ABSTRACT

MAYER, MICHELLE LYNNE. Assessment of Bioenergy Crop Production Potential for North Carolina Department of Transportation Highway Rights-of-Way. (Under the direction of Dr. Matthew Veal).

As the competition between energy crops and food crops for agricultural land continues to intensify, it is becoming increasingly important to utilize non-agricultural land for energy crop production. In a similar effort, the North Carolina Department of Transportation (NCDOT) sponsored a two-year project involving the cultivation of oilseed crops along North Carolina highway rights-of-way (ROWs) for ultimate conversion to biodiesel and use in their fleet of motor vehicles. While various oilseed crops have proven to be viable feedstock for renewable fuel production in the United States, their suitability for production in the highly eroded, highly compacted, low nutrient soils of North Carolina highway ROWs has not been evaluated. Therefore, the goal of this research was to evaluate the feasibility of maintaining a sustainable oilseed crop production system on these non-agricultural soils of NCDOT highway ROWs for utilization as a source of feedstock for producing the biodiesel fuel. To achieve this goal, objectives were established to (1) evaluate oilseed crop requirements and eligibility for production based on North Carolina’s climatic conditions and highway rights-of-way characteristics; (2) perform a series of plot trials to select an optimal tillage method (3) develop a GIS program to quantify and map eligible NCDOT highway ROW acreage based on seasonal rainfall and temperature observations, ROW widths and slopes, highway characteristics and adjacent traffic volumes, and wildlife and motorist safety regulations.

Beginning in June 2009 and concluding in June 2011, research was conducted in five locations in North Carolina. Experimental sites were established in Faison, Knightdale, Mount Airy, Pittsboro, and Rutherfordton. Depending upon location, canola (*Brassica napus L.*), safflower (*Carthamus tinctorius*), and sunflower (*Helianthus annuus)* were cultivated in rotation under one or three different tillage methods (maximum tillage, minimum tillage, and no-till). Seed yields were evaluated to determine main and interaction effects among tillage, location, and year of cultivation (initial cultivation versus subsequent cultivation) on crop productivity in a three × three × two factorial experiment.

For both 2009 and 2010 planting seasons, year and site displayed significant effects on seed yield, while tillage treatment showed a significant influence only when comparing maximum to no-tillage and minimum to no-tillage treatments in 2010 plantings. Interactions of site × tillage, tillage × year, and site × tillage × year did not show significant effect in either planting season; however, the effects of site × year interactions were significant, and all plots observed significantly higher yields in the second year of harvest as compared with initial cultivations. In 2009, the maximum tillage treatment produced the highest average yields [1241 kg ha^{-1}] followed by minimum tillage [926 kg ha^{-1}] and no-till [858 kg ha^{-1}], respectively. However, in the second year, the comparative intensity of productive effects from maximum tillage was lower, and plots cultivated under the minimum tillage treatment resulted in the highest average yields of 2698 kg ha^{-1}, followed sequentially by maximum tillage and no-tillage, at 2687 kg ha^{-1} and 1906 kg ha^{-1}, respectively.

Recommendation of an initial deep tillage treatment followed by subsequent no-till practices for canola cultivation was supported by an evaluation of economics typical of these tillage practices and a lack of significant difference between yields observed from maximum versus minimum tillage. Additional investigation is needed to verify that increased productivity in subsequent seasons could be attributed wholly to productive effects of a

single deep tillage treatment on soil structure and reinforced by ability of canola’s rooting system to break up compaction and return nutrients to the soil. Based upon a derived equation for ROW eligibility, GIS analysis was utilized in identifying 24,079 km of eligible ROW, thus totaling approximately 7,340 ha of total eligible land base.

Assessment of Bioenergy Crop Production Feasibility along North Carolina Department of Transportation Highway Rights-of-Way

by
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DEDICATION

To Mom and Dad and Emily and Philip

BIOGRAPHY

Michelle Lynne Mayer was born in Houston, Texas on January 3, 1985, to the two most wonderful, supportive, and humorous parents, and best big sister, and soon-to-be (2 years later) little brother for which a girl could ever ask. After moving from Texas to Tampa, Florida then Marietta, Georgia in just a few short years, the Mayer family finally settled for a while in beautiful Lake Guntersville, Alabama. They soon learned that when you move to Alabama, the first thing “y’all” do is pick a college football team. Luckily, Dad picked Auburn. So, upon graduating from high school, of course Michelle headed off to “God’s Country” to begin her undergraduate career at Auburn University, thereby validating her lifelong love of the Auburn Tigers.

While studying civil engineering (the fifth of six choices of majors) at Auburn, Michelle became interested in bioenergy research. After visiting with professors in the Biosystems Engineering Department and being afforded the opportunity to live and conduct research in Freising, Germany, she became convinced “Going Green” was the only way to go, and she joined the Biosystems crew immediately upon return to the States. Upon another joyous graduation in the great state of Alabama, Michelle decided to continue her education and travels, and by luck or grace of God, was granted an amazing opportunity to work for a fellow Auburn Tiger and a group of wonderful engineers and personnel at the North Carolina Department of Transportation and North Carolina State University on a bioenergy research project. And, thus, this thesis is produced. Following graduation, Michelle will continue pursuing her love of research through collaborating on a bio jet fuel research project with NCSU and the U.S. Department of Energy Advanced Research Projects Agency – Energy.

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CHAPTER 1 BACKGROUND AND REVIEW OF LITERATURE

1.1 Need for Renewably-Sourced Transportation Fuels

Motivated by the ubiquitous pursuits for technological advancement and compounded by unprecedented world population growth, energy demands continue to rise on a global scale. Consequently, the non-renewable fossil fuels which historically and currently constitute the majority of that energy source are being depleted at an insurmountable rate. In 2009, worldwide oil consumption totaled 30.7 billion barrels (bbs), representing a demand that is expected to continue to rise, reaching a projected 36.1 bbs annually by the year 2035 (WEO, 2010). In 2010, there existed only a total of 1,354 bbs of petroleum oil (the non-renewing fossil fuel and main source from which gasoline and diesel transportation fuels are derived) in the proved world reserves (IEO-a, 2010). As the exploitation of fossil fuels for energy production proceeds, the need for production of fuels from renewable sources emerges in paramount importance not only to improve environmental impact but also to ensure national economic independence.

In 2007, the transportation sector accounted for the 27% of the world energy demand, second only to the industrial sector at 51% and followed by residential at 14% and commercial at 7% (IEO-b, 2010). The world energy demand is projected to increase by 1.3 percent annually until 2035, primarily driven by energy use associated with heavy-duty trucking operations (EIO, 2010). Of the total energy consumption, 26,327 trillion BTUs were produced by use of non-renewable fossil fuels, while only 1,098 trillion BTUs were supplied by renewable resources (EIA, 2011). Furthermore, 56.6% of the world supply (754.2 bbs) is controlled by Middle Eastern countries including Saudi Arabia, Iraq, Iran, Kuwait, etc. (BP, 2010). In 2009, the United States controlled only 28.4 bbs (2.1% of the global supply) and consumed 6.82 bbs that year alone (BP, 2010). This circumstance of the majority of world petroleum reserves being centrally controlled creates a virtual monopoly of these resources and compromises the economic well-being of countries such as ours. Because of deficits such as these and our continued growing demand for transportation fuels, our nation's energy and economic security have been threatened by our dependence upon foreign sources of oil. However, given the abundance of opportunities for the production of renewable energy resources throughout the United States, this dependency unnecessarily debilitates our national homeland security and economic prosperity.

To promote national economic independence, federal mandates and incentives have been established to decrease consumption of petroleum-based fuels and increase the use of renewable fuels in the United States. The Energy Policy Act of 2005 required that 7.5 billion gallons of fuel produced from renewable resources be added to gasoline blends by 2012 (RFS, 2011), and the Energy Independence and Security Act (EISA) of 2007 extended the mandate to require 36 billion gallons of renewable fuel be added to gasoline and diesel blends by 2022 (RFS, 2011).

To help meet these progressive mandates, biodiesel production in the United States is being facilitated with edible vegetable oil as its main source. Such oil is produced by oilseed crops including canola, safflower, soybeans, and sunflower (NCAT, 2006). These types of crops are highly suited for domestic production and provide various environmental benefits inherent in their cultivation.

In addition to economic growth, the federal government is focused on reducing our negative environmental impact. Petroleum-derived gasoline and diesel fuels produce gaseous emissions having hazardous effects on air quality and other environmental health issues (Van Dyne and Raymer, 1992), and there is an urgent need for nationwide implementation of sustainable systems for the production of cleaner-burning fuels. The United States currently controls production of approximately 423 million tonnes of biomass (Milbrandt, 2005), included in which is an amount of feedstock sufficient to support the production of 1.7 billion gallons of biodiesel fuel annually (EERE, 2010). Reaching such production capacity would negate 5% of the use of petroleum-derived diesel fuel each year (EERE, 2010). This represents the potential for a substantial offset; however, it is critical that additional programs be developed to encourage and facilitate an advanced level of clean, renewable fuel production.

1.2 Utilization of Marginal Land for Bioenergy Crop Production

With our nation operating under the current status of energy and economic crises, there have been numerous ventures enacted to facilitate the production of renewable energy resources to bolster economic independence and negate harmful environmental impact. However, widespread implementation of renewable fuel production operations is inhibited by sociopolitical controversies that have arisen targeting the use of agricultural land for production of bioenergy feedstock rather than food sources. As a result, the utilization of agriculturally marginal land is emerging as an attractive alternative for producing energy crops.

Marginal lands are not currently managed for agricultural purposes, may have poor or contaminated soils or terrain conditions, but may be capable of supporting plant growth (Tang et al., 2010; Bardos et al., 2008). While these types of soils may be inappropriate for food-grade crop production, characteristic lands may be suitable for production of feedstock with end-uses such as the production of biofuels (Bardos et al., 2008; Bhardwaj et al., 2011). In poor or developing countries, marginal lands have been exploited as cropland and have successfully supported numerous types of bioenergy feedstock including cassava, corn, jatropha, sorghum, sugarcane, and sweet potatoes (Braun and Pachauri, 2006; Qui et. al, 2011). Similarly, crops such as wheat and alfalfa have been cultivated along highway rights-of-way (ROWs) for hay-harvesting operations in several states in the throughout the United States. Even furthermore, certain types of bioenergy feedstock, such as oilseed crops, have production characteristics that make them more adaptable to the unfavorable soil conditions of agriculturally marginal land (Bhardwaj et al., 2011).

1.3 Oilseed Crop Characteristics and Production Requirements

Biodiesel fuels derived from oilseed crops such as canola, sunflowers, safflower, and soybeans provide enhanced air quality emissions, are non-toxic, and are more biodegradable than petroleum-based diesel fuels (Van Dyne and Raymer, 1992). These types of oilseed crops hold the potential to produce significant amounts of biodiesel to offset fossil fuel use in the United States (Auld et al., 1991; Kurki et al., 2006; Van Dyne and Raymer, 1992). Soybeans currently serve as the primary source of feedstock for the U S. biodiesel industry, accounting for approximately 90% of its production (Kurki et al., 2006). Contributing factors to the popular use of soybeans include their ability to fix nitrogen, marketability as a food source, and ready availability as a byproduct from the high-demand production of soybean meal (Kurki et al, 2006). However, due to their comparatively low oil content versus oilseeds such as canola, sunflower, and safflower, an alternative crop may prove to be a more advantageous feedstock for biodiesel production.

Canola, a cool season crop and low-acid, edible cultivar of rapeseed (*Brassica napus L*), provides numerous soil-building benefits, also may be marketed for human consumption and livestock feed, and produces seeds with 40% oil content compared to soybeans' 18.5% (Kurki et al., 2006; Maier et al., 1998) This makes canola a highly desirable rotation crop as well as the highest oil-yielding oilseed crop in the United States, averaging an oil yield of 1,141 L ha^{-1} (122 gal ac^{-1}) (Kurki et al., 2006). Safflower and sunflower, both warm season crops, also offer excellent sources for biodiesel production, holding the potential to produce 98 and 80 (gal ac^{-1}) each year, respectively (Kurki et al., 2006). These crops provide environmental benefits similar to those of canola, and all of the crops produce valuable by-products that may be profitable in other markets, including renewable energy industries.

In addition to its suitability for biodiesel production, canola provides other valuable environmental benefits including replenishment of plant-available water and nutrients, reduction of soil-borne diseases and pathogens, and enhancement of weed and erosion control (Canola Council of Canada, 2003; Kurki et al., 2006). Furthermore, the amount of carbon dioxide released with the burning of canola-derived biodiesel is offset by the requirement of the plant to incorporate CO_2 into its growth cycle, thereby inherently reducing harmful emissions into the biosphere (Canola Council of Canada, 2011).

Specific to the interests of this study, North Carolina has been found to produce the second highest oil yield compared with all experimental sites in the southeastern U.S. based on research conducted by Van Dyne and Raymer (1992). Furthermore, efforts equivalent to those for maintaining of one-half of the current winter wheat production in North Carolina hold the potential to produce in excess of 113.5 million liters (30 million gallons) of oil annually (NCCP, 2007). Findings such as these suggest that the climatic conditions and soil properties in North Carolina are highly compatible with canola production requirements and could support a sustainable biodiesel production program with canola targeted as the main feedstock.

