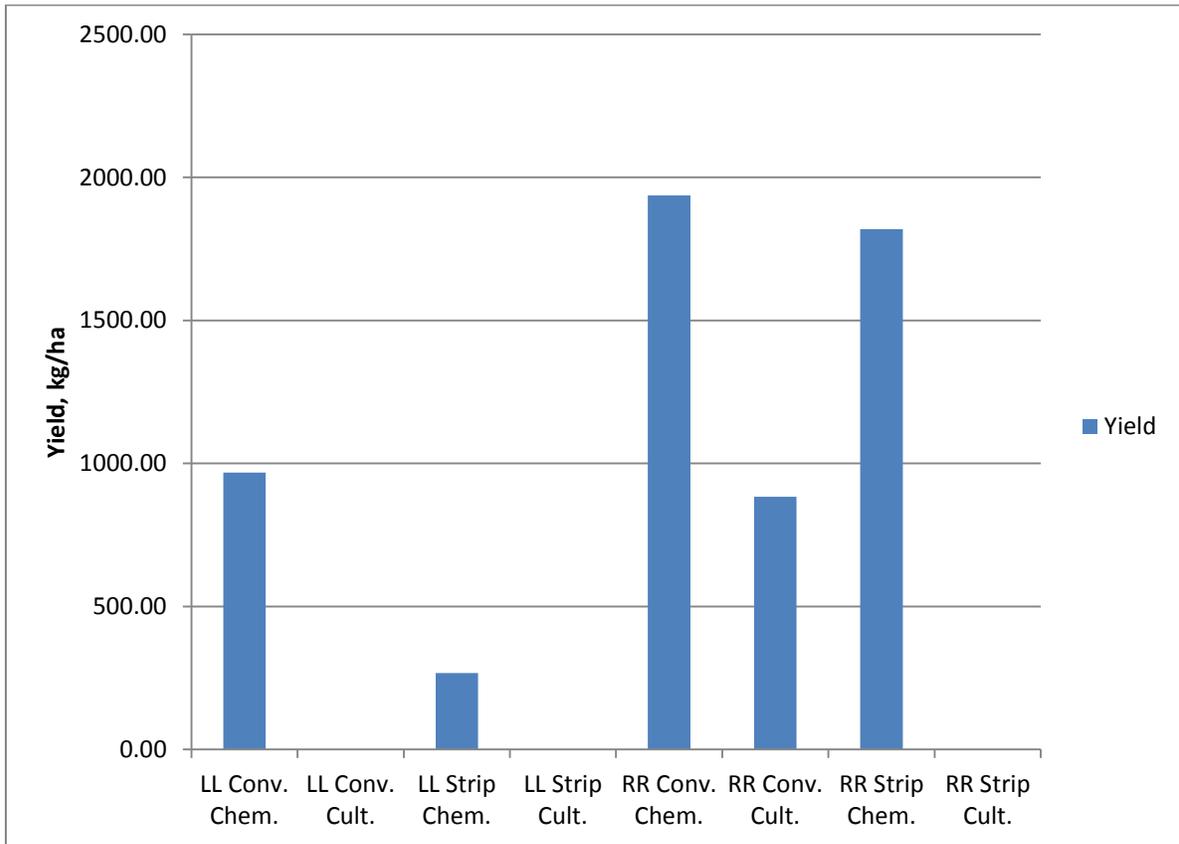


**Figure 27. Average weed density values for each treatment type at the Central Crops Research Station for the 2010 Cotton season.**

The weed population figure for CCRS illustrates a few trends. In-row weed pressure is always greater than between row weed pressure for the cotton plots that received mechanical post-emergence weed control (i.e. row cultivated). This is an expected result as the Danish tine cultivator is only operating in the between row zone, there is no mechanism for mechanical removal of weeds in row. Generally, the chemically post-emergence controlled plots provided the best overall weed control, particularly in-row. The combination of the chemical application and shading of the cotton canopy most likely hindered the growth of *Palmer amaranth* in these plots.

In terms of yield, Figure 28, the results are difficult to fully interpret because the cotton simply did not reach a level of maturity to warrant harvest. The major trend that can be seen is the plots that used herbicides as post emergence weed control were salvageable and could be harvested. Only 1 of the 4 treatments that experienced mechanical post-

emergence weed control was harvested. The mechanically cultivated plots had the highest in row weed density, which lowered the probability that the plots could be harvested.



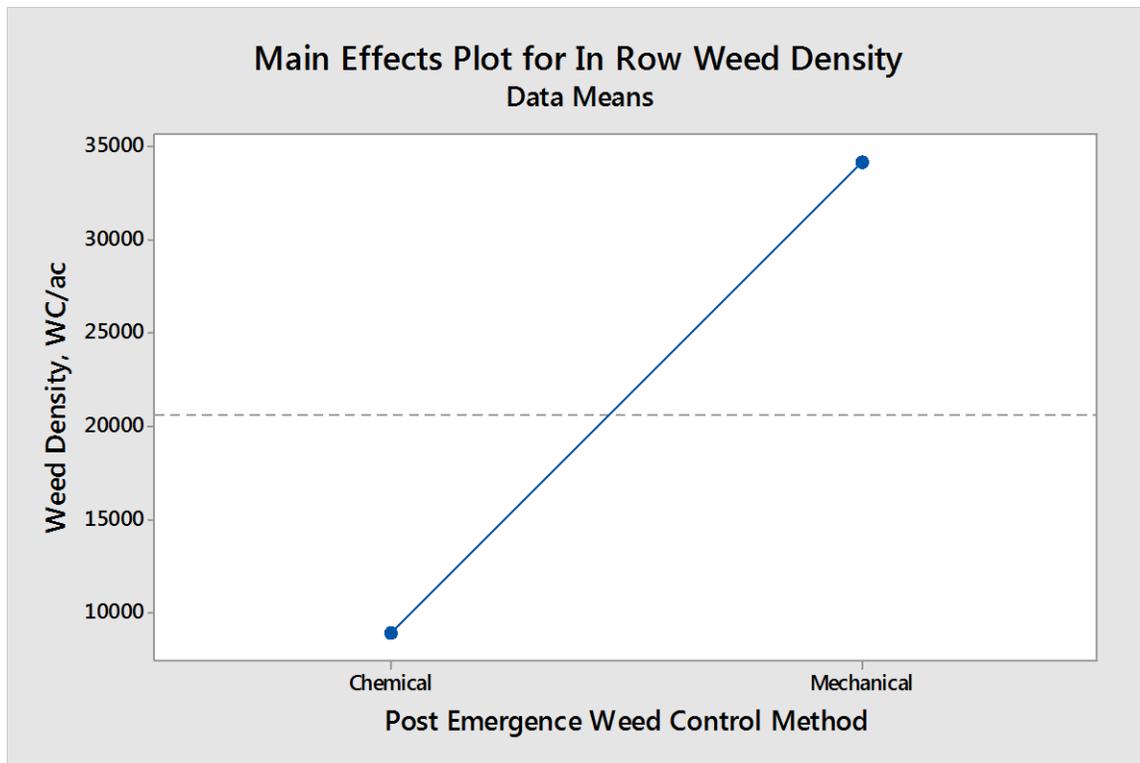
**Figure 28. Cotton yield values at the Central Crops Research Station for the 2010 Cotton season.**

An ANOVA analysis was carried out on the *Palmer amaranth* density data to determine the significant factors influencing the proliferation of the weed species. For the cotton cultivated at CCRS a total of three main effects and the associated interactions were considered. The main factors included: seed variety, tillage method, and post-emergence weed control. The response variables used in the ANOVA analysis in-row weed density, between row weed density and total plot weed density. There were 9 total unique treatments

including the control. The factor that proved to be significant to in row and between row weed densities was the post emergence weed control method. This can be seen, Figure 29 and Figure 31, with the low P-Values for that factor. The significance of post emergence weed control type was expected. It confirmed the trend observed in the weed density graphical summary shown in Figure 27. Figure 29 provides the ANOVA output for in-row weed densities, for all factors and interactions. A main effects plot was established, Figure 30, to graphically discern which factors were significant to weed proliferation. It can be concluded that the post emergence herbicide application outperformed the mechanically cultivated plots, in terms of weed density in-row. To support the conclusion, it should be noted that the mechanically cultivated plots showed an average weed density of approximately 34,000 weeds per ac, whereas the plots that received a post emergence herbicide application showed an average weed density of 9,000 weeds per ac.

Factor Information								
Factor	Type	Levels	Values					
Seed	Fixed	2	Liberty Link, Round Up Ready					
Tillage	Fixed	2	Conventional, Strip Till					
Post Emer Control	Fixed	2	Chemical, Mechanical					
Analysis of Variance								
Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value	
Seed	1	96195284	0.92%	19898996	19898996	0.09	0.772	
Tillage	1	197165232	1.89%	445309998	445309998	1.93	0.180	
Post Emer Control	1	4522127910	43.36%	4301844210	4301844210	18.68	0.000	
Seed*Tillage	1	424968038	4.07%	505686177	505686177	2.20	0.154	
Seed*Post Emer Control	1	11710124	0.11%	11710124	11710124	0.05	0.824	
Tillage*Post Emer Control	1	105809751	1.01%	105809751	105809751	0.46	0.506	
Seed*Tillage*Post Emer Control	1	465301932	4.46%	465301932	465301932	2.02	0.171	
Error	20	4606359715	44.17%	4606359715	230317986			
Total	27	10429637986	100.00%					

**Figure 29. ANOVA analysis Minitab output of in row weed densities with main effects of seed type, tillage, and post emergence weed management strategy.**



**Figure 30. Main effects plot for the post emergence weed control factor for in-row weed density.**

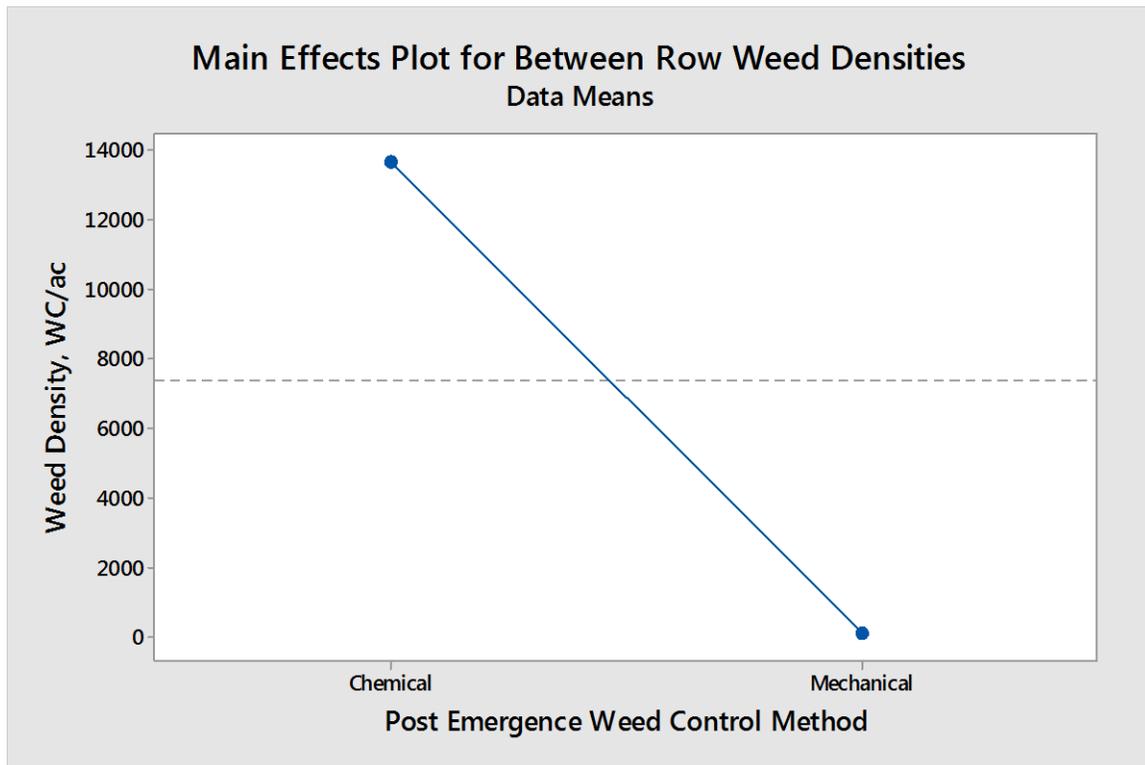
Figure 31 provides the ANOVA analysis for between row weed densities for all factors. Similar to the ANOVA for in-row relative weed density, the between row ANOVA shows that there is a statistical difference between the post emergence weed control treatments. This result was expected, because the mechanical cultivation physically removes the weeds from between the rows, so it should show a significant improvement in post emergence weed control over the herbicide application. Figure 32, shows the main effects plot for between row relative weed densities, which confirms the conclusion that the mechanically cultivated plots showed a significantly lower weed population. In this instance the mechanically cultivated plots generated an average of 0 weeds per ac, whereas the herbicide applied plots had an average of 14,000 weeds per ac.

Factor Information			
Factor	Type	Levels	Values
Seed	Fixed	2	Liberty Link, Round Up Ready
Tillage	Fixed	2	Conventional, Strip Till
Post Emer Control	Fixed	2	Chemical, Mechanical

Analysis of Variance							
Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Seed	1	90282	0.00%	3237002	3237002	0.01	0.904
Tillage	1	36103095	0.60%	52750724	52750724	0.24	0.628
Post Emer Control	1	1328336417	21.90%	1256421591	1256421591	5.76	0.026
Seed*Tillage	1	158340538	2.61%	122807015	122807015	0.56	0.462
Seed*Post Emer Control	1	1750165	0.03%	1750165	1750165	0.01	0.930
Tillage*Post Emer Control	1	46059843	0.76%	46059843	46059843	0.21	0.651
Seed*Tillage*Post Emer Control	1	133588792	2.20%	133588792	133588792	0.61	0.443
Error	20	4362083272	71.91%	4362083272	218104164		
Total	27	6066352406	100.00%				

**Figure 31. ANOVA analysis Minitab output of Between Row Weed Densities with main effects of seed type, tillage, and post emergence weed management strategy.**



**Figure 32. Main effects plot for post emergence weed control factors on between row weed density.**

The ANOVA that analyzed total plot weed density, Figure 33, showed that there was no statistical difference between any of the factors or interactions. When looking at the treatment as the only factor, Figure 34, it also showed that there was no statistical difference.

Total Weed Density								
Factor Information								
Factor	Type	Levels	Values					
Seed	Fixed	2	Liberty Link, Round Up Ready					
Tillage	Fixed	2	Conventional, Strip Till					
Post Emer Control	Fixed	2	Chemical, Mechanical					
Analysis of Variance								
Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value	
Seed	1	11721537	0.36%	7727173	7727173	0.05	0.821	
Tillage	1	1899733	0.06%	10159635	10159635	0.07	0.795	
Post Emer Control	1	3084859	0.09%	3158410	3158410	0.02	0.885	
Seed*Tillage	1	124233	0.00%	1653291	1653291	0.01	0.917	
Seed*Post Emer Control	1	180794	0.01%	180794	180794	0.00	0.972	
Tillage*Post Emer Control	1	65223124	2.01%	65223124	65223124	0.44	0.513	
Seed*Tillage*Post Emer Control	1	232470594	7.16%	232470594	232470594	1.58	0.223	
Error	20	2933613449	90.31%	2933613449	146680672			
Total	27	3248318323	100.00%					

**Figure 33. ANOVA Analysis Minitab Output of Total Weed Density with main effects of seed type, tillage, and weed management strategy**

Factor Information								
Factor	Type	Levels	Values					
Trmt Number	Fixed	8	1, 2, 3, 4, 5, 6, 7, 8					
Analysis of Variance								
Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value	
Trmt Number	7	314704873	9.69%	314704873	44957839	0.31	0.943	
Error	20	2933613449	90.31%	2933613449	146680672			
Total	27	3248318323	100.00%					