1.4 Agricultural Operations in Highway Rights-of-Way

Hay-harvesting operations historically have been performed along DOT highway rights-of-way in several states in the western United States. When performing agricultural operations such as these in close proximity to highly trafficked highways, it is important to consider human and wildlife safety, maintenance requirements, visual appeal, sustainability, and cost-effectiveness (KDOT, 2008; NCDOT, 2011). The Bureau of Construction and Maintenance of the Kansas Department of Transportation prohibits mowing within a distance of 8' of traveled lanes; on slopes equal to or greater than 3:1, highly erodible slopes, or waterways; in areas designated for wildlife, wildflowers, or wetlands; and on medians, interchange quadrants, or rest areas (KDOT, 2009). Furthermore, the NCDOT provides detailed guidelines for establishing ground vegetation, shrubbery, and trees within close proximity of NCDOT highway ROWs (NCDOT, 2011). For the purposes of this project, NCDOT may benefit from observing similar safety regulations; however, since the operations will be more centrally supervised, it may be reasonable and advantageous to alter or reduce the restrictions, particularly for restricted areas of medians, interchanges, and rest areas.

1.5 Right-of-Way Soil Properties

The soils found in highway ROWs are not naturally-occurring in those locations, but have been redistributed from adjacent construction areas or nearby "borrow pits" following roadway construction (Booze-Daniels et al., 2000; Rentch et al., 2005). As a result, several different soil types may be present in the uppermost layers of the soil, soil properties may vary greatly over a short distance, and soils may be highly compacted due to heavy construction machinery traffic. Such soil characteristics render highway ROWs particularly difficult areas for which to plan vegetative establishment since the land may be subject to disturbance over long, narrow strips that may span numerous different soil and topological properties, each requiring site-specific management for optimal productivity (Booze-Daniels et al., 2000). Additionally, since the surface layers of the ROWs have been redistributed from highly disturbed soils of construction sites, their profiles to lack the true topsoil materials of traditional cropland. Booze-Daniels et al. (2000) indicate that upon redistribution, these soils are typically highly compacted, deeply extracted, and unevenly mixed subsoils with low air- and water-filled porosity, low organic matter, and low nutrient content; however, when properly graded and amended, subsoil may actually prove more suitable for vegetative production than naturally occurring topsoil. This is due to the fact that subsoil has higher clay content and lower silt content than topsoil, thus holding the potential to reduce runoff, increase water infiltration, and increase plant-available water for enhanced crop growth (Booze-Daniels et al., 2000). Similarly, compaction on sandy soils actually may increase the soil's water and nutrient retention capacities, thereby increasing plant available water and reducing nutrient leaching (Lipiec and Stepniewski, 1995).

1.6 Soil Compaction and Tillage Effects on Soil Properties and Crop Production

1.6.1 *Effects of Compaction on Soil Properties*

The severe compaction on highway ROWs is similar to that of surface-mined land which is found to have post-mining bulk density of 1.7 to 1.8 Mg m^{-3} and penetration resistance between 2.0 and 2.5 MPa (Dunker and Barnhisel, 2000). Dunker et al. (1995)

indicate that penetration resistance, which is a measure of soil strength and inversely related to soil moisture content (Williams and Weil, 2004), is a much more indicative measure of soil compaction than bulk density. According to Trukmann et al. (2008) and Hanna and Al-Kaisi (2009), the high compaction due to excessive agricultural traffic on highway ROWs has a negative effect on soil physical properties such as moisture content, air-filled porosity, and hydraulic conductivity. Conversely, tillage treatments unsuitable for specific soils and crops may cause unnecessary soil moisture loss, organic matter loss, soil structure degradation, and soil erosion issues (Canola Council of Canada, 2003).

Hanna and Al-Kaisi (2009) indicate that the harmful effects of compaction can be negated if factors such as soil moisture content, amount of rainfall, and fertilization are maximized for plant-specific cultivation requirements. However, if optimal conditions like increased rainfall and sufficient fertilization are infeasible, then measures such as loosening of the soil by natural means, such as strong taproots loosening hard pan, or tillage often must be performed to alleviate soil compaction for increased crop productivity (Botta et al., 2006; Chan et al., 2005; Williams and Weil, 2004).

1.6.2 *Descriptions and Implications of Tillage Methods*

Commonly implemented tillage practices to alleviate compaction include conventional tillage (CT), deep tillage (DT), minimum tillage (MT), and no-tillage (NT). Conventional tillage typically is characterized by shallow depths of soil disturbance limited to less than 30 cm. Deep tillage (including practices such as subsoiling and chisel plowing) involves more intense soil structure disturbances to greater soil depths, and therefore if performed improperly or scheduled poorly, may increase soil moisture loss. Due to the increased level of machinery use, CT and DT methods both carry considerably higher costs for implementation than do MT and NT methods. While MT incurs relatively lower cost requirements, these methods may provide insufficient compaction relief and aeration, depending upon the pre-existing soil conditions. No-tillage practices involve planting directly into the soil through any existing ground cover, thus providing minimal compaction relief but also the holding the potential to preserve soil moisture and increase soil erosion control.   The energy expenditures and labor requirements to perform no-till treatments are minimal, thus accounting for the benefit of lowest input costs compared with all other tillage methods.

1.6.3 *Effects of Compaction on Oilseed Crop Productivity*

Botta et al. (2006) and Riechert et al. (2009) indicate that it is difficult to compare the complex effects of soil compaction on the productivity of various crops because there are multiple factors affecting crop productivity including soil physical properties, climatic conditions, growing season, cultivation scheduling, and nutrient management. Williams and Weil (2004) observed that canola roots were able to penetrate compacted silt loam soils having bulk density of 1.55 – 1.61 Mg m^{-3} and penetration resistance of 2.2 – 2.25 MPa. However, Hamza and Anderson (2005) indicate that plant root penetration is severely restricted at soil strength greater than 2 MPa, and Dunker and Barnhisel (2000) recommend maximum critical bulk densities of 1.6 Mg m^{-3} and 1.75 Mg m^{-3} for successful root penetration in clay and sand soils, respectively.

Chan et al. (2005) found that canola experienced a 34% reduction in yield on compacted Vertisol sodic brown clay soil with bulk density between 1.5 and 1.58 Mg m^{-3} and penetration resistance of greater than 2 MPa compared with canola yield on soil not trafficked by the tractor wheel. Deep ripping increased the grain yield by 20% from 2.0 to 2.4 t ha^{-1} (Chan et al., 2005). Similarly, Malhi and Lemki (2007) reported that CT on a Gray Luvisol soil had a significant positive effect on canola seed yield compared with NT (2082 kg ha^{-1} vs. 1909 kg ha^{-1}); however DT practices were not evaluated.

Through this review of literature, it is evident that satisfactory results have been achieved when applying various tillage methods to soils displaying a diverse array physical properties and compaction levels. Deep tillage on highly compacted, mined land has proven successful in experimental research and has resulted in increased yield of corn, wheat, soybean, and grain sorghum on test plots in southern Illinois (Dunker et al., 1995). Chan et al. (2005), Dunker and Barnhisel (2000) Malhi and Lemki (2007), and Torabi (2007) all reported positive effects of CT or DT over MT and NT for canola or soybean yield, and all of the soils under observation had substantial clay content. Contrastingly, Williams and Weil (2004) report no significant effect of CT or DT over NT practices, and their experiments were conducted on silt loam soils. From these observations, it can be concluded that soils lacking substantial clay content are less susceptible to productive results from CT and DT practices than those soils carrying high clay content. Dunker and Barnhisel (2000) attribute the success of crop yield in deeply tilled mined clay soil to increased porosity and water-holding capacity, providing a possible explanation for the contrasting results of tillage on silt loams compared with clayey soils.

Similarly, Hamza and Anderson (2005) and Jayawardane and Chan (1994) indicate that the strong taproot system of safflower can provide alleviation of compaction in clay soils. Trukmann et al. concluded that spring canola is suitable for production in compacted soil due to the ability of the large taproots of canola to break up hardpan and penetrate compacted layers (Kurki, 2006; Williams and Weil, 2004). Furthermore, Williams and Weil (2004) found that, when planted after canola, soybean root growth followed in the root channels of the preceding canola crop, even in highly compacted soil. The authors indicated that this allowed for penetration of soybean roots to subsoil layers having more plant-available water than topsoil. This type of compaction relief also may provide for successful canola seedling emergence if canola is planted in rotation with safflower on soils having similar properties and prevent the need for energy-expending tillage.

Considering the contradictory results from Williams and Weil (2004) versus Chan et al. (2005) and Malhi and Lemki (2007), a question lies in whether, or to what extent, compaction affects the rooting system based on soil type. Reichert et al. (2008) suggested that an increase in yield under DT could be attributed to the sensitivity of canola’s taproot system to soil compaction, since the characteristics of rooting systems of crops and cultivars greatly affect response to soil compaction. However, it is recommended that, for optimal yields, canola should be sown into a firm seedbed to allow immediate contact of the seed with moisture in the soil (NCCP, 2007).

Trukmann et al. (2008) found that canola root and shoot mass in compacted soils increased significantly under un-compacted soils when the incident rainfall for that growing season was unusually high, but decreased under compaction in the second year of planting when rainfall was typical to the region. This discrepancy may support the assertion by Hanna and Al-Kaisi (2009) that substantial rainfall and increased soil moisture may compensate for the negative effects of compaction. In total, these findings may be indicative of the need for site-specific management when selecting a tillage method since ROW soils commonly are an amalgamation of many different soil types.

1.6.4 *Effects of Tillage on Soil Properties and Oilseed Crops*

Botta et al. (2006) and Riechert et al. (2009) affirm that it is difficult to identify the specific effects of soil compaction on the productivity of various crops since there are multiple factors affecting crop productivity. Similarly, it may be difficult to identify the most optimal tillage practice for a given soil due to differing plant-soil requirements and season of crop cultivation.

Botta et al. (2006) indicated that subsoiling and chisel plowing significantly reduced compaction on soil with unloosened soil strength of 1.91 MPa at 300 mm depth; highest sunflower yields were found under subsoiling (4400 kg ha^{-1}) followed by chisel plowing (3100 kg ha^{-1}) and NT (2230 kg ha^{-1}). Dunker and Barnhisel (2000) found that DT also significantly increased soybean yield when performed to a depth of 90 -120 cm on severely compacted soil. Williams and Weil (2004) found that heavy tillage at 30 cm depth had no effect on soybean yield, although the majority of soybean roots remain in the top 15-30 cm of soil (McWilliams et al., 2004). These contradictory results support the assertion by Dunker et al. (1995) that optimal depth of tillage is dependent upon the initial soil strength and has a considerable effect on crop yield.

Torabi et al. (2007) found that canola yield and oil production were highest under CT compared with MT and NT treatments. However, they suggest that it may be more advantageous to plant the seeds earlier in the growing season (early to mid-September rather than early to late October) and utilize MT or NT practices. Bonari et al. (1994) and Torabi et al. (2007) support this suggestion in asserting that the combination of increased yield resulting from early planting dates with the economic advantage of practicing MT or NT may outweigh the sole benefit of increased yield under CT.

As is evident from the findings in research evaluated in the review, tillage treatments should be designed based on assessment of site-specific soil conditions and relevant crop requirements to maximize productivity. Soil properties (including soil type and texture, bulk density, and penetrometer resistance) should be evaluated for targeted land before management practices are implemented. Degree and depth of compaction should be considered for selection of a tillage practice that will maximize productive yield while minimizing costs. Climatic conditions also will be taken into consideration since factors such as rainfall and temperature are shown to greatly affect soil properties and tillage requirements (Hanna and Al-Kaisi; 2009). Similarly, the time of year for which tillage is performed should be considered since DT during exceedingly hot, dry months could cause unnecessary soil moisture depletion (Canola Council of Canada, 2003).

Furthermore, tillage effects must be “immediate and permanent” if they are to be beneficial to production (Dunker et al., 1995). Karunatilake and van Es (2002) indicate that, although CT increases soil porosity upon loosening, the ability of the soil to maintain this benefit is influenced by the soil structural stability, the rainfall pattern over the growing season, and the frequency and intensity of incident agricultural traffic following tillage. Chan et al. (2005), Hamza et al. (2005), and Botta et al. (2006) found that a significant degree of re-compaction occurred within two years of conventional tillage when the soil experienced agricultural machinery traffic.

These indications of transient tillage benefits and the requirement for repeat tillage treatments may further encourage the use of NT practices over CT if compaction is not severely limiting to root growth; otherwise DT may be more advantageous since it has proven to produce persistent results. For instance, Vazquez et al. (1988) observed a greater reduction in soil penetration resistance when subsoiling (a special form of DT) was performed with NT compared with CT even when penetration resistance exceeded 2.5 MPa. Furthermore, Booze-Daniels et al. (2000) indicate that the use of NT seeders eliminates the need for tillage, reduces erosion control issues, and has proven successful in establishing wildflower plots along North Carolina ROWs. This is a promising indication that at least certain areas of the North Carolina ROWs may be suitable to reap the benefits of NT practices.

1.6.5 *Energy Requirements and Economics of Tillage Methods*

Gilandeh et al. (2006) suggest implementation of site-specific tillage (SST) to reduce energy expenditures; with these practices, they found a 50% reduction in energy requirement and a 30% reduction in fuel consumption for SST over uniform depth conventional tillage (UDCT) in a loamy sand soil. On Faceville loamy sand, Fuquay sandy loam soil types, and Lakeland sandy soil types, the researchers observed energy requirements of 1.099 kW-hr for SST and 2.219 kW-hr for UDCT at 46 cm; 1.185 kW-hr for SST and 1.49 kW-hr for UDCT; and 0.712 kW-hr for SST and 0.963 kW-hr for UDCT, respectively. Botta et al. (2006) observed an efficiency of only 13.6 $m^3 MJ^{-1}$ for chisel plowing at depth 280 mm and 55.4 $m^3 MJ^{-1}$ for subsoiling, and Vazquez et al. (1988) indicate that CT requires an energy expenditure of approximately 180% of that for NT (2900 MJ ha^{-1} for CT and 1600 MJ ha^{-1} for NT).