**Figure 34. ANOVA Analysis Minitab Output of Total Weed Density for effect of Treatment Only**

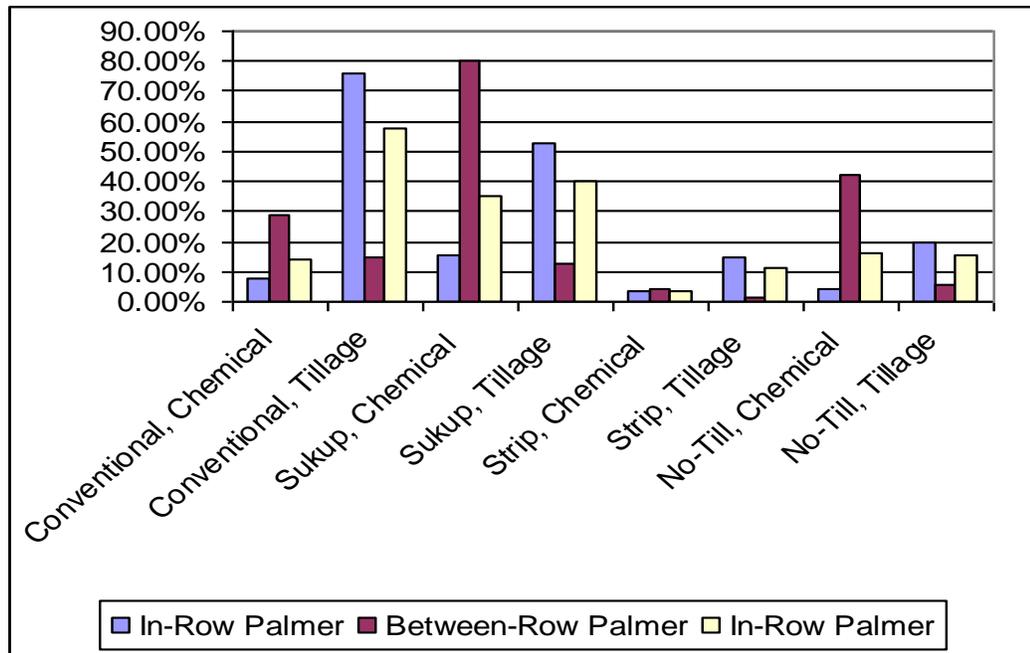
Perhaps the most interesting aspect of the ANOVA analysis is the general lack of a significant difference in the overall treatments in the prevention of *Palmer amaranth* populations in the cotton plots. The treatment method used did not influence the resulting total *Palmer amaranth* population. As expected the mechanically cultivated plots had significantly fewer between row weeds and the herbicide managed plots had significantly fewer in-row weeds. This was the only significant, repeatable finding of the trials at CCRS. A treatment that was not evaluated in this study but would possibly have had an effect on the total *Palmer amaranth* population would have been to use both chemical and mechanical weed control methods simultaneously.

Because the yield data was incomplete as a result of harvest ability concerns it was not possible to generate higher level statistical analysis of any importance/significance. However, the 4 of the 5 treatment types that were harvested received herbicide which suggests the chemical application was capable of somewhat minimizing the influence of *Palmer amaranth* on cotton production. This is reflected in the relatively smaller size of the *Palmer amaranth* weeds in these plots which allowed harvest operations to be completed. The in-row *Palmer amaranth* observed in the row cultivated plots were typically larger than the cotton plants and present tremendous challenges for mechanized harvest. The large *Palmer amaranth* plants have the potential to destroy spindles and other parts on the picking heads of spindle type cotton pickers.

#### *5.1.2 Upper Coastal Plain Research Station Results*

The results of the *Palmer amaranth* census from the Upper Coastal Plain Research Station (UCPRS) are provided in Figure 35 and Figure 36 . Data were collected for both the

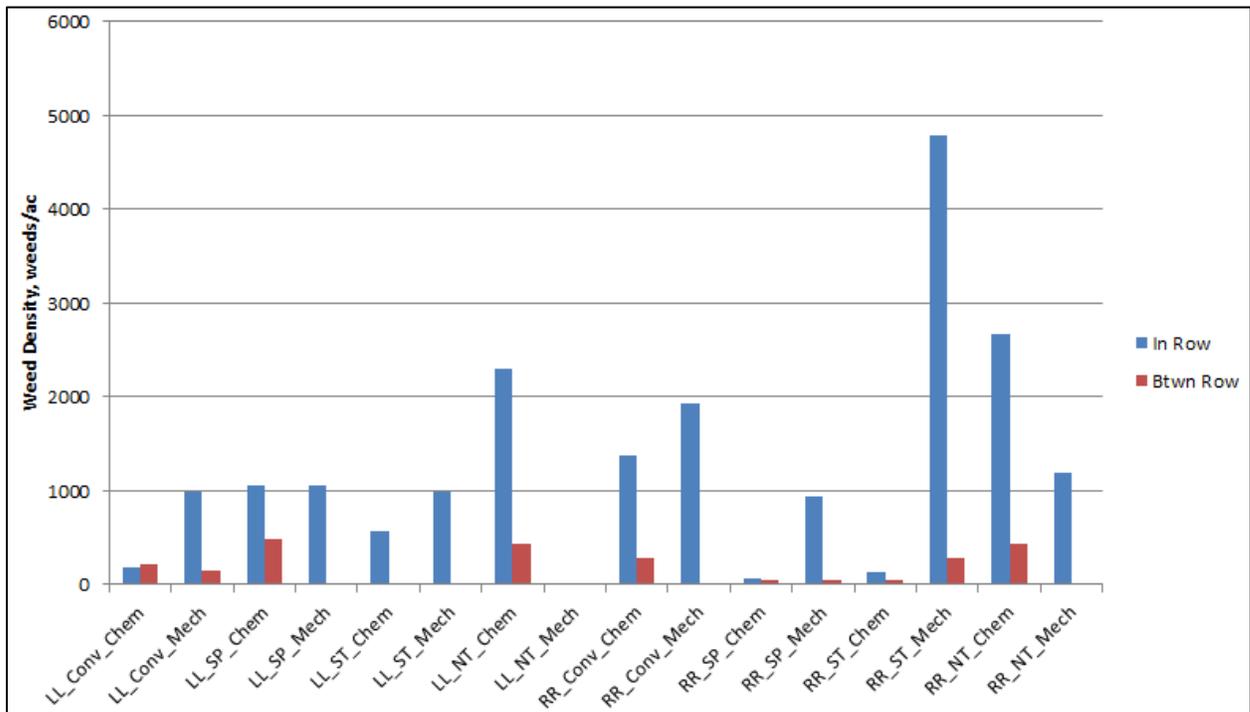
2009 cropping season, Figure 35, and 2010 cropping season, Figure 36. This is the only research station that had multiple years of data. The 2009 data set compared the weed counts in the plots to the control plots, which yielded a relative weed pressure value. Whereas the 2010 data analyzed weed density, the same calculation as CCRS. A key difference is the change in weed densities in 2010 compared to 2009 as there was a dramatic decrease in weed density attributed to *Palmer amaranth*.



**Figure 35. Weed density values at the Upper Coastal Plains Research Station for the 2009 Cotton season.**

In the 2009 research, *Palmer amaranth* was the only weed that showed significant competition with the cotton crop, but morning glories and grass were also sporadically observed throughout the entire field. In August 2009, a glyphosate herbicide application was conducted to allow the crop to be mechanically harvested. After the salvage operation, it was

concluded that roughly half of the research plot at UCPRS contained resistant *Palmer amaranth*. It should be noted that during the 2009 trials, that almost every treatment experienced at least one replication where over 200 *Palmer amaranth* plants were observed in the plot. In 2009, pre-planting operations that introduced more soil disturbance (i.e. conventional tillage and the Sukup plow) showed the highest *Palmer amaranth* populations.



**Figure 36. Weed density values at the Upper Coastal Research Station for the 2010 Cotton season.**

The *Palmer amaranth* population in 2010 was considerably lower than the populations witnessed in 2009. It should be noted that the control plots in 2009 and 2010 had similar *Palmer amaranth* populations, so the variability of year to year *Palmer amaranth* pressure was not the cause. Visual observation indicated that the field and plots seemed much cleaner and weed pressure was lessened in 2010. This result was surprising as the field

was confirmed in 2009 as containing glyphosate –resistant *Palmer amaranth* and the population was so high.