Such findings indicate considerable energy savings over CT practices. Furthermore, since the targeted ROW soils are largely composed of sandy soils and will not be irrigated, the energy savings from NT may be more profitable than incorporating CT into the management process (Vazquez et al., 1998). For example, recall the findings of Torabi et al. (2007) that canola yield and oil production were highest under CT over MT and NT. Despite this, they suggested planting seeds earlier in the growing season (early to mid-September rather than early to late October) and utilizing MT or NT practices to realize the benefits of increased yield from early planting dates and the economic advantage of practicing MT.

1.7 Need and Benefit for North Carolina Department of Transportation

The NCDOT maintains a proactive approach to incorporating the use of renewable fuels in their fleet of motor vehicles (Veal, 2009). The agency also reserves a large portion of their budget for the substantially high costs associated with mowing and maintenance of highway ROWs. Approximately $15 million is allocated for maintenance of the NCDOT's system of highways annually (NCDOT, 2010). Large-scale intra-agency production of renewable fuel would provide an avenue for the NCDOT to reduce fuel and maintenance costs substantially while improving their environmental impact and meeting federal mandates requiring the use of fuels from renewable resources.

1.8 Statement of Objectives

To support the ventures for practical utilization of marginal land for energy crop production, the North Carolina Department of Transportation (NCDOT) sponsored a two-year research study beginning in May 2009 and involving the production of various oilseed crops on their rights-of-way (ROWs) for the ultimate conversion to biodiesel and use in fueling their fleet of diesel motor vehicles.

The goal of the research was to evaluate the feasibility of maintaining a sustainable oilseed crop production system on NCDOT-owned, marginal land for utilization as a source of feedstock for producing biodiesel for the agency's motor fleet. To achieve this goal, objectives were established to (1) produce a GIS program to identify and map eligible NCDOT highway ROWs based on average seasonal rainfall and temperature observances, ROW widths and slopes, adjacent traffic volumes, and wildlife/motorist safety regulations; (2) evaluate oilseed crop requirements and eligibility for production based on N.C. regional climate conditions and ROW conditions; and (3) perform a series of plot trials to select an optimal tillage method based on level of soil compaction in ROWs, oilseed production requirements, observed crop yield, energy input requirements, and observed biodiesel yield.

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CHAPTER 2 PRODUCTION OF OILSEED CROPS ON MARGINAL LAND

2.1 Introduction

2.1.1 *Characteristics of Marginal Lands*

With the growing demand for production of domestic, renewable feedstock and the rising controversies regarding the competition between food and energy crops for agricultural land, the utilization of agriculturally marginal land is emerging as an attractive alternative for producing energy crops (Tang et al., 2010; Bardos et al., 2008). By definition, marginal lands may have nutrient-poor soils, contaminated soils, or poor terrain conditions and thus are not commonly managed for agricultural purposes; however, these lands may be capable of sustaining satisfactory plant growth for certain applications (Tang et al., 2010; Bardos et al., 2008). Reclaimed strip minefields and highway rights-of-way represent examples of agriculturally marginal land, and while the soils in these land areas may be inappropriate for food-grade crop production, they hold potential for supporting growth of feedstock with end-uses such as the production of biofuels, thus nullifying the displacement of food crops from agricultural farmland (Bardos et al., 2008; Bhardwaj et al., 2011).

2.1.2 *Applications for Oilseeds Grown on Marginal Lands*

Historically, in poor or developing countries, marginal lands have been adapted as cropland and have supported numerous types of bioenergy feedstock successfully, including cassava, corn, jatropha, sorghum, sugarcane, and sweet potatoes (Braun and Pachauri, 2006; Qui et. al, 2011). Similarly, crops such as wheat and alfalfa have been cultivated along highway rights-of-way (ROWs) for hay-harvesting operations in several states throughout the U.S. Furthermore, certain types of bioenergy feedstock, such as oilseed crops, possess production characteristics that make them especially adaptable to the unfavorable soil conditions of agriculturally marginal land (Bhardwaj et al., 2011). In particular, canola, a cool season oilseed, has various soil-building properties, strong taproots capable of penetrating highly compacted soils, and ground cover characteristics for inhibiting weed growth and enhancing erosion control (Canola Council of Canada, 2003; Kurki et al., 2006). In addition to its valuable environmental benefits, canola and its byproducts are marketable for several types of applications, including human and animal consumption, cosmetics or pharmaceuticals composition, and biodiesel production.

The soils found in highway ROWs are not natively occurring in these locations, but have been redistributed from adjacent construction areas or nearby “borrow pits” following roadway construction (Booze-Daniels et al., 2000; Rentch et al., 2005). As a result, several different soil types may be present in the uppermost layers of the soil, soil properties may vary greatly over a short distance, and soils may be highly compacted due to heavy construction machinery traffic. Such soil characteristics render highway ROWs particularly difficult areas for which to plan vegetative establishment since the land may be subject to disturbance over long, narrow strips that may span numerous different soil and topological properties, each requiring site-specific management for optimal productivity (Booze-Daniels et al., 2000). Additionally, since the surface layers of the ROWs have been redistributed from highly disturbed soils of construction sites, their profiles to lack the true topsoil materials of traditional cropland. Booze-Daniels et al. (2000) indicate that upon redistribution, these soils are typically highly compacted, deeply extracted, and unevenly mixed subsoils with low air- and water-filled porosity, low organic matter, and low nutrient content; however, when properly graded and amended, subsoil may actually prove more suitable for vegetative production than naturally occurring topsoil.

However, tillage effects must be “immediate and permanent” if they are to be beneficial to production (Dunker et al., 1995). Karunatilake and van Es (2002) indicate that, although CT increases soil porosity upon loosening, the ability of the soil to maintain this benefit is influenced by the soil structural stability, the rainfall pattern over the growing season, and the frequency and intensity of incident agricultural traffic following tillage. Chan et al. (2005), Hamza et al. (2005), and Botta et al. (2006) found supporting evidence that a significant degree of re-compaction occurred within two years of conventional tillage when the soil experienced agricultural machinery traffic. Furthermore, since the targeted ROW soils may be composed largely of sandy and clayey soils in some locations and will not be irrigated, the energy savings from NT may be more profitable than incorporating CT into the management process (Vazquez et al., 1998). For example, recall the findings of Torabi et al. (2007) that canola yield and oil production were highest under CT over MT and NT. Despite this, they suggested planting seeds earlier in the growing season (early to mid-September rather than early to late October) and utilizing MT or NT practices to realize the benefits of increased yield from early planting dates and the economic advantage of practicing MT.

These indications of transient tillage benefits and the requirement for repeat tillage treatments may further encourage the use of NT practices over CT if compaction is not severely limiting to root growth; otherwise DT may be more advantageous since it has proven to produce persistent results. For instance, Vazquez et al. (1988) observed a greater reduction in soil penetration resistance when subsoiling (a special form of DT) was performed with NT compared with CT even when penetration resistance exceeded 2.5 MPa. Furthermore, Booze-Daniels et al. (2000) indicate that the use of NT seeders eliminates the need for tillage, reduces erosion control issues, and has proven successful in establishing wildflower plots along North Carolina ROWs. These all are promising indications that at least certain areas of the North Carolina ROWs may be suitable to reap the benefits of NT practices.

2.2 Materials and Methods

2.2.1 *Experimental Design*

The experiment consisted of a complete, crossed balanced blocking design with factorial combination of location (3 levels—Faison, Knightdale, and Mount Airy), tillage treatment (3 levels—maximum, minimum, and no-till), and year (2 years—2009 and 2010). Tillage treatments were performed in triplicate at each site and were considered to be completely randomized for purposes of statistical analysis. However the NC Department of Transportation road crews initiated plot establishment and planting prior to statistical design approval by authors; therefore, there were limitations to authors' control of the design and some systematic assignment of tillage treatment was made to plots in Faison and Mount Airy whereas plots in Knightdale were assigned randomly (Figure 2.1a-c).

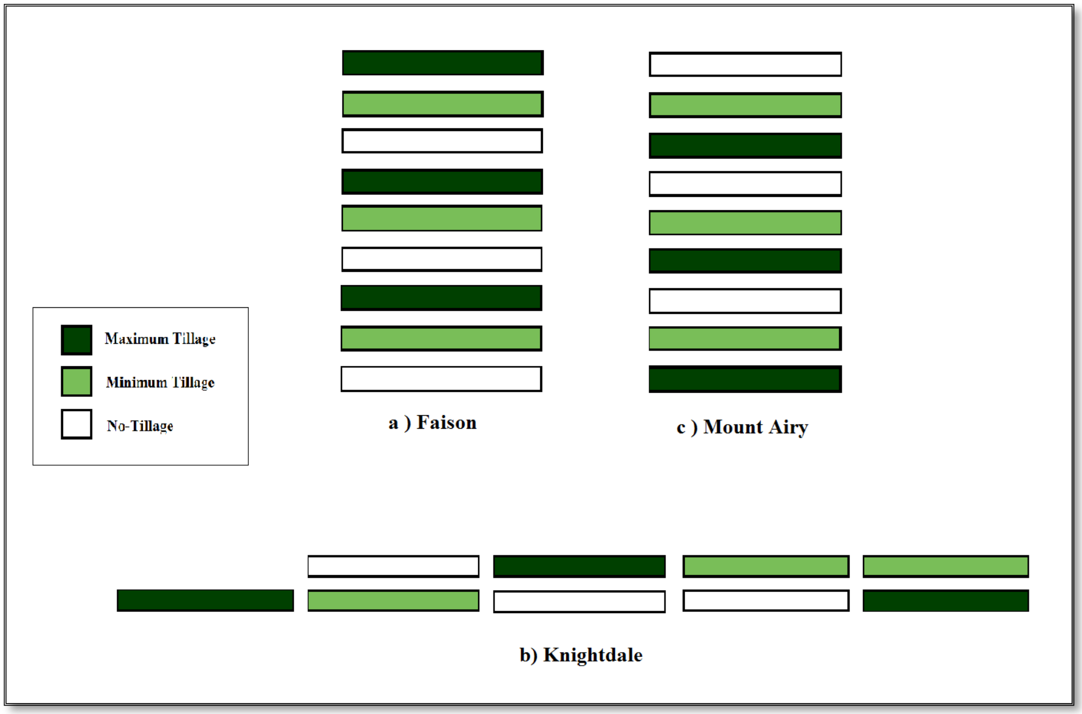

Figure 2.1 Experimental plot layouts for a) Faison, b) Knightdale, and c) Mount Airy

2.2.2 *Site Descriptions*

Beginning in mid-June 2009, a two-year field study was conducted in the Inner Coastal Plains, Mountain, and Piedmont regions of North Carolina to assess the effects of different climates, topography, and soil types on canola production along highway rights of way (ROWs). Experimental plots were established in highway ROW soils in Faison, Knightdale, and Mount Airy.

2.2.2.1. *Faison, Duplin County, N.C.*

The experimental site of the Inner Coastal Plain region was located in the northwestern corner of Duplin County, N.C. along the intersection of Highway NC 50 and Highway NC 403 in Faison (35^{o}07'N, 78^{o}09'W) (Figure A1.1). See Appendix A1 for aerial imagery indicating location of each research site. The original plot layout in Faison consisted of nine 3.05 m x 60.96 m (10 ft x 200 ft) plots spaced 3.05 m apart arranged in parallel with Highway NC 50 (Figure 2.1a. The 2009 cultivations were performed according to the plot layout at the base of a low hill on a field that appeared to have flooding or drainage issues near its center (Figure A1.1). In the 2010 planting season, the configurations of plots 3 and 7 were altered from the original design as presented in Figure 2.1b to avoid poorly drained areas in the field. While tillage treatment was held constant to assigned plots, in the second year of planting, spacing between plots was reduced to 1.5 m (5 ft) between the nine plots arranged parallel to Highway NC 50 for October 2010 canola planting. The seedbed was one previously cultivated for wildflower production in accordance with the NCDOT Wildflower Program wildflower cultivation practices (NCDOT, 2011). Wildflower bed soils have been worked previously through agricultural operations including tillage and nutrient restoration to remediate typical ROW soils to reflect properties more similar to agricultural cropland soils.

2.2.2.2. *Knightdale, Wake County, N.C.*

The experimental site of the Piedmont region was established in Knightdale (35^{o}46'N, 78^{o}30'W), located in eastern Wake County, N.C. (Figure A1.2). Nine 3.05 m x 60.96 m (10 ft x 200 ft) plots were arranged in two rows spaced 3.05 m (10 ft) apart, running parallel to each other and to US Highway 540, with in-row plots each spaced 3.05 m (10 ft) apart (Figure 2.1b). The seedbed was established in a site targeted as a future roadbed for expansion of Interstate 540. Soil properties of future roadbeds are characterized by excessive compaction, high load-bearing capacity, low soil moisture, and possible incorporation of crushed rock for preparation as a reliable subgrade material, thereby making the soils highly incompatible for traditional agricultural production, and thus rendering the Knightdale research site a "worst case" scenario regarding soil quality for agricultural production (WSDOT, 2011).