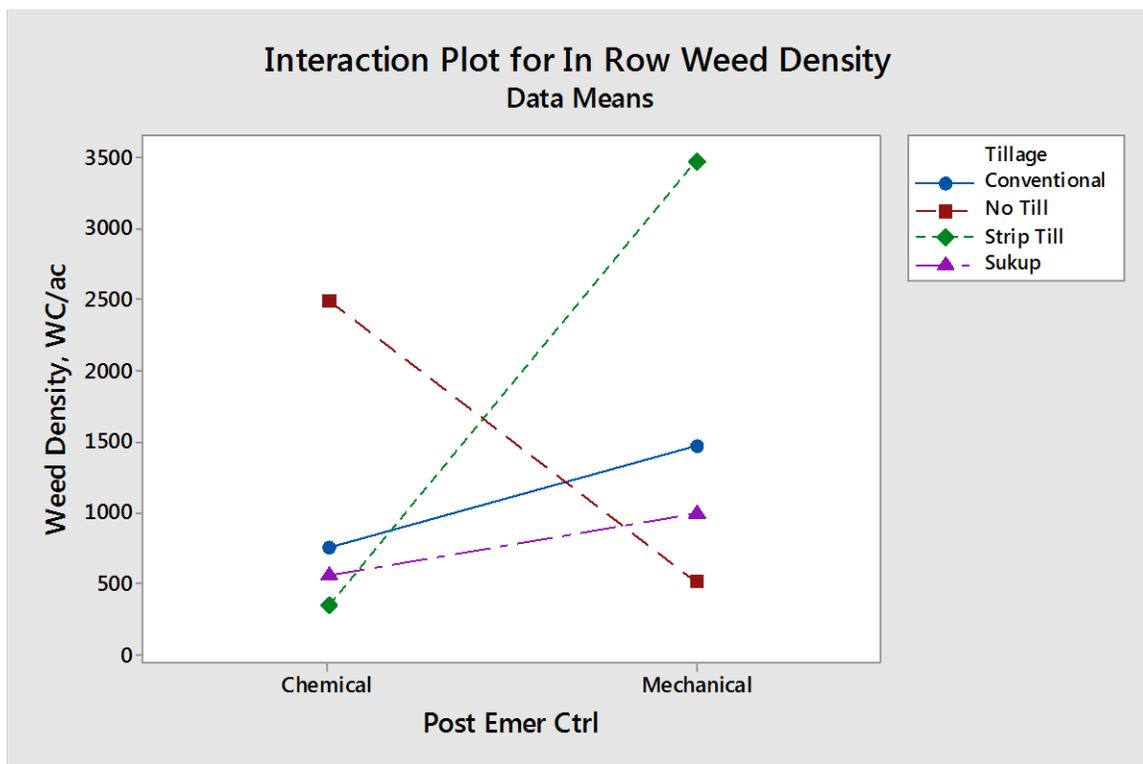
The exact reason for the sudden change in weed counts is unknown. Even the trends seen in 2009 with regards to a supposed link between surface disturbance and *Palmer amaranth* pressure is not as credible based on 2010 data. No-till and strip-till plots in 2010 had some of the highest weed density values. It could be that the *Palmer amaranth* seed was pushed deep in the soil to depth that will not allow germination or tillage operations in 2009 raised *Palmer amaranth* seed to a depth that made germination more prolific. It appears there is some variability in the population of a *Palmer amaranth* stand and how this changes year to year in conjunction with management practices cannot be determined from this study.

ANOVA analyses were conducted on the *Palmer amaranth* population data set for 2010 to determine if there were any significant interactions. Figure 37 shows the ANOVA of the in-row weed densities. It was found that the interaction between pre-plant tillage treatment and post emergence weed control was significant.

General Linear Model: In Row Per Ac versus Seed, Tillage, Post Emer Ctrl						
Factor Information						
Factor	Type	Levels	Values			
Seed	Fixed	2	Liberty Link, Round Up Ready			
Tillage	Fixed	4	Conventional, No Till, Strip Till, Sukup			
Post Emer Ctrl	Fixed	2	Chemical, Mechanical			
Analysis of Variance						
Source		DF	Adj SS	Adj MS	F-Value	P-Value
Seed		1	4676621	4676621	2.28	0.140
Tillage		3	6847064	2282355	1.11	0.358
Post Emer Ctrl		1	3499413	3499413	1.71	0.200
Seed*Tillage		3	6212100	2070700	1.01	0.400
Seed*Post Emer Ctrl		1	5514467	5514467	2.69	0.111
Tillage*Post Emer Ctrl		3	32835202	10945067	5.35	0.004
Seed*Tillage*Post Emer Ctrl		3	5306128	1768709	0.86	0.470
Error		32	65509308	2047166		
Total		47	132958686			

**Figure 37. ANOVA Analysis Minitab Output of In-Row Weed Density with main effects of seed type, tillage, and weed management strategy**

An interaction plot, Figure 38, was created to analyze the interaction that was found to be significant in the ANOVA analysis of in-row weed density. From the plot, it can be concluded that when a pre-plant conventional tillage system, Sukup® plow system or a strip till system is used; in row weed pressure is higher when mechanical cultivation is used as the post emergence weed control practice.



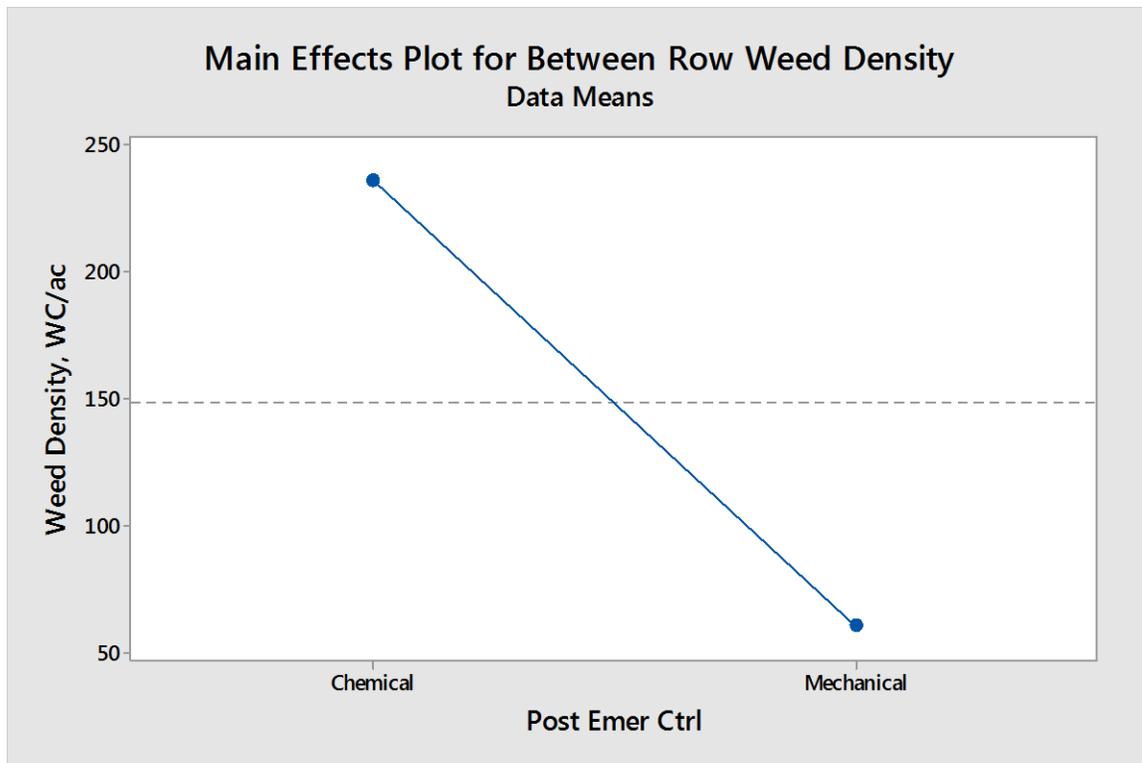
**Figure 38. Interaction plot for in row weed density for the pre-plant tillage and post emergence weed control factors.**

The ANOVA of the between row weed density, Figure 39, showed that the post emergence weed control factor was statistically significant. The statistical significance between the mechanical cultivation and herbicide application as method of post emergence weed control was expected.