2.2.2.3. *Mount Airy, Surry County, N.C.*

In the Mountain region, the experimental site was located in Mount Airy, Surry County, N.C. (36^{o}26'N, 80^{o}36'W). The nine 3.05 m x 60.96 m (10 ft x 200 ft) plots spaced 3.05 m apart (Figure 2.1c) were arranged in parallel with US Highway 74 near the intersection of US Highway 74 and Park Drive within the exit loop of the Exit 13 westbound exit ramp (Figure A.3). Like the Faison research site, this seedbed was one previously cultivated for wildflower production in accordance with the NCDOT Wildflower Program cultivation practices (NCDOT, 2011).

2.2.3 *Tillage Treatments*

2.2.3.1. *Maximum Tillage*

The maximum tillage treatment was characterized by three consecutive passes of a New Holland 6640 tractor (New Holland North America, Inc., New Holland, Pa.) coupled with a surface cultivator (M&W Dyna-Drive, M&W, EarthMaster, Gibson City, Ill.) for rotary tillage to a depth of 20.3 cm (8 in.) (Figure A2.1). This method served to substantially alleviate soil compaction while providing a firm seedbed for subsequent planting with John Deere 1590 no-till drill (Deere & Company, Moline, Ill.) (Figure B.4). Appendix A2 provides a visual example of the operating equipment in the field and a depiction of soil disturbance caused by respective tillage treatments.

2.2.3.2. *Minimum Tillage*

The minimum tillage treatment was characterized by an initial single pass of the New Holland 6640 tractor and surface cultivator for rotary tillage to a depth of 10.16 – 15.24 cm (4 – 6 in.). This was followed by planting with the no-till drill. Appendix A2 provides a visual example of the operating equipment in the field and a depiction of soil disturbance caused by respective tillage treatments.

2.2.3.3. *No Tillage*

The no tillage (no-till) treatment employed exclusive use of the no-till drill for planting directly into the soil through any existing residue, causing only enough soil disturbance to sow the seed to the recommended depths of 1.27 cm (0.5 in.) (Figure A2.3). Appendix A2 provides a visual example of the operating equipment in the field and a depiction of soil disturbance caused by respective tillage treatments.

2.2.4 *Crop Production and Management Schedule*

2.2.4.1. *Planting Season 2009*

Several weeks prior to planting, herbicide treatment (Gramoxone 1 qt ac^{-1} and glyphosate at 2 qt ac^{-1}) was applied to eliminate existing vegetation in all locations. In October 2009, following appropriate tillage treatment, a no-till drill (John Deere 1590, Deere & Company, Moline, Ill.) was used for planting canola (varieties DKW 41-10, 45-10, and 47-15; DeKalb®, Monsanto Company, St. Louis, Mo.) in Faison, Knightdale, and Mount Airy. The drill was calibrated for the small size of canola seed for planting at the recommended rate of 6.72 – 8.96 kg ha^{-1} (6-8 lb ac^{-1}) to recommended depth of approximately 1.27 cm (.5 in). Fertilizer (10-20-20) at a rate of 448 kg ha^{-1} (400 lb ac^{-1}), two quarts of glyphosate herbicide (Roundup®, Monsanto Company, St. Louis, Mo.), and one pint of granular herbicide (Pendulum 2G, BASF Corporation, RTP, N.C.) were applied immediately following planting. In February 2010, fertilizer (32-3-8) was applied to all plots for topdressing at a rate of 336 kg ha^{-1} (300 lb ac^{-1}) (NCDOT, 2011). In early June 2010, canola was harvested from all locations using a combine (Gleaner K2, AGCO Corporation, Duluth, Ga.) with a 3.96 m (13 ft) grain head attachment.

2.2.4.2. *Planting Season 2010*

In late June 2010, soil samples were taken from each location for nutrient analysis at North Carolina Department of Agriculture and Consumer Services (NCDA&CS) Agronomic Services Division, in Raleigh, N.C. (Appendix C). In addition, bulk density of soil to depths reaching 20.32 cm (8 in.) was measured using a digital compaction meter (SC-900, Envco Environmental Equipment Suppliers, Brisbane, Australia). In mid-October 2010, following the appropriate tillage treatment, canola seed (DKW46-15, DeKalb, Monsanto Company, DeKalb, Ill.) was sown with the no-till drill utilizing the recommended seeding rate of 6.72 – 8.96 kg ha^{-1} (6-8 lb ac^{-1}) to recommended depth of 1.27 cm (.5 in) at all locations. Sulfur was applied immediately following planting in Faison and Knightdale. Due to the broadcast application method utilized given the lack in availability of adequately suitable equipment, in combination with windy conditions observed on the day of planting, sulfur application rate was variable across the plots and not continued in Mount Airy planting operations. Fertilizer (18-24-12) was broadcast at a rate of 243.4 kg ha^{-1} (217 lb ac^{-1}) in Faison and Knightdale and at a rate of 338.8 kg ha^{-1} (302.5 lb ac^{-1}) in Mount Airy. Two quarts of glyphosate herbicide treatment and one pint of granular herbicide (Pendulum 2G, BASF Corporation, RTP, N.C.) were applied following planting to reduce likelihood for weed competition. In February 2011, fertilizer (32-3-8) was applied to all plots for topdressing at a rate of 336 kg ha^{-1} (300 lb ac^{-1}) (NCDOT, 2011). Crops were harvested using a combine (Gleaner K2, AGCO Corporation, Duluth, Ga.) without grain head attachment in early June 2011.

2.2.4.3. *Crop Rotation*

Due to its high susceptibility to certain vegetative diseases, it is recommended that canola be grown in rotation with non-canola warm season crops which do not exhibit susceptibility. Therefore, canola was cultivated in rotation with safflower and sunflower crops during each respective growing season for the duration of the study with sequence varying by location (Table 2.1).

Table 2.1 Oilseed crop rotations by location and year of planting

Location	June 2009 – Oct 2009	Oct 2009 – Jun 2010	Jun 2010 – Oct 2010	Oct 2010 – Jun 2011
Faison	Sunflower	Canola	Safflower	Canola
Knightdale	Sunflower	Canola	Safflower	Canola
Mount Airy	Sunflower	Canola	Sunflower	Canola

In June 2009, sunflower crops were cultivated following the respective tillage treatment based upon canola plot designs randomized tillage treatments on plots in Faison, Knightdale, and Mount Airy. Following appropriate tillage treatment, the no-till drill (Tye NoTill Sod Seeder, AGCO Corporation, Duluth, Ga.) was used to plant at the recommended rate of 6.72 – 8.96 kg ha^{-1} (6 – 8 lb ac^{-1}) and to the recommended depth of 1.27 cm (.5 in.). Plots received standard recommended fertilizer and herbicide application (NCDOT, 2011).

In June 2010, following respective tillage treatments, safflower (S-208 variety) was planted with a no-till drill (John Deere 1590, Deere & Company, Moline, Ill.) at an approximate rate of 16.8 kg ha^{-1} (15 lb ac^{-1}) in Faison and Knightdale. Immediately following planting, fertilizer (32-3-8) (Halifax Fertilizer Company, Enfield, N.C.) was broadcast at a rate of 696 kg ha^{-1} (625 lb ac^{-1}). Two quarts of glyphosate herbicide and one pint of granular herbicide treatment (Pendulum 2G, BASF Corporation, RTP, N.C.) were applied. Both the Faison and Knightdale sites experienced rainfall events on the same day of planting. Sunflower (3480 NS/CL/DM, Syngenta Seeds, Inc., Minneapolis, Minn.) was planted in Mount Airy in June 2010. The sunflower crops were harvested early October 2010 with a Gleaner K2 combine with 3.96 m (13 ft) grain head attachment and resulted in insufficient yields (data not presented here). Safflower plots were not harvested but sprayed with a "burn-down" herbicide in mid-September to eliminate crops in preparation for subsequent planting of canola.

2.2.5 *Statistical Analysis*

Statistical analysis was performed for analysis of variance (ANOVA) for comparison of the main and interaction effects of site, tillage, and year on canola yields (SAS v. 9.2, SAS Institute, Inc., Cary, N.C.). Analysis was based on the three [location] by three [tillage] by two [year] factorial design where tillage and location were treated as fixed effects to analyze yield data for inferences about performance in response to regional differences in soil properties, climatic characteristics and topographical conditions across the state. The Tukey-Kramer Method was performed for pairwise comparisons of all combinations of all levels of site, tillage, and year (CSCS, 2008). Differences of least squares means were evaluated for main and interaction effects with significance considered at an adjusted P value < 0.05.

2.3 Results

2.3.1 *Effects of Year, Site, and Tillage on Canola Seed Yields*

Overall, the main and interaction effects of site and year proved to have the strongest influence on seed yields. Tillage treatment did show some influence on yield in some cases, but that effect was highly dependent upon site and year. In both 2009 and 2010 planting seasons, site displayed a significant effect on seed yield, while tillage treatment showed a significant effect only when comparing maximum to no-tillage and minimum to no-tillage treatments in 2010 plantings (Table 2.2). Interactions of site × tillage, tillage × year, and site × tillage × year were not found to have significant effect in either planting season (and thus were excluded from Table 2.2); however, interaction effects of site × year were significant when comparing data between years (Table 2.3).

Table 2.2 Selected ANOVA tables for main effects of site and tillage. Site and tillage treated as fixed and year treated as random effect.

	Effect	Factor1	Factor2	Estimate	Adj P	Significance
2009	Site	Faison	Knightdale	427.26	0.0293	**
	Site	Faison	Mount Airy	-188.32	0.4179	NS
	Site	Knightdale	Mount Airy	-615.58	0.0028	**
	TillageTreatment	Max	Min	280.50	0.1840	NS
	TillageTreatment	Max	No	341.55	0.0979	*
	TillageTreatment	Min	No	61.0494	0.9124	NS
2010	Site	Faison	Knightdale	1850.23	<.0001	***
	Site	Faison	Mount Airy	1204.10	0.0004	**
	Site	Knightdale	Mount Airy	-646.14	0.0760	*
	TillageTreatment	Max	Min	-10.6053	0.9991	NS
	TillageTreatment	Max	No	648.17	0.0610	*
	TillageTreatment	Min	No	61.0494	0.9124	NS
Both Years	Site	Faison	Knightdale	1134.25	0.3259	NS
	Site	Faison	Mount Airy	503.75	0.7091	NS
	Site	Knightdale	Mount Airy	-630.50	0.6114	NS
	TillageTreatment	Max	Min	135.31	0.8302	NS
	TillageTreatment	Max	No	499.36	0.2668	NS
	TillageTreatment	Min	No	364.05	0.4018	NS

*** = Highly Significant Adj P < .0001
** = Significant 0.0001 < Adj P < 0.05
* = Slightly Significant 0.05 < Adj P < 0.10
NS = Not Significant Adj P > 0.10

Table 2.3 Selected ANOVA tables for main and interaction effects of site, tillage, and year.

	Effect	Factor1	Year	Factor2	Year	Estimate	Adj P	Significance
Site Fixed Tillage Fixed Year Fixed	Site	Faison		Knightdale		1138.75	<.0001	***
	Site	Faison		Mount Airy		507.89	0.0074	**
	Site	Knightdale		Mount Airy		-630.86	0.0021	**
	TillageTreatment	Max		Min		134.95	0.6760	NS
	TillageTreatment	Max		No		494.86	0.0189	**
	TillageTreatment	Min		No		359.91	0.0860	*
	Year	2009		2010		-1285.46	<.0001	***
	Site*Year	Faison	2009	Faison	2010	-2223.93	<.0001	***
	Site*Year	Faison	2009	Mount Airy	2010	-1019.83	0.0034	**
	Site*Year	Faison	2010	Knightdale	2009	2651.19	<.0001	***
	Site*Year	Faison	2010	Knightdale	2010	1850.23	<.0001	***
	Site*Year	Faison	2010	Mount Airy	2009	2035.6	<.0001	***
	Site*Year	Faison	2010	Mount Airy	2010	1204.10	0.0005	**
	Site*Year	Knightdale	2009	Knightdale	2010	-800.95	0.0397	**
	Site*Year	Knightdale	2009	Mount Airy	2010	-1447.09	0.0002	**
	Site*Year	Mount Airy	2009	Mount Airy	2010	-831.51	0.0238	**

*** = Highly Significant Adj P < .0001
** = Significant 0.0001 < Adj P < 0.05
* = Slightly Significant 0.05 < Adj P < 0.10
NS = Not Significant Adj P > 0.10

2.3.1.1. *Year Effects*

In treating year as a fixed effect, it was possible to compare the differences in productivity observed in the first season of cropping versus second season cultivations with correlation to site and tillage effects. Total average yields observed in 2010 were significantly greater than those observed in the 2009 planting season (Table 2.2), and all locations observed significantly higher yields in the second year of cropping as compared with initial cultivations when averaging across tillage treatment (Table 2.2). In some instances, 2010 yields were increased more than 300% over 2009 results for corresponding locations (Table 2.3). Notably, in Faison, even the lowest yielding treatment (no-tillage) in the 2010 planting season produced significantly greater yields over the highest yielding treatment (maximum tillage) from that the same site in 2009 (Table D.4).

2.3.1.2. *Site Effects*

In the 2009 planting season, Faison (980 lb ac^{-1}) and Mount Airy (1168 lb ac^{-1}) plots produced statistically similar yields, both of which were significantly higher than those observed in Knightdale (Table 2.4). Contrastingly, in the 2010 planting season, the Knightdale and Mount Airy locations produced yields statistically similar to each other, and Faison produced significantly higher yields than those two sites (Table 2.4). Specifically, in 2010, maximum and no-tillage treatments produced overall average yields greater than 200% of those observed on similarly tilled plots in 2009 cropping, and the minimum tillage treatment increased seed yields almost 300% (Table 2.4).