General Linear Model: Btwn Row Per Ac versus Seed, Tillage, Post Emer Ctrl						
Factor Information						
Factor	Type	Levels	Values			
Seed	Fixed	2	Liberty Link, Round Up Ready			
Tillage	Fixed	4	Conventional, No Till, Strip Till, Sukup			
Post Emer Ctrl	Fixed	2	Chemical, Mechanical			
Analysis of Variance						
Source		DF	Adj SS	Adj MS	F-Value	P-Value
Seed		1	6815	6815	0.07	0.797
Tillage		3	104784	34928	0.34	0.794
Post Emer Ctrl		1	358199	358199	3.53	0.070
Seed*Tillage		3	194303	64768	0.64	0.596
Seed*Post Emer Ctrl		1	61332	61332	0.60	0.443
Tillage*Post Emer Ctrl		3	464707	154902	1.53	0.227
Seed*Tillage*Post Emer Ctrl		3	168729	56243	0.55	0.649
Error		32	3250302	101572		
Total		47	4658913			

**Figure 39. ANOVA Analysis Minitab Output of Between-Row Weed Density with main effects of seed type, tillage, and weed management strategy.**

A main effects plot, Figure 40, was established to analysis the statistical difference seen in the post emergence weed control factor. The figure shows that when herbicide application as the sole post emergence weed control method, the cotton plots had, on average, four times the weed density as the plots that received the mechanical cultivation treatment.



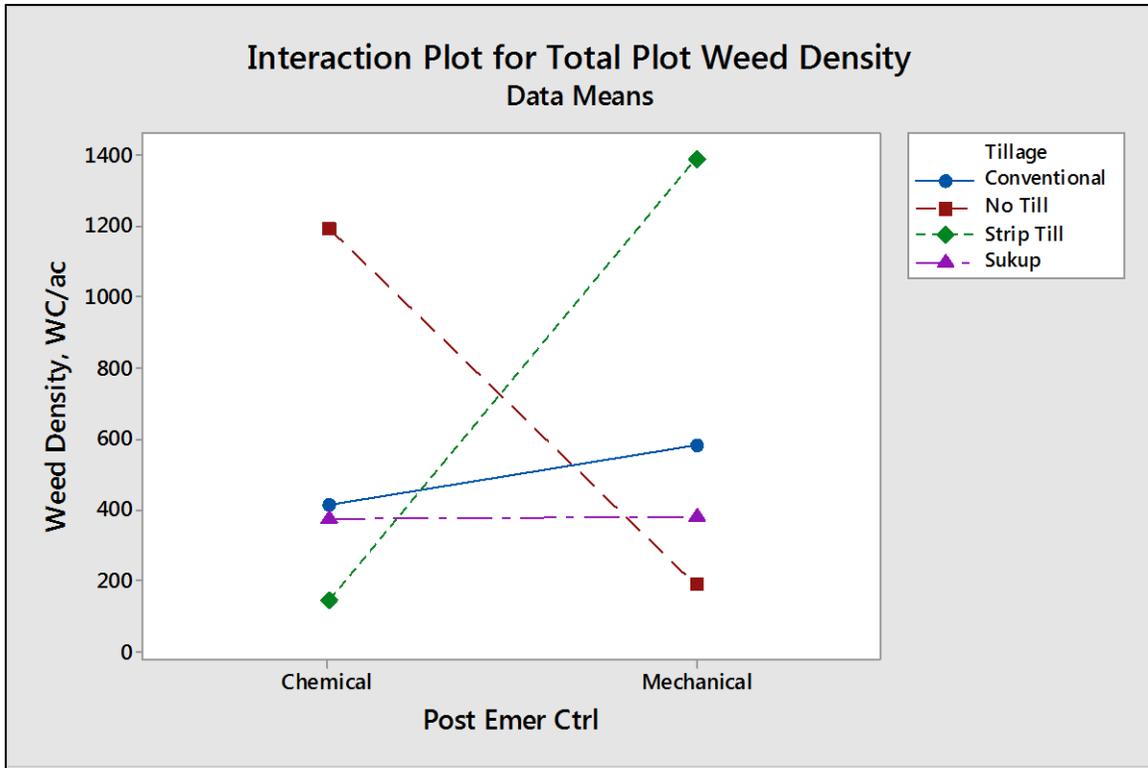
**Figure 40. Main effects plot for the post emergence weed control factor for between row weed density.**

The ANOVA of the total plot weed density, Figure 41, shows that similarly to the in row weed density analysis, the interaction of pre plant tillage system and post emergence weed control method was statistically significant.

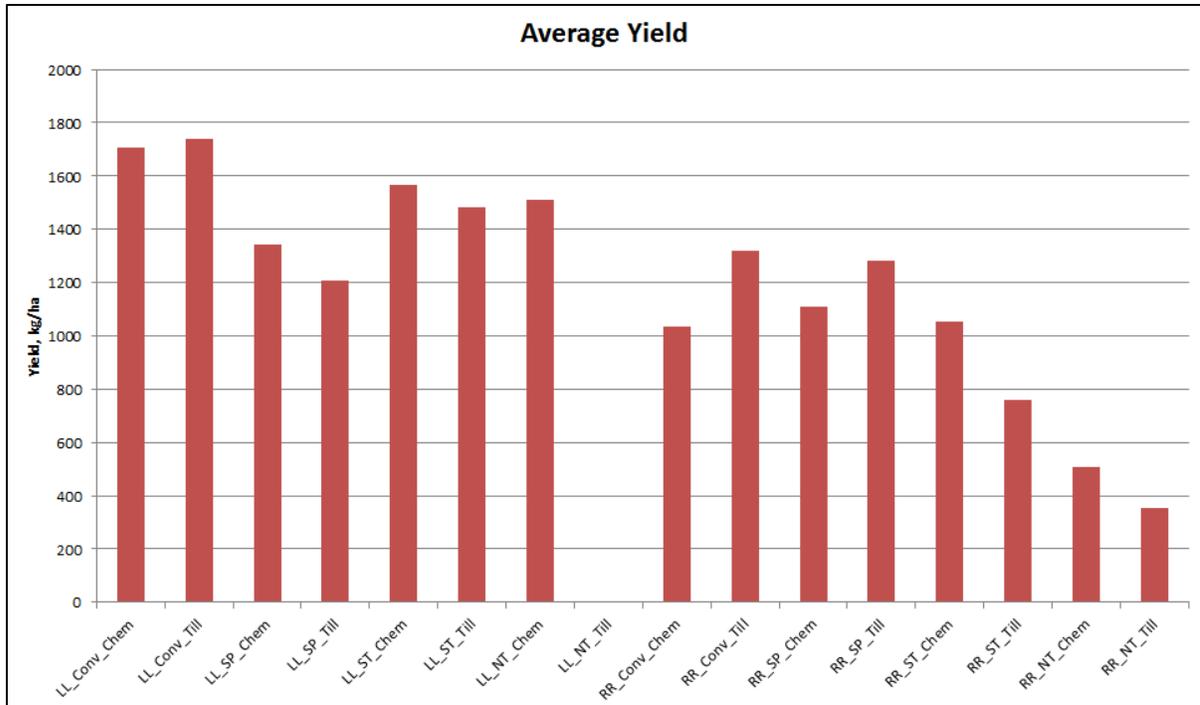
General Linear Model: Total Per Ac versus Seed, Tillage, Post Emer Ctrl						
Factor Information						
Factor	Type	Levels	Values			
Seed	Fixed	2	Liberty Link, Round Up Ready			
Tillage	Fixed	4	Conventional, No Till, Strip Till, Sukup			
Post Emer Ctrl	Fixed	2	Chemical, Mechanical			
Analysis of Variance						
Source		DF	Adj SS	Adj MS	F-Value	P-Value
Seed		1	554416	554416	1.45	0.238
Tillage		3	946331	315444	0.82	0.491
Post Emer Ctrl		1	96843	96843	0.25	0.619
Seed*Tillage		3	1383179	461060	1.20	0.325
Seed*Post Emer Ctrl		1	1043610	1043610	2.72	0.109
Tillage*Post Emer Ctrl		3	6433084	2144361	5.59	0.003
Seed*Tillage*Post Emer Ctrl		3	951587	317196	0.83	0.489
Error		32	12274009	383563		
Total		47	24235451			

**Figure 41. ANOVA Analysis Minitab Output of Total Weed Density with main effects of seed type, tillage, and weed management strategy.**

An interaction plot was also created, Figure 42, for this analysis to graphically illustrate the significance of the interaction. The same holds true for total weed density as it did for the in row weed density, when a pre plant conventional tillage system, a Sukup® plow system or a strip till system is used; total weed pressure is higher when mechanical cultivation is used as the post emergence weed control practice.



**Figure 42. Interaction plot for total weed density for the pre plant tillage and post emergence weed control factors.**

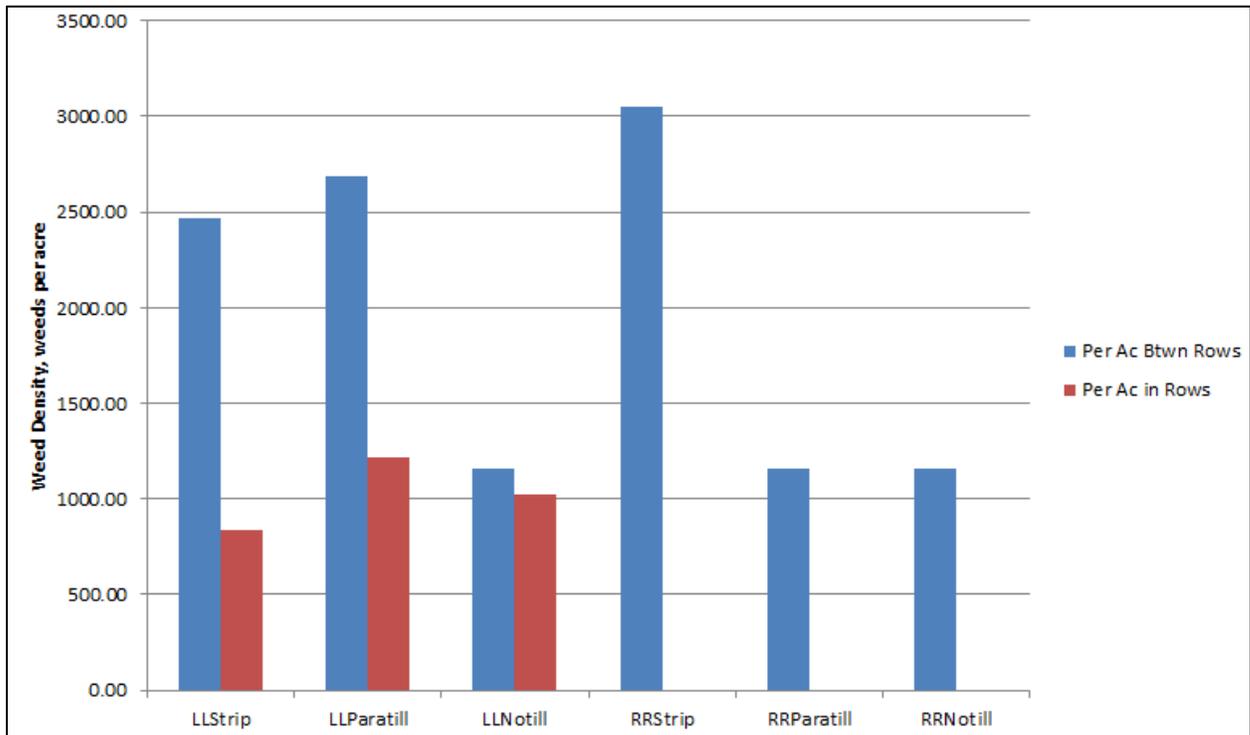


**Figure 43. Yields for Upper Coastal Plains Research Station.**

In terms of yields, Figure 43, the Liberty Link® seed variety showed better results than Round Up® Ready. This can be attributed to the difference in the modes of actions for the two post emergence weed control chemicals. One thing of importance to note is the poor performance of the no till treatments, especially for the Round Up® Ready seed variety. It was expected that the less soil disturbance would slow the proliferation of *Palmar Amaranth*, but the data, shows the exact opposite. Based on research from 2009, there is no logical explanation for this occurrence.

### 5.1.3 Cherry Research Farm Results

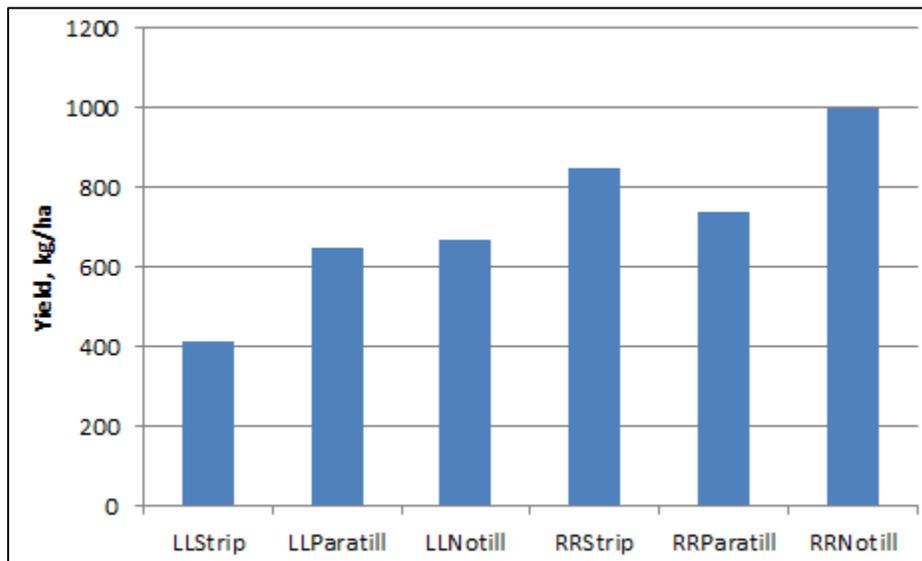
The results of the *Palmer amaranth* census from Cherry Research Farm (CRF) are provided in Figure 44. The weed pressure at CRF was dramatically lower than the other study sites used during this project. The worst treatment in terms of *Palmer amaranth* weed density had a population that was just above 3000 weeds per acre.



**Figure 44. Weed census for the field studies at Cherry Research Farm.**

The weed census for CRF illustrates a somewhat different trend than what was seen at previous sites. In-row weed density was lower in all plots compared to between row. This could be attributed to the shading of the canopy or that the only post emergence weed control practice used was an herbicide application. As a pre-plant treatment, no-till appeared to be the most successful method in suppressing *Palmer amaranth* when all other factors are

considered. Leaving the soil surface undisturbed seems to have prevented a large *Palmer amaranth* population from developing. Additionally, in a no-till system most likely a vegetative ground cover would have been established over the winter fallow months (this could be volunteer or a managed winter cover crop). The competition for natural resources that these winter cover crops provided as well as a soil surface barrier that was developed may be key in preventing *Palmer amaranth* germination and dissemination.



**Figure 45. Yield analysis for Cherry Research Farm.**

In terms of yield, Figure 45, the results were approximated using cotton insurance adjustment estimation tools that were primarily based on boll count. There are very few trends that are evident from the graphical representation of the yields. There appears to be a slight yield improvement with the use of Round-Up Ready cotton versus the Liberty-Link cotton. But most interesting the yield graph does not resemble the weed pressure graph.

This would indicate that the weed pressure variations in the plots did not influence the cotton yield. As noted earlier, the weed populations in the cotton plots at CRF were dramatically lower than weed populations at other research sites. Most likely a weed pressure threshold was not crossed in any of the plots that would have negatively impacted the cotton yields at CRF.

Higher level analysis of neither weed pressure nor yield was completed due to the manner in which the trials were set up. Timing and logistical issues at planting caused the research to only contain one replication of each treatment, so there was insufficient data to do a more in depth analysis or to make any conclusions. The above statements are only observations.

#### *5.1.4 Field Study Conclusions*

When looking at the overall trends from the weed density research conducted at CCRS and UCPRS, it can be concluded that the post emergence weed control method was the only common significant factor at both locations.

The statistical analysis of the CCRS showed that for in row weed density, herbicide application as the post emergence weed control method yielded significantly lower weed densities than mechanical cultivation, whereas the opposite holds for between row weed densities. Overall, the plots that received a post emergence herbicide application performed better than the plots that received mechanical cultivation. This can be seen in the weed census as well as the yield results. Although statistical analysis was not conducted on the

yield data, it can be seen that 4 out of the 5 treatments that could be harvested used herbicide application as the post emergence weed control.