Table 2.4 Main effects of site across tillage treatment on canola seed yields

Site	2009*	2010*
	Seed Yield (lb ac^{-1})	
Faison	980a	3204a
Knightdale	553b	1354b
Mount Airy	1168a	2000b

*Statistical comparisons were made at α level 0.05. Means followed by similar letters within a single column represent statistically similar yields as evaluated by year.

Table 2.5 Main effects of tillage treatment across site on canola seed yields.

Tillage Treatment	2009*	2010*
	Seed Yield (lb ac^{-1})	
Maximum	1108a	2399a
Minimum	827a	2409a
No-Till	766a	1750a

*Statistical comparisons were made at α level 0.05. Means followed by similar letters within a single column represent statistically similar yields as evaluated by year.

2.3.1.3. *Tillage Effects*

In the first year of cropping, the maximum tillage treatment produced the highest average yields [1241 kg ha^{-1} (1108 lb ac^{-1})] followed by minimum tillage [926 kg ha^{-1} (827 lb ac^{-1})] and no-till [858 kg ha^{-1} (766 lb ac^{-1})], respectively (Table 2.5). However, in the second year, the comparative intensity of productive effects from maximum tillage was lower, and plots cultivated under the minimum tillage treatment resulted in the highest average yields [2698 kg ha^{-1} (2409 lb ac^{-1})], followed sequentially by maximum tillage [2687 kg ha^{-1} (2399 lb ac^{-1})] and no-tillage [1906 kg ha^{-1} (1750 lb ac^{-1})], respectively (Table 2.5).

The statistical analysis of these results report no significant effect of tillage on yield in the 2009 planting season, and, although the main effect of tillage on seed yield was found to be significant for the 2010 planting season (Pr > F, 0.0343; α = 0.05), the pairwise comparisons between tillage treatments did not support this finding (Table 2.5). However, while the differences in maximum versus no-tillage (Adj. P = .0610) and minimum versus no-tillage (Adj. P = .0563) were not considered statistically significant at α = .05 (Table 2.2), they produced differences in yields of 648 and 659 lb ac $^{-1}$, respectively, with improvements corresponding to increased levels of tillage. The marked improvement associated with higher levels of tillage may provide justification for recommending incorporation of more intensive methods rather than exclusively no-tillage. Nonetheless, there was no significant difference in the effects of maximum versus minimum tillage in the 2010 planting season; therefore, depending upon additional factors, including size of proposed operation, it may not be justifiable to recommend implementation of a more energy-expending maximum tillage treatment.

2.4 Discussion and Conclusions

The results of plot trials show obvious trends of increased canola yields with successive year of planting at all locations. In Faison, the 2010 planting season produced seed yields equal to approximately 300% of the yields observed in 2009, and in Mount Airy, yields increased roughly 200% from 2009 to 2010. Precipitation data obtained from weather stations in closest proximity to each experimental location can be viewed in Appendix B2

(NC CRONOS/ECONet Database, State Climate Office of North Carolina, Raleigh, N.C.). In consideration of lower rainfall observations in the second year of planting, the increase in productivity on crop response cannot necessarily be attributed to the effects of precipitation. Rather, the results could reasonably be indicative of increased productivity due to improved seedbed conditions following previous agricultural working of the soil. These improved seedbed conditions can be achieved in both instances of previous wildflower cultivation practices and project-specific oilseed crop cultivation. The persistence of compaction relief achieved following initial deep tillage treatment appears to have provided productive effects sufficient to nullify any requirement for repetition of the conventional tillage treatment in subsequent seasons of cropping. These persistent effects may be reinforced by the ability of canola's rooting system to alleviate soil compaction.

Additionally, Faison and Mount Airy plots were established in soils previously cultivated for wildflower production. Typical methods for wildflower seedbed preparation and crop management are detailed in NCDOT North Carolina Wildflower Program Wildflower Planting Instructions in a procedural handbook (NCDOT, 2011). Unlike the Faison and Mount Airy plots, Knightdale crops were cultivated on land targeted for future roadway expansion of Interstate 540, and thus likely composed of exceptionally low quality soil. Roadbed soils are characteristically composed of exceptionally low quality soil and thus most poorly suited for agricultural productivity. Accordingly, the Knightdale location served as a "worst-case" scenario for observation of yields on extraordinarily highly-compacted, nutrient-depleted soils. While the Knightdale plots did produce the lowest yields each season, the yields of each crop were improved significantly upon subsequent plantings. Moreover, the greater seed yields observed in previous wildflower beds plots versus previously uncultivated ROW soils suggest that it may be advantageous for soils be conditioned in accordance with NCDOT wildflower production procedures (NCDOT, 2011) prior to initial oilseed crop cultivation. However, since these results could be resultant of the productive effects from (1) initial maximum tillage treatment, (2) previous agricultural working of the soil, or (3) interactions between the two effects, further research and additional seasons of cropping are needed to attribute the effects explicitly to an specific influencing factor or interaction of factors. Particular attention should be paid to those areas exhibiting low emergence for which greater soil properties analysis (bulk density, infiltration, toxicity, pH, fertilizer requirements, etc.) should be performed.

Also, it is important to note that canola exhibits a high susceptibility to crop diseases including Sclerotinia rot and blackleg (Berglund et al, 2007). Therefore, canola should not be cultivated in immediate succession with canola or other similarly susceptible crops, but instead rotated with suitable summer crops not displaying susceptibility (Berglund et al 2007). In this study, sunflower and safflower plots produced exceptionally low yields; therefore, evaluation of adaptability of other summer crops should be explored in further project implementation.

Overall, improved results with subsequent year of planting may support the conclusion that the combination of that a single initial tillage treatment, the ability of canola to reincorporate nitrogen into the soil, and the post-harvest return of extraneous crop residues into the soil provide sufficient working of the soil and nutritive restoration to increase the productivity of ROW soils to a level competitive with, or comparable to, traditional agricultural cropland. Since the yields were not significantly different between maximum and minimum tillage methods, alteration or addition of cultivation methods may be evaluated, including fertilizer application rates, time of planting, or variety of oilseed.

The results of tillage treatment effects on oilseed yield provide a guide for selecting the proper tillage method for implementation on these ROW soils. Through the review of literature, it is evident that satisfactory results have been achieved under very different soil compaction conditions and tillage methods. Therefore, it may be more productive and economical to select management practices regarding tillage based on assessment of site-specific soil conditions and relevant crop requirements; site-specific ROW characteristics (slope, soil properties (including soil type and texture, bulk density, penetrometer resistance, infiltration/drainage issues, etc.) should be evaluated for targeted land before management practices are implemented. Degree and depth of compaction should be considered for selection of a tillage practice that will maximize productive yield while minimizing costs. Planting date also is an important factor in oilseed productivity and yield. Plantings and harvests are often delayed to due scheduling conflicts for availability of equipment necessary to perform planting and harvesting operations; however, it is important to recognize that yields may increase with earlier planting dates for canola in North Carolina. Likewise, incidences of abnormal climatic conditions should be taken into consideration as factors including rainfall intensity and temperature extremes are shown to greatly affect soil properties and tillage requirements (Hanna and Al-Kaisi, 2009).

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CHAPTER 3 PRODUCTION OF CANOLA ON NORTH CAROLINA HIGHWAY RIGHTS-OF-WAY

3.1 Introduction

As the competition between energy crops and food crops for agricultural land continues to intensify, it is becoming increasingly important to exploit non-agricultural land for energy crop production. Currently, the vast majority of North Carolina highway rights-of-way are seeded with various perennial grasses following roadway construction and subsequently maintained primarily for soil erosion control purposes. Routine mowing operations are performed, incurring costs of approximately $6,000,000 annually, with no avenue for return on that investment (NCDOT, 2010). While the North Carolina Department of Transportation maintains a reputable wildflower program, providing beautification of several statewide roadsides, there is neither economic advantage nor exceptional environmental benefit to be realized from such ventures. Production of oilseed crops along these highway ROWs provides a similar aesthetic benefit while providing an opportunity to supplement economic growth and enhance environmental impact. Furthermore, putting otherwise fallow land to productive use combats the necessity for displacement of agricultural land managed for producing food crops.

Various oilseed crops have proven to be viable feedstock for renewable fuel production in the United States; however, their suitability for production in non-agricultural soils of North Carolina highway rights-of-way has not been evaluated. Winter canola (*Brassica napus L.*), a low-acid cultivar of canola and currently the highest oil-yielding oilseed crop in the United States, averaging an oil yield of 1,141 L ha^{-1} (122 gal ac^{-1}) (Kurki et al., 2006), has performed successfully in field trials throughout North Carolina (George et. al, 2008). Additionally, canola has been found to produce the second highest oil yield in North Carolina compared with all experimental sites in the southeastern U.S. (Van Dyne and Raymer, 1992), and efforts equivalent to those for maintaining of one-half of the current winter wheat production in North Carolina hold the potential to produce in excess of 30 million gallons of oil annually (NCCP, 2007). These findings suggest that the climatic conditions and soil properties in North Carolina generally are highly compatible with canola production requirements and could support a sustainable biodiesel production program with canola targeted as the main feedstock. Therefore, the goal of this study was to evaluate the feasibility of maintaining a sustainable canola crop production system on the highly eroded, highly compacted, low nutrient soils of the North Carolina Department of Transportation (NCDOT) highway rights-of-way for utilization as a source of feedstock for producing biodiesel fuel that can supplement their motor vehicle fleet.

Like most agricultural crops, winter canola has sensitive production requirements and thus requires consideration of various climatic conditions when determining site selection for production. North Carolina experiences a high level of variability both spatially (west to east) and temporally (season to season) in terms of temperature and precipitation observations (SCONC, 2011). Spatial analysis tools, including geographic information systems (GIS), are available for mapping such climatic conditions and production parameters. For this study, GIS mapping software (ArcGIS, ESRI, Redlands, Cal.) was used to help determine regions of the state having proper climatic conditions and areas of ROWs having suitable land characteristics for canola production. Specific factors considered in the analysis included (1) right-of-way characteristics (e.g., slope and width); (2) roadway characteristics (e.g., route classification, number of lanes, traffic volume); and (3) regional climatic conditions (e.g., seasonal rainfall and temperature observations). Utilization of the specially-developed GIS program assisted in estimation of available ROW acreage eligible for project implementation based on areas meeting specifications for all of these criteria. Specific objectives were to (1) evaluate canola production requirements and eligibility for production based on North Carolina's climatic conditions and highway rights-of-way characteristics; (2) cultivate and evaluate the performance of canola research plots at five locations across North Carolina; and (3) use GIS analysis software to map NCDOT highway ROWs and model site selection and quantification eligible land base acreage for crop production.

3.2 Materials and Methods

Beginning in June 2009 and concluding in June 2011, canola (*Brassica napus L.*) production research was conducted in five locations in North Carolina. Plots were established in Faison, Knightdale, Mount Airy, Pittsboro, and Rutherfordton along NC ROWs and canola seed yields were evaluated to determine productivity for two cropping seasons.

3.2.1 *Site Descriptions*

3.2.1.1. *Faison, Duplin County, N.C.*

The experimental site of the Inner Coastal Plain region was located in the northwestern corner of Duplin County, N.C. along the intersection of Highway NC 50 and Highway NC 403 in Faison (35°07'N, 78°09'W) (Figure 3.1) . In 2009, the 610 m (2000 ft) by 3.05 m (10 ft) plot was established parallel to Highway 403 near the base of a low hill adjacent to a field that appeared to have flooding or drainage issues near its center. In 2010, the plot was shifted approximately 36.6 m (120 ft) to the east to avoid poorly drained areas of the field prior to subsequent canola planting.

Figure 3.1 Aerial imagery of Faison research site (Google Maps, 2011).

3.2.1.2. *Knightdale, Wake County, N.C.*

The experimental site of the Piedmont region was established along an embankment and extended under an overpass near Exit 26A at the intersection of US Highway 64 and Interstate 540 in Knightdale (35^{o}46'N, 78^{o}30'W), located in eastern Wake County, N.C (Figure 3.2). The seedbed was one previously cultivated for wildflower production in accordance with the NCDOT Wildflower Program wildflower cultivation practices (NCDOT, 2011). Wildflower bed soils have been worked previously through agricultural operations including tillage and nutrient restoration to remediate typical ROW soils to reflect properties more similar to agricultural cropland soils.