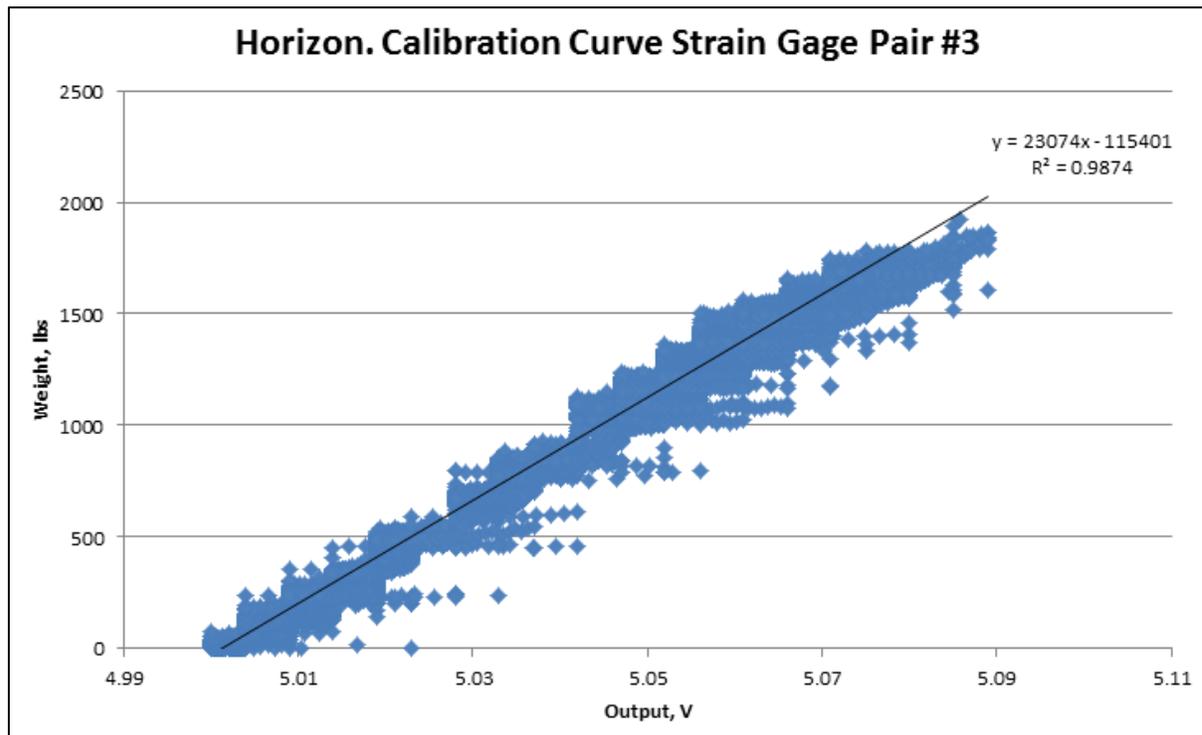
At UCPRS, where research was done in 2009, showed lower weed populations in 2010. It was concluded from the 2009 research that the treatments that had the most pre plant soil disturbance (i.e. Sukup plow) had the highest weed densities, whereas in 2010, the no till and strip till plots had the highest weed densities. This disproves the hypothesis that lowering the preplant soil disturbance will slow the proliferation of *Palmer amaranth*. The interaction between pre plant tillage and post emergence weed control for in row and total plot weed densities was unique to UCPRS. This interaction showed that when a pre-plant conventional tillage system, Sukup® plow system or a strip till system is used; in row and total plot weed densities are higher when mechanical cultivation is used as the post emergence weed control practice.

## **5.2 Tractor Performance**

### *5.2.1 Dynamometer Results*

It was hypothesized that strain gage pairs 1, 3 and 5 would be best for predicting the vertical load whereas pairs 2, 4 and 6 would be best to predict the horizontal load (Figure 16). After conducting the dynamometer calibration activities, calibration curves were established for each pair strain gages, in the vertical and horizontal planes. The calibration curves that showed the better regression were used for the dynamometer testing analysis. It was found that the strain gage pairs 1, 3 and 5 were indeed the best predictors of vertical load, but it was also concluded that the same pairs were the better predictors for the

horizontal load as well. Figure 46 shows an example of one of the calibration curves used to analyze data collected from the dynamometer.



**Figure 46. Calibration curve used for the left side bottom link of the three point hitch dynamometer.**

After the calibration curves were established, the implements were drawn through the trial field. The recorded data from the dynamometer was then used to calculate the horizontal force used to pull each implement. The calibration curves for strain gage pairs 1, 3 and 5 were used to calculate the forces. The assumptions used to calculate the estimated draft load, per ASABE D497.7, can be found in Table 4. The trial field was assumed to have a medium textured soil. The speeds used were measured by the GPS antenna on the data acquisition

system. Table 5 shows the results of the test pulls, compared to the draft values listed for each implement in ASABE Standard D497.7.

**Table 4. Assumptions used to estimate the draft load of each of the four implements tested, using ASABE D497.7.**

	<b>ASABE Listed Implt</b>	<b>F<sub>2</sub></b>	<b>A</b>	<b>B</b>	<b>C</b>	<b>Speed, kmh</b>	<b>Width</b>	<b>Till. Depth, cm</b>
<b>Danish Tine - DH</b>	Row Crop Cult.–S-Tine	0.85	140	7	0	6.95	4 Rows	12.7
<b>Danish Tine - UH</b>	Row Crop Cult.–S-Tine	0.85	140	7	0	7.13	4 Rows	12.7
<b>Field Cult – DH</b>	Field Cult. – Prim. Till.	0.85	46	2.8	0	8.51	25 Tools	10.16
<b>Field Cult – UH</b>	Field Cult. – Prim. Till.	0.85	46	2.8	0	8.35	25 Tools	10.16
<b>Chisel Plow – DH</b>	Chisel – 5 cm st. pt.	0.85	91	5.4	0	6.07	9 Tools	17.78
<b>Chisel Plow – UH</b>	Chisel – 5 cm st. pt.	0.85	91	5.4	0	7.26	9 Tools	17.78
<b>Paratill – DH</b>	Subsoiler – Nar. Pt.	0.7	226	0	1.8	4.89	2 Tools	35.56
<b>Paratill - UH</b>	Subsoiler – Nar. Pt.	0.7	226	0	1.8	4.02	2 Tools	35.56

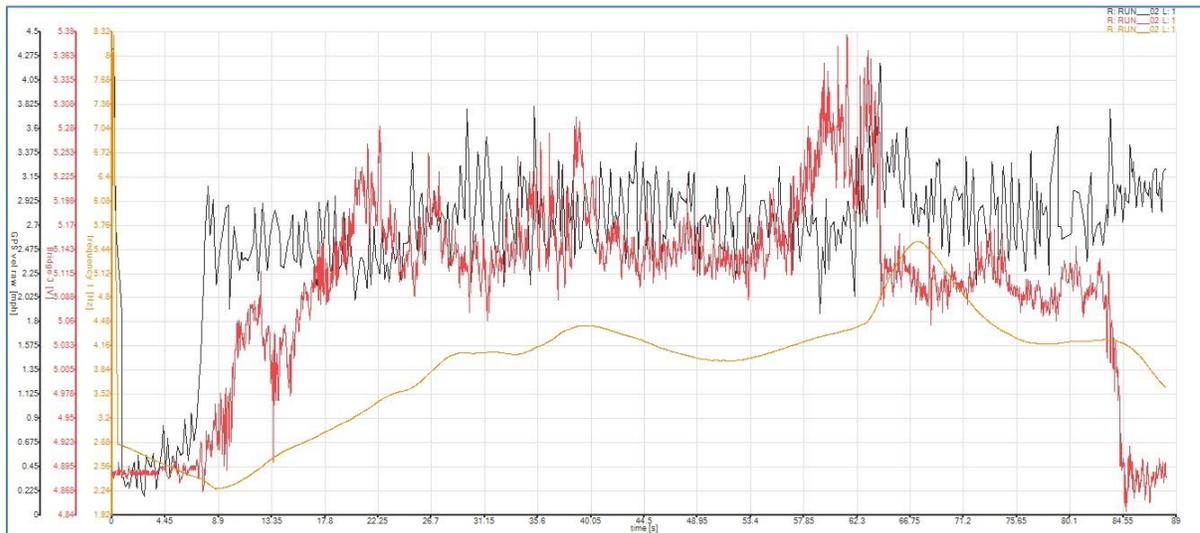
**Table 5. Draft load for the four implements tested compared to the ASABE D497.7.**

	<b>Measured Draft, N</b>	<b>ASABE Estimated Draft, N</b>	<b>ASABE Expected Variation, %</b>	<b>% Difference</b>
<b>Danish Tine - DH</b>	13310	8146	+/- 15	63
<b>Danish Tine - UH</b>	12996	8200	+/- 15	58
<b>Field Cult - DH</b>	8462	15076	+/- 30	-44
<b>Field Cult - UH</b>	9460	14980	+/- 30	-37
<b>Chisel Plow - DH</b>	27739	16835	+/- 50	65
<b>Chisel Plow - UH</b>	37351	17707	+/- 50	111
<b>Paratill - DH</b>	40220	13391	+/- 50	200
<b>Paratill - UH</b>	20931	12701	+/- 50	65

The comparison of the implements, Table 5, shows that the dynamometer measured results did not match the ASABE estimated draft. The expected variation of the draft load calculated using ASABE D497.7, can explain why the draft results do not match exactly with the estimations. The expected variations stem from the empirical nature of the estimation. Another component of this variation comes from the fact that the data collected for ASABE D497.7 comes from multiple measurement devices. If the ASABE estimation was adjusted using the expected variation, many of the measured draft results would be less than 20% from the estimated value. It should be noted that the ASABE D497.7 does not specifically include a Paratill or Danish Tine, so the coefficients for the subsoiler and s-tine row crop cultivator were used, respectively. The two trials that showed the highest percent difference, Chisel Plow- Uphill and Paratill – Downhill, may have been subjected to a special cause variation, such as a hard pan in the trial field. Overall, the dynamometer showed that draft measurement is repeatable, and comparable to established draft estimation calculations.

### 5.2.2 Fuel Flow Meter and Data Acquisition Feasibility

The fuel flow meter and the data acquisition systems performed as expected. An example of the real time graph that can be seen through communication with the data acquisition system can be seen in Figure 47. The figure shows tractor speed, one of the dynamometer bridge outputs and the fuel flow meter output. It should be noted that, for this example, that the correlation of the three signals are as expected. When the GPS output showed a higher ground speed, the force seen by the dynamometer increased, and the fuel consumption increases. This confirms that the whole system worked as anticipated.



**Figure 47. Example output from the data acquisition system.**

## 6.0 Future Research

More research needs to be done to determine/replicate the correlation of soil disturbance and weed proliferation. A full trial, with the needed replications, that includes all of the tillage tools used across the three research stations in this research, would be a good starting point. This would ultimately decide if soil disturbance affects weed proliferation.

The high variations when comparing the measured draft load to the ASABE standard is concerning. This research proves that the dynamometer will work in this system, but more research could go into why there were such large variations on some of the tillage tools and not others. Potential issues could be signal noise from hitting a rock, different compaction ratings for different parts of the test field, etc... Hardware integrity was one issue that was encountered during the dynamometer trial. Since the research was more of a proof of concept, there was no justification to spend the extra time and money to make the wiring harness more robust. This would be an upgrade that should be done if this research is continued.

Another place that future research would be warranted would be to tie the crop production best practices to the cost of those practices. As mentioned before, mechanical cultivation costs more than using herbicides for post emergence weed control. So if it is not financially justified, by lower weed incidence and ultimately better yields, it doesn't make sense to mechanically cultivate. The ultimate goal would be to produce an Extension Publication that would allow producers to "input" their current parameters (weed densities, pre plant tillage, seed type, etc...) and determine if they have hit a weed outbreak severity level that would warrant a change to a more aggressive weed control practice, like mechanical cultivation.

## 7.0 Bibliography

- Alberta Farm Machinery Research Centre. 1991. Evaluation Report for Tye Paratill Model 118-610. Alberta, Canada
- American Society of Agricultural and Biological Engineers. 2003. Agricultural wheeled tractors and implements - Three-point hitch couplers - Part 1: U-frame couple. ASABE Standard 278.7 (R. 2009)
- American Society of Agricultural and Biological Engineers. 2011. Agricultural Machinery Management Data. ASABE Data 497.7
- Bandy, S. M., W. A. Babacz, S. W. Searcy and B. A. Stout. 1986. Measurement of three-point hitch forces on agricultural tractors. SAE Paper No. 86-1255. Warrendale, PA: SAE
- Bayer CropScience. Liberty Link Cotton Fact Sheet. Available at: <http://www.bayercropscience.com.au/resources/pdf/LibertyLinkCottonFactSheet080806.pdf>. Accessed 4/19/2010
- Bernier, H., G. Bostack, G. S. V. Raghavan, and R. S. Broughton. 1987. Subsoiling Effects on Moisture Content and Bulk Density in the Soil Profile. Applied Engineering in Agriculture. 5(1): 24-28.
- Bigham Brothers Shear Bolt Paratill - Subsoiler Available at: <http://www.bighambrothers.com/ptillshr.htm>. Accessed 12/2/2009.
- Bowers, C.G. Jr. 1989. Tillage Draft and Energy Measurements for Twelve Southeastern Soil Series. Transactions of the ASABE. 32 (5): 1492-1502.
- Brown, Steve M., A. Stanley Culpepper, Jerry W. Davis, Timothy L. Grey, Wayne W. Hanna, Jeremy M. Kichler, William K. Vencill, Theodore M. Webster, and Alan C. York. 2006. Glyphosate-resistant Palmer amaranth confirmed in Georgia. Weed Science 54(4): 620-626.
- Burgos, Nilda, Stanley Culpepper, Peter Dotray, J. Andrew Kendig, Robert Nichols, and John Willcut. Managing Herbicide Resistance in Cotton Cropping Systems. December 2006. Available at: <http://www.cotton.org/tech/pest/upload/07CIweedresistbulletin.pdf>. Accessed 12/2/2009.
- Chaplin, J., M. Leuders and Y. Zhao. 1987. Three-point hitch dynamometer design and calibration. Applied Engineering in Agriculture 3(1): 10-13
- Currie, Randall S., Michael J. Horak, and John Boyer Jr. 2001. Interference of Palmer amaranth in corn. Weed Science 49: 202-208.

- Ehleringer, James. 1983. Ecophysiology of *Amaranthus palmeri*, a Sonoran Desert Summer Annual. *Oecologia* , Vol. 57, No. 1/2 , pp. 107-112.
- Gamer, T. H., R. B. Dodd, D. Wolf and U. M. Peiper. 1988. Force analysis and application of a three-point hitch dynamometer. *Transactions of the ASAE* 31 (4): 1047-105.
- Johnson, C. E. and W. B. Voorhees. 1979. A force dynamometer for three-point hitches. *Transactions of the ASAE* 22(2):226-228, 232.
- McLaughlin, N. B., L. C. Heslop, D. J. Buckley, G. R. St. Amour, B. A. Compton and P. Van Bodegom. 1989. A tractor instrumentation and data logging system for tillage research. ASAE Paper No. 89-1041. St. Joseph, MI: ASAE
- Mississippi State University Department of Agricultural Economics. 2009. Cotton 2009 Planning Budgets. Accessed November 21, 2009. Mississippi State, Miss.: Mississippi State University.
- Monsanto. All About Cotton. Available at: [http://www.monsanto.com/products/seeds\\_traits/cotton/about\\_cotton.asp](http://www.monsanto.com/products/seeds_traits/cotton/about_cotton.asp). Accessed 4/19/2010.
- Museum, Tractor. Test 1446: Allis-Chalmers and Deutz-Allis 8010 Powershift Diesel 12-Speed. 1982. *Nebraska Tractor Tests*. Paper 1761.
- Palmer, A.L. 1992. Development of a Three-Point-Linkage Dynamometer for Tillage Research. *J. agric. Engng Res.* 52: 157-167.
- Pollock, C. and R. Reeder. 2010. No-Till: Plenty of Positives. *Resource* 17(1): 4-7.
- Prevention and Control of Palmer amaranth in Cotton - Virginia Cooperative Extension Available at: <http://pubs.ext.vt.edu/2805/2805-1001/2805-1001.html>. Accessed 12/2/2009.
- Upadhyaya, S. K., L. J. Kemble, N. E. Collins and F. A. Camargo, Jr. 1985. Accuracy of mounted implement draft prediction using strain gages mounted directly on three-point hitch linkage system. *Transactions of the ASAE* 28(1):40-46, 50.
- USDA. 2008. National Resources Conservation Services. USDA-NRCS Energy Estimator for Tillage. Washington , D.C. Available at: <http://ecat.sc.egov.usda.gov/Default.aspx>. Accessed 4/19/2010.
- USDA-NASS. 2008. North Carolina Agriculture Statistics. Raleigh, NC: USDA National Agricultural Statistics Service.
- Zoerb, G. C, N. G. Musunda and R. L. Kushwaha. 1983. A combined drawbar pin and force transducer. *Can. Agricultural Engineering* 25(2): 157-161.