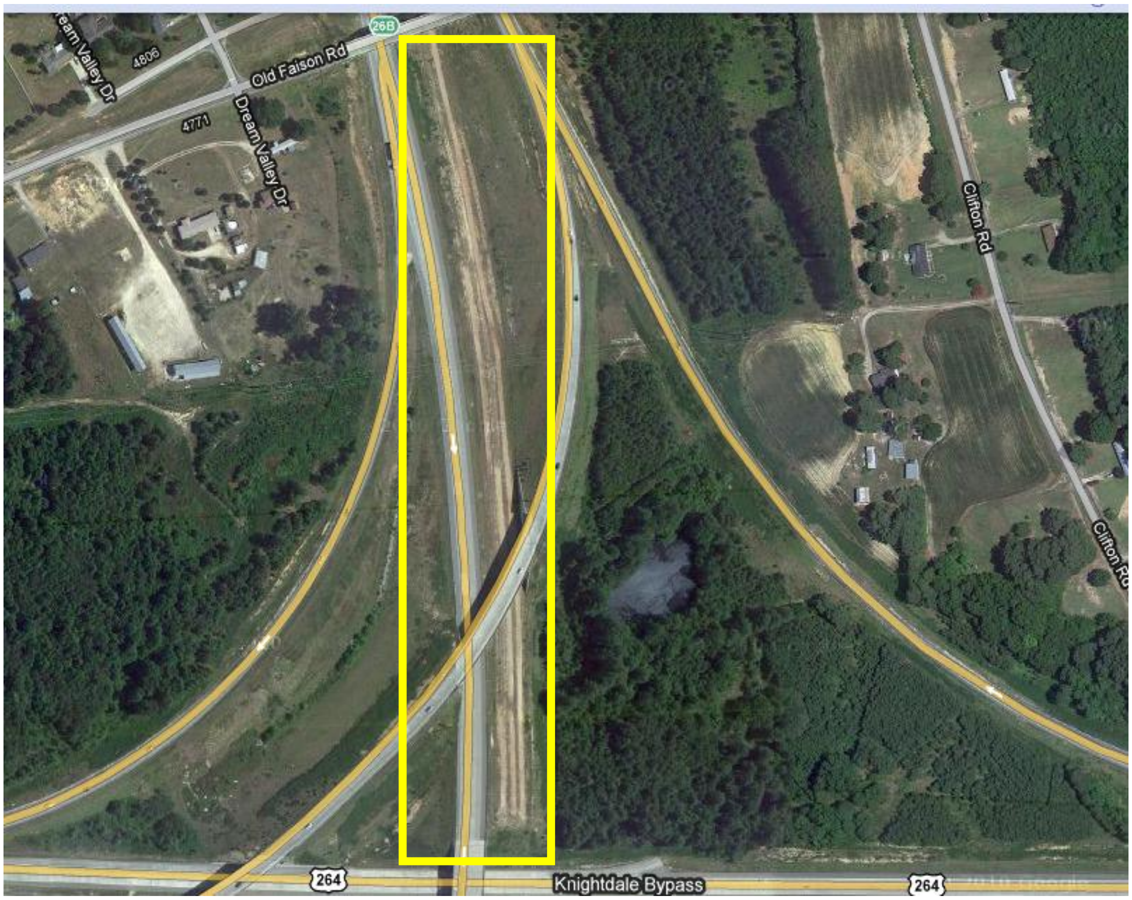

Figure 3.2 Aerial imagery of Knightdale research site (Google Maps, 2011).

3.2.1.3. *Mount Airy, Surry County, N.C.*

In the northern Mountain region, the experimental site was located in Mount Airy, Surry County, N.C. (36^{o}26’N, 80^{o}36’W) (Figure 5). The 3.05 m by 609.6 m (10 ft by 2000 ft) plot was established approximately .8 km (.5 mi) northwest of the Park Drive Exit 13 in Mount Airy, N.C. (36^{o}26’N, 80^{o}36’W) (Figure 3.3).

Figure 3.3 Aerial imagery of Mount Airy research site (Google Maps, 2011).

3.2.1.4. *Rutherfordton, Rutherford County, N.C.*

In the southern Mountain region, the experimental site was located in Rutherford County in a seedbed previously cultivated for the NCDOT Wildflower Program at the intersection of US Highway 74 and Union Road near Rutherfordton, N.C. (35^{o}17’N, 82^{o}00’W) (Figure 3.4).

Figure 3.4 Aerial imagery of Rutherfordton research site (Google Maps, 2011).

3.2.1.5. *Pittsboro, Chatham County, N.C.*

The plots were located in the Chatham County, N.C., beginning near the intersection of U.S. Route 64 and U.S. Route 501 in Pittsboro (35°44'N, 79°09'W), running parallel to U.S. Route 64, and extending approximately 9.66 km (6 mi) westward (Figure 3.5). The plots were cultivated on a 3.05 m width strip extending the length of ROW totaling approximately 9.66 km (6 mi), partitioned only by previously-defined breaks in ROW caused by the presence of on-ramps, exit ramps, and overpasses (Figure 3.5).

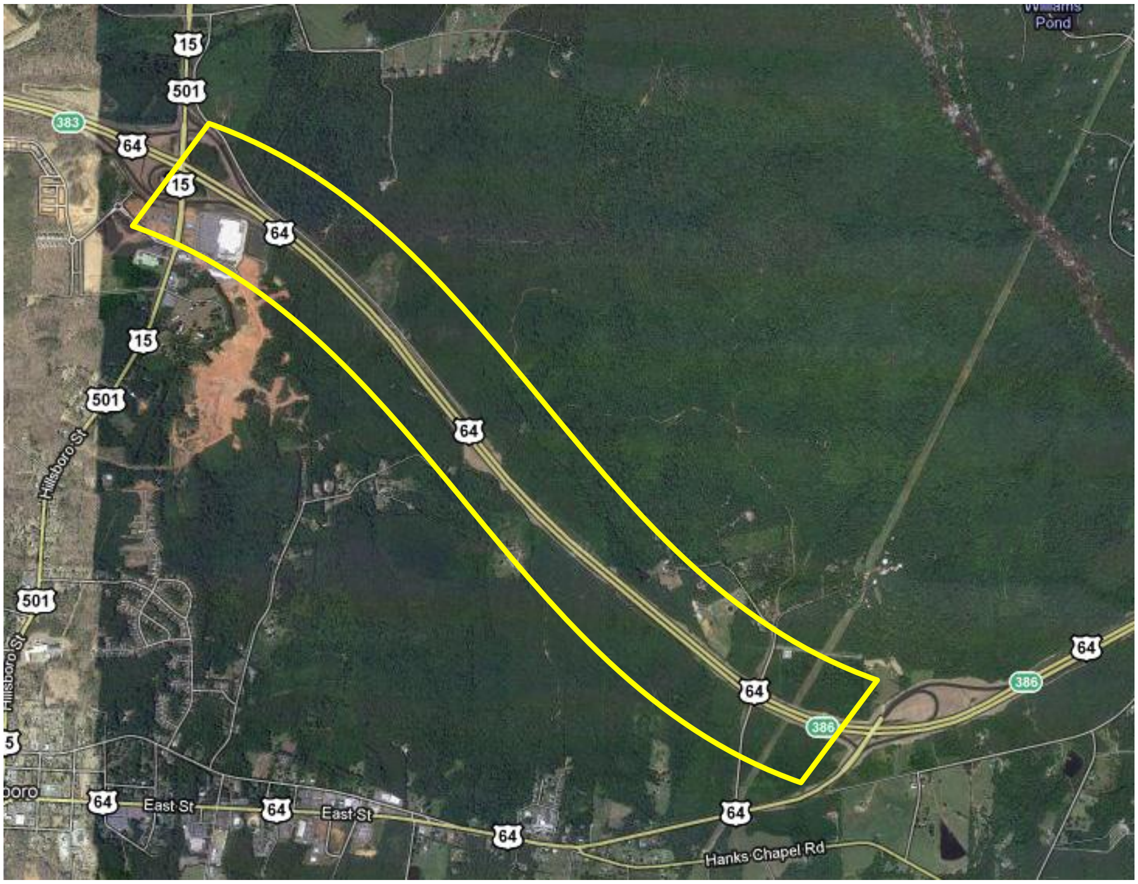

Figure 3.5 Aerial imagery of Pittsboro research site (Google Maps, 2011).

3.2.2 *Crop Production and Management Schedule*

Maximum tillage treatments were performed on plots in Faison, Knightdale, Mount Airy, and Rutherfordton. In Pittsboro, plots were only established in the second year of the program to examine the impact of no-till operations on yield at a larger scale. Tillage methods were applied immediately prior to planting at corresponding locations.

3.2.2.1. *Planting Season 2009*

In October 2009, a John Deere 1590 no-till drill (Deere & Company, Moline, Ill.) was used for planting canola (DKW 45-10, DeKalb, Monsanto Company, DeKalb, Ill.) in Faison, Knightdale, Mount Airy, and Rutherfordton. The drill was calibrated for the small size of grain for planting at the recommended rate of 6.72 – 8.96 kg ha^{-1} (6-8 lbs ac^{-1}) to depth of approximately 1.27 cm (.5 in). Plots received recommended fertilizer and herbicide application immediately following planting (NCDOT, 2011). In June 2010, canola was harvested with a Gleaner K2 combine (AGCO Corporation, Duluth, Ga.) from all sites.

3.2.2.2. *Planting Season 2010*

In October 2010, canola (DK46-15, DeKalb, Monsanto Company, DeKalb, Ill.) was reestablished in Faison, Knightdale, and Mount Airy and was cultivated for the first time at the Pittsboro site. At all locations, following the maximum tillage treatment, seed was sown with a no-till drill (John Deere 1590, Deere & Company, Moline, Ill.) at the recommended seeding rate of 6.72 – 8.96 kg ha^{-1} (6-8 lbs ac^{-1}) and depth of 1.27 cm (.5 in). Sulfur was applied immediately following planting in Faison and Knightdale, and fertilizer (18-24-12) was broadcast at a rate of 243.4 kg ha^{-1} (217 lb ac^{-1}) in Faison. Due to the broadcast application method utilized given the equipment available, in combination with high winds on the day of planting, sulfur application was variable across the plots. Sulfur was not applied to Mount Airy plots. Two quarts of glyphosate herbicide treatment (Roundup, Monsanto Company, St. Louis, Mo.) and one pint of granular herbicide (Pendulum 2G, BASF Corporation, RTP, N.C.) were applied following planting to reduce likelihood for weed competition. Recommended fertilizer was applied to all canola plots in early February 2011 (NCDOT, 2011). Crops were harvested using a Gleaner K2 combine (AGCO Corporation, Duluth, GA) in June 2011 for all sites.

3.2.2.3. *Crop Rotation*

Canola exhibits a high susceptibility to diseases including Sclerotinia rot (George, 2008). Therefore, canola should not be cultivated in immediate succession with canola, but instead should be rotated with suitable summer crops not displaying susceptibility. Initial cropping occurred in late June 2009 and continued through mid June 2011. For the duration of the study, Faison and Knightdale followed a sunflower-canola-safflower-canola rotation, and Mount Airy followed a sunflower-canola-sunflower-canola rotation (Table 1). During the first year, Rutherfordton followed a sunflower-canola-sunflower rotation, and in the second year, Pittsboro maintained a single season of canola cropping (Table 3.1).

Table 3.1 Oilseed crop rotation by location and season

Location	**June 2009 – Oct 2009**	**Oct 2009 – Jun 2010**	**Jun 2010 – Oct 2010**	**Oct 2010 – Jun 2011**
Faison	Sunflower	Canola	Safflower	Canola
Knightdale	Sunflower	Canola	Safflower	Canola
Mount Airy	Sunflower	Canola	Sunflower	Canola

3.2.3 *GIS Program Analysis*

For the project, a GIS program was created to assist in determining the amount of land eligible for oilseed crop production along North Carolina's highway rights-of-way (ROWs). Eligible areas of ROW were defined by a sequential process of selection and spatial analysis using GIS analysis software (ArcGIS 9.3.1, ESRI, Redlands, Cal.). Analysis criteria included ROW characteristics (width, slope, adjacent traffic volume) and N.C. climatic conditions (minimum, maximum, and average seasonal rainfall and temperature observations).

3.2.3.1. *Description of Data Files*

The data required for the project were obtained from the North Carolina Department of Transportation (NCDOT) and the United States Department of Agriculture (USDA) (Table 3.2). The shapefiles containing precipitation maps, temperature maps and NCDOT roads characteristics maps were added to the model for selection based on project-specific criteria (Table 3.3).

Table 3.2 Shapefile data used to map eligible ROWs for canola production

Shapefile Name	Description	Geometry	Source
Rd_Char_Mlpst	A theme containing road characteristics from which major US highways, NC highways, and interstates were selected. Roads having sufficient ROW width were selected and buffered.	Polyline	NCDOT 2010
CountyBoundaryShoreline	A theme containing the boundary of North Carolina and boundaries of all counties within the state.	Polygon	NCDOT 2010
DOTDivisionBoundary	A theme containing the boundaries of the fourteen NCDOT transportation divisions.	Polygon	NCDOT 2006
precip_a_nc	A theme containing annual rainfall data for the state of North Carolina from which areas experiencing adequate rainfall were selected.	Polygon	USDA 2010
temp_a_nc	A theme containing annual temperature data for the state of North Carolina from which areas experiencing suitable temperature ranges were selected.	Polygon	USDA 2010

Table 3.3 Minimum and maximum values for ROW selection criteria

Attribute	Minimum	Maximum
ROW Slope	---	1:3
ROW Width (ft)	18	---
Lanes of Traffic	1	6
Traffic Volume	0	1000
Temperature (^{o}C)	0	35
Precipitation (in.)	15	---

3.2.3.2. *Selection Process and Model*

Major interstates, NC highways, and US highways were selected from the roads characteristics shapefile (Rd_Char_Mlpst) based on route classification (RTE_1_CLSS) from the roads characteristics shapefile using a selection/definition query:

"RTE_1_CLSS" = 'I' OR 'NC' OR 'US'

Metadata associated with the shapefiles was used to properly label road data polylines with corresponding attributes (e.g., median width, right-of-way width, and shoulder width) in the roads characteristics shapefile (Table 3.3). The shapefiles were overlayed with aerial imagery (Google Earth) for visual inspection of attributes and verification of proper correspondence of attribute values with labeled units of measure (e.g., width and length values measured in feet). Following verification of proper correspondence between metadata and attributes, an equation was developed to calculate ROW width for NC highways, US highways, and US interstates:

$$ROWCALC = \left(\frac{RW\_WID}{2}\right) - \left(\frac{MDN\_WID}{2}\right) - SRFC\_WID - SHLDR\_L - SHLDR\_R$$

where

RW_WID = Total width of land designated for the roadway facility, ft
MDN_WID = Total median width, ft
SRFC_WID = Width of road surface, ft
SHLDR_L = Width of left shoulder, ft
SHLDR_R = Width of right shoulder, ft
(NCDOT RD_CHAR_MLPST shapefile attribute metadata)

To estimate total acreage of the eligible ROW [assuming plot width of 3.05 m (10 ft)], records having calculated ROW width (ROWCALC values) greater than or equal to 5.49 m (18 ft) were selected. The total length of ROW for these selected road segments was identified within the “Statistics” (Open Attribute Table > right-click Shape_Leng > select Statistics > Sum) corresponding to the newly created field of geometry (ROWCALC). The total length of 24,079,834.8 m (79,002,082.66 ft) was multiplied by the assumed 3.05 m (10 ft) plot width to estimate a total acreage of eligible land (based solely upon ROW width) equaling 7,339.53 ha (18,136.38 ac).

Eligible climate regions based on precipitation and temperature observations were defined in several ways. First, the “Union” tool was used to create new shapefiles containing seasonal rainfall averages, maximums, and minimums. These new shapefiles were added to a model as input data files for further processing by “Select” tool which selected areas receiving user-specified rainfall amount [greater than 38.1 cm (15 in.)] (Figure 3.6).

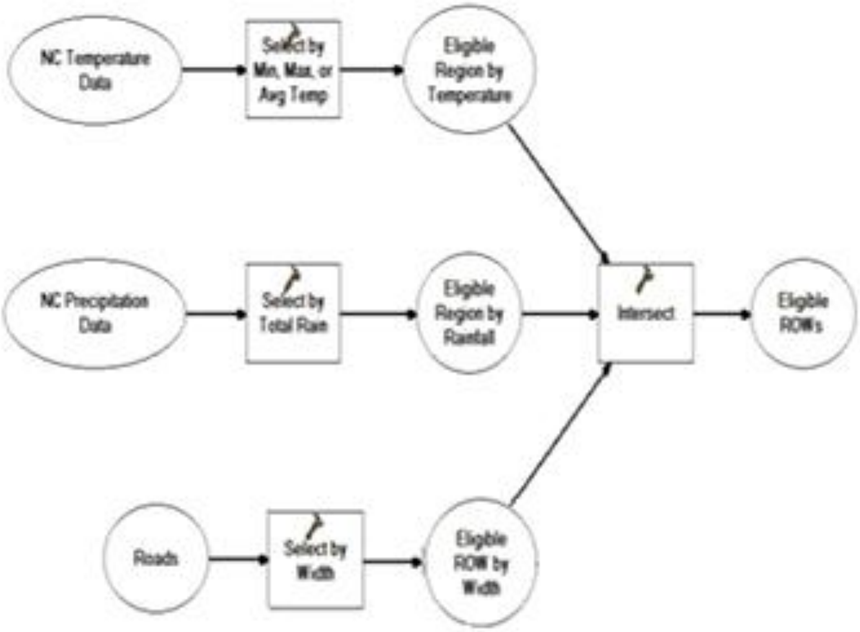

Figure 3.6 ArcGIS Model: Eligible ROW selection process

North Carolina regional precipitation (i.e., 0-15 in., 16-17 in., etc.) and temperature ranges (i.e., 18.5-29, 29.5-32.5, 32.5-33°C)] were reclassified and mapped. The new shapefiles displaying reclassified ranges of precipitation (Figure 3.7) and temperature (Figure 3.8) data were generated and mapped separately for more appropriate visualization of these attributes based on oilseed crop requirements. Selection was based on requirements specific to canola production (i.e., greater than 15 in. rainfall and less than 35 °C (95°F) maximum temperature (Table 3.3) (Canola Council of Canada, 2003). Therefore, based on the data available, no areas of the state were excluded due to temperature range unsuitable for canola production.

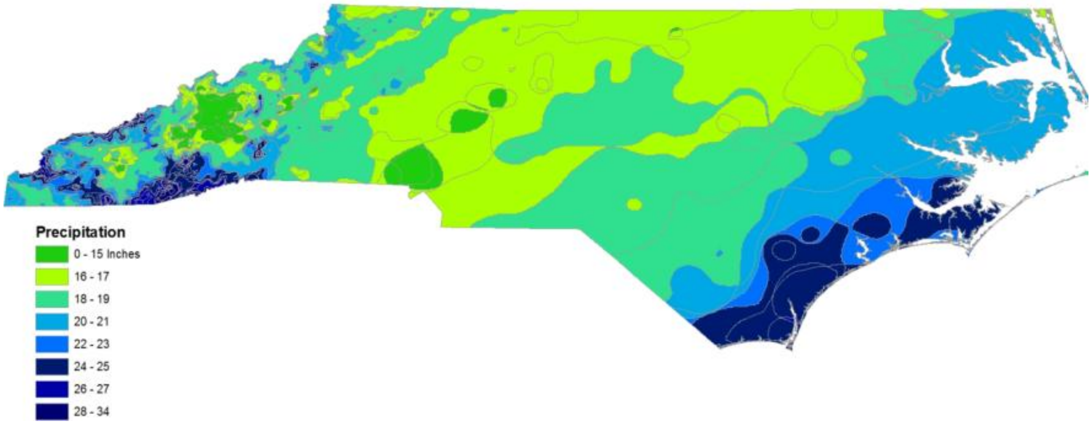

Figure 3.7 GIS analysis showing average annual precipitation observations across North Carolina

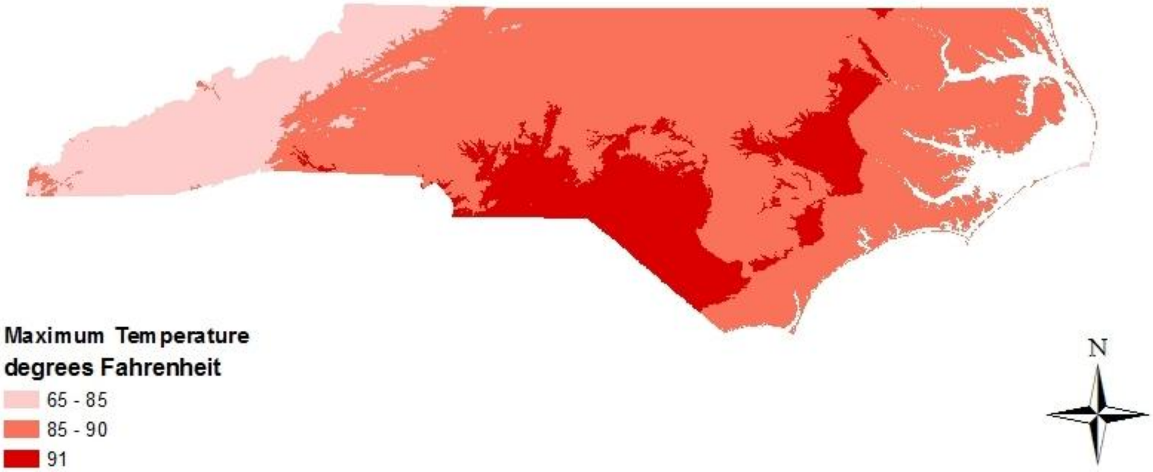

Figure 3.8 GIS analysis showing average annual maximum temperature ranges across North Carolina

Figure 3.9 GIS analysis showing eligible regions and ROWs of North Carolina for canola crop production

3.2.4 *Model Development*

"Model Builder" is a tool in ArcGIS that facilitates replication of a selection process that can be easily altered for execution based on various selection parameters. Through utilization of "Model Builder", several data management processes were performed simultaneously. In the model, areas of the state experiencing appropriate seasonal temperature ranges (based on averages, maximums, and minimums) were selected (Figure 3.6). Eligible ROWs were selected and buffered based on the calculated width value (ROWCALC), and ROWs having appropriate areas of suitable width [e.g., greater than 5.49 m (18 ft)] were selected. Finally, all areas meeting individual selection criteria requirements were intersected to identify potential eligible locations throughout the state (Figure 3.9).

Following this selection and intersection process, the acreage of the resulting areas of eligible ROW was calculated by adding a new field to the attribute table of the final output file and performing a "Calculate Geometry" process to update the attributes of the created feature class. Once all selections were performed and eligible areas were mapped, the statewide data was separated into separate shapefiles based on the fourteen NCDOT transportation divisions for more effective mapping demonstration.

The results of the GIS program analysis report the amount of ROW acreage available based on selection criteria and indicate regions of North Carolina that are most suitable for project implementation. If it is found that there is inadequate acreage of ROW to make this crop cultivation approach a profitable investment, the GIS program is available for parameter manipulation to identify land areas in North Carolina that may be more suitable for producing these crops. The parameters of the selection criteria in the model (Figure 3.6) are easily alterable for predicting eligible ROWs based on specific oilseed requirements and can be used with data specific to other state departments of transportation.

3.3 Results and Discussion

3.3.1 *Field Operations*

Overall, the highest seed yields were observed in Faison, Mount Airy, and Rutherfordton, respectively, and the lowest in Knightdale. In 2009, Mount Airy plots produced the highest seed yields of all locations, while, in 2010, Faison observed the highest yields (Table 3.4). In both years, the Knightdale plots experienced the lowest yields compared with all other locations (Table 3.4).

Table 3.4 Canola seed yields from maximum tillage scale-up plots for 2009 and 2010 cropping seasons.

Site	2009	2010
	Seed Yield (lb ac^{-1})	
Faison	737	3162
Knightdale	622	915
Mount Airy	1934	---
Pittsboro	---	1209
Rutherfordton	1715	---

It is also important to note that Faison, Mount Airy, and Rutherfordton, plots were established in soils previously cultivated by typical methods for wildflower seedbed preparation and crop management (NCDOT, 2011). However, in Knightdale and Pittsboro, initial crops were established in previously uncultivated, undisturbed ROW soil, and only no-till operations were performed in Pittsboro. The Knightdale plot was cultivated in soils allocated as the roadbed for future expansion of Interstate 540. This plot produced the lowest yields each season; however, the yields still were improved substantially with subsequent planting. The characteristics of roadbed soils are of the most poorly suited for agricultural productivity; consequently, the Knightdale location served as a “worst-case” scenario for observance of yields on highly-compacted, low-nutrient soils. Similarly, the experiment in Pittsboro produced inconsistent results throughout the expanse of the plot, with some areas producing substantial yields and some areas exhibiting sparse emergence.

The higher seed yields observed in previously cultivated wildflower beds versus previously uncultivated ROW soils suggest that it may be advantageous for soils to be conditioned in accordance with NCDOT wildflower production procedures prior to initial oilseed crop cultivation. However, since these increased yields may have resulted from the productive effects from (1) maximum tillage management, (2) previous agricultural working of the soil, or (3) a combination of these two phenomena, further research and additional seasons of cropping are needed to attribute the effects to a particular influencing factor or interaction of factors. Additionally, since the results were only available for one season in

Pittsboro and were highly variable over short distances, these results could support an argument for the productive effects from initial deep tillage, previous agricultural working of the soil, or interactions between the two effects. However, when conducting additional research to increase productivity in the future, particular attention should be paid to those areas exhibiting low emergence for which greater soil properties analysis (bulk density, infiltration, toxicity, pH, fertilizer requirements, etc.) should be performed with additional planting seasons.

When available for successive cropping seasons (i.e. Faison and Knightdale), the results of plot trials show obvious trends of increased canola yields with subsequent year of planting. In Faison, 2010 seed yields were approximately 3:1 compared with those observed from 2009 planting. In consideration of lower rainfall observations in the second year of planting, the increase in productivity cannot be attributed necessarily to climatic effects on crop response. Precipitation data was retrieved from weather stations in closest proximity to each experimental location (NC CRONOS/ECONet Database, State Climate Office of North Carolina, Raleigh, N.C.) (Appendix C). Rather, the results reasonably could be indicative of increased productivity due to improved seedbed conditions following previous agricultural working of the soil. These improved seedbed conditions could be achieved in both instances of previous wildflower cultivation practices and project-specific oilseed crop cultivation.

Overall, improved results with subsequent year of planting may support the inference that the combination of tillage, the ability of canola roots to penetrate compacted soil and reincorporate nitrogen into the soil, and the post-harvest return of extraneous crop residues into the soil provide sufficient working of the soil and nutritive restoration to increase the productivity of ROW soils to a level competitive with, or comparable to, traditional agricultural cropland.

Considering canola yield differences observed between Pittsboro (no-till) and the other sites (maximum tillage) during the 2010 planting season, degree and depth of compaction should be considered for selection of a tillage practice that will maximize productive yield while minimizing costs. If the primary constraints in a prospective location correspond to soil conditions, level of compaction, or highway safety measures, then these areas must be evaluated beyond the use of GIS analysis.

Planting date is also an important factor in oilseed productivity and yield. However, scheduling of planting and harvesting operations often is affected by unavoidable circumstances (e.g., equipment availability and operatory issues, weather considerations, additional scheduling conflicts, etc.). Since incidences of abnormal climatic conditions should be taken into consideration as factors including rainfall and temperature are shown to greatly affect soil properties and tillage requirements (Hanna and Al-Kaisi; 2009), yields may increase with utilizing earlier planting dates for canola in North Carolina.

3.3.2 *GIS Analysis*

When analyzing North Carolina seasonal temperature and precipitation data based on the 8 month growing season of canola, it was determined that there are no substantial geographical regions of the state to be excluded from similar project implementation. The estimated total acreage of the eligible ROW amounted to 7,340 ha (18,136 ac) [assuming plot width of 3.05 m (10 ft) and calculated total eligible ROW length of 24,079,835 m (79,002,083 ft)].

The results of the GIS program analysis report the amount of ROW acreage available based on selection criteria and indicate regions of North Carolina that are most suitable for project implementation. Additional information regarding safety regulations either were not available in formats compatible with GIS mapping software, the files were too large or outside the budget of the project, or the resolution of the data available was too low for meaningful analysis. Although these additional factors, including human and wildlife safety, were not available for analysis in the GIS program, they should be considered for site selection nonetheless. These factors include slope, adjacent traffic volume, and human and wildlife safety considerations. Slope of the land is especially important to consider when planning agricultural production operations along ROWs. However, slope data files were not available to resolutions high enough to analyze ROW characteristics within the specified distance of 5.49 m (18 ft) from the roadway. Therefore, once sites are selected based on the parameters analyzed with ArcGIS software, slope should be visually inspected to ensure safety of machinery operation.

3.4 Conclusions

Overall, increased seed yields were observed with subsequent year of planting. In the absence of data suggesting more favorable climatic conditions in 2010 versus 2009, the improved yields may support the conclusion that the combination of that a single initial tillage treatment, the ability of canola to reincorporate nitrogen into the soil, and the post-harvest return of extraneous crop residues into the soil provide sufficient working of the soil and nutritive restoration to increase the productivity of ROW soils to a level competitive with, or comparable to, traditional agricultural cropland. Moreover, the greater seed yields observed in previous wildflower beds plots versus previously uncultivated ROW soils suggest that it may be advantageous for soils be conditioned in accordance with NCDOT wildflower production procedures prior to initial oilseed crop cultivation. However, since these results could be resultant of either the productive effects from 1) initial MT tillage treatment, 2) previous agricultural working of the soil, or 3) interactions between the two effects, further research and additional seasons of cropping are needed to attribute the effects to a particular influencing factor or interaction of factors. Particular attention should be paid to those areas exhibiting low emergence for which greater soil properties analysis (bulk density, infiltration, toxicity, pH, fertilizer requirements, etc.) should be performed.

Additionally, the increased yields in the northernmost sites versus more southerly sites may be influenced by characteristics of soil types found in these locations. While the soils in ROWs have been redistributed to the roadsides and thus cannot be easily analyzed on a large scale (i.e., via GIS mapping), there still exist trends of soils commonly native to specific regions of the state (e.g., sandy soils near the coast, etc.) that should be considered when planning scale-up project implementation.

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APPENDICES

Appendix A: Agricultural Roadside Operations

Appendix A1: Research Sites

Appendix A1.1 Aerial imagery of Faison research site (Google Maps, 2011).

Figure A1.1a Aerial image of Faison research site (Google Maps, 2011).

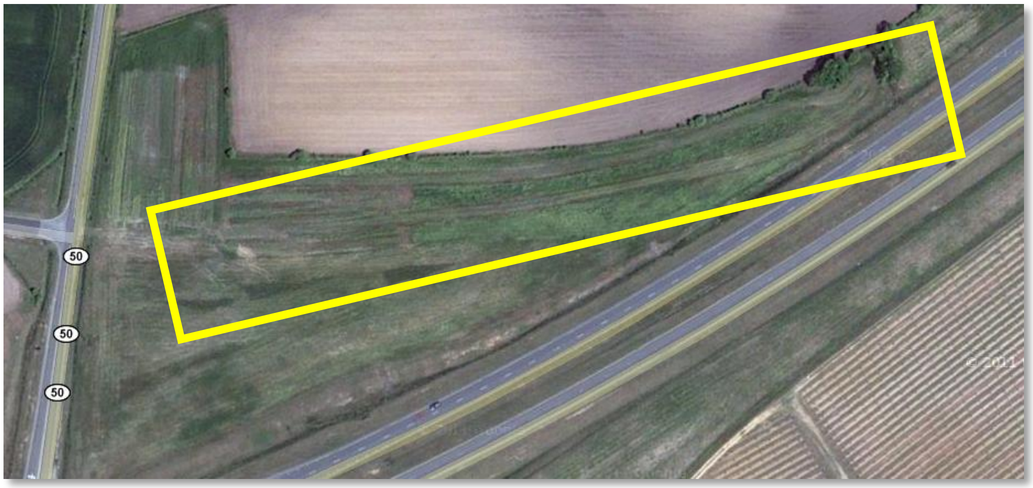

Figure A1.1b Aerial imagery of Faison maximum tillage plots (Chapter 3) (Google Maps, 2011).

Appendix A1.2 Aerial imagery and plot layout of Knightdale research site (Google Maps, 2011).

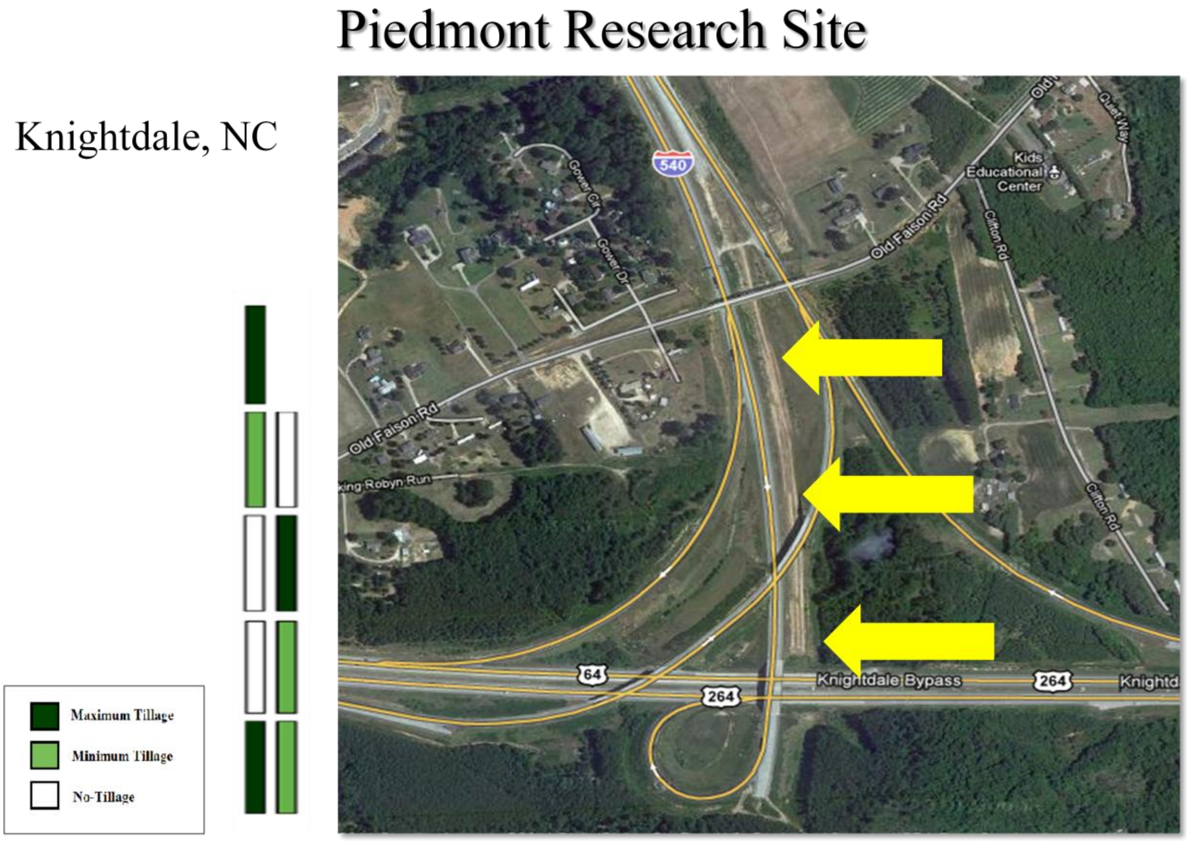

Figure A1.2. Aerial image and plot layout of Knightdale research site (Google Maps, 2011).

Appendix A1.3 Aerial imagery of Mount Airy research site (Google Maps, 2011).

Figure A1.3a. Aerial imagery of Mount Airy research site (Chapter 2) (Google Maps, 2011).

Figure A1.3b. Aerial view of Mount Airy maximum tillage plots (Chapter 3) (Google Maps, 2011).

Appendix A1.4 Aerial imagery of Pittsboro research site (Google Maps, 2011).

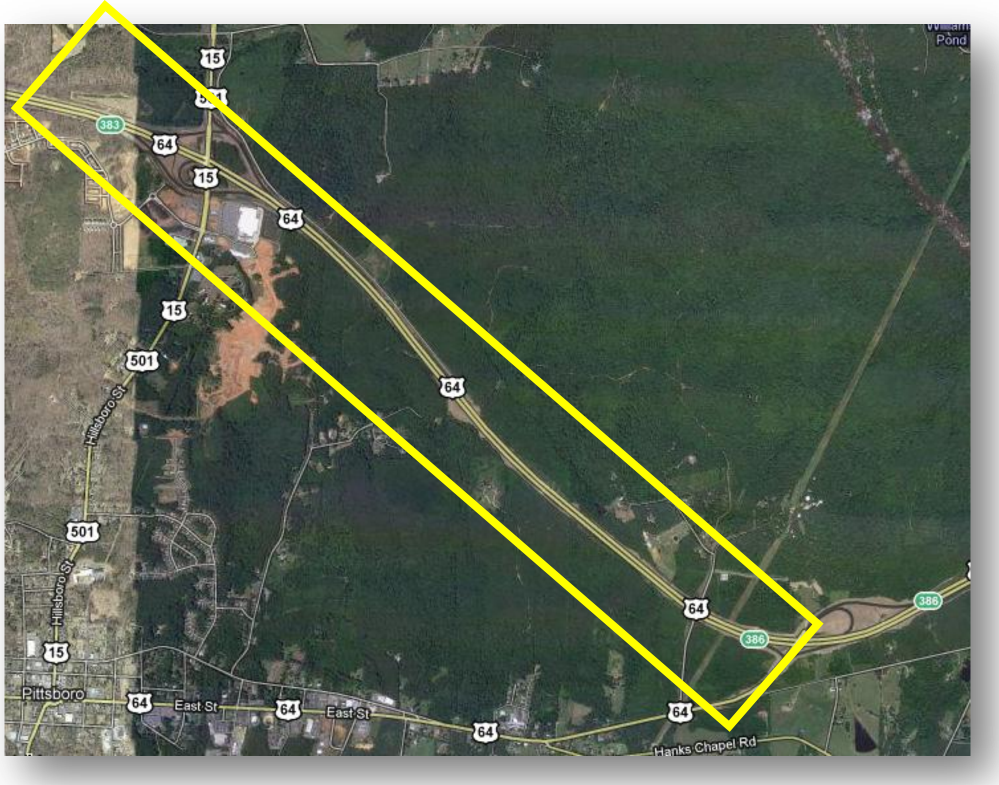

Figure A1.4. Pittsboro research plots location (Google Maps, 2011).

Appendix A1.5 Aerial imagery of Rutherfordton research site (Google Maps, 2011).

Figure A1.5. Rutherfordton research plots locations (Google Maps, 2011).

Appendix A2: Agricultural Equipment and Seedbed Preparation

Appendix A2.1 Tillage Treatments

Figure A2.1.1 Rotary tillage with New Holland 6640 tractor coupled with M&W Dyna-Drive surface cultivator (1 pass, followed by planting with no-till drill for minimum tillage treatment; 3 passes, followed by planting with no-till drill for maximum tillage treatment) (photo courtesy of NCDOT).

Figure A2.1.2 Planting with John Deere 1590 no-till drill following maximum tillage treatment at Knightdale research site (photo courtesy of NCDOT).

Figure A2.1.3 Seedbed preparation by maximum tillage treatment at Knightdale research site (photo courtesy of NCDOT).

Figure A2.1.4 Seedbed preparation by minimum tillage treatment (left) and no-till planting (right) at Knightdale research site (photo courtesy of NCDOT).

Figure A2.1.5 Seedbed following maximum tillage and planting at Knightdale research site (photo courtesy of NCDOT).

Figure A2.1.6 Depiction of minimal soil disturbance associated with no-till treatment with John Deere 1590 at Knightdale research site (photo courtesy of NCDOT).

Appendix A2.2 Canola Yields

Figure A2.1 Flowering by no-till treatment at Pittsboro research site (photo courtesy of NCDOT).

Figure A2.2 Flowering at Faison research site in April 2011 (2010 cropping season) (photo courtesy of NCDOT).

Figure A2.2 Flowering at Knightdale research site (photo courtesy of NCDOT).

Figure A2.2 Mature canola crop at Faison research site (photo courtesy of NCDOT).

Appendix B: NCDA&CS Agronomic Division Soil Reports

Appendix D.1 Soil report for Rutherfordton research plot (NCDA&CS Agronomic Division 2011)

SAMPLE ID	BASE SAT.	AC	pH	P	K	Ca	Mg	Mn	Mn Avail Crop1	Mn Avail Crop2	Zn	Zn Avail	Cu	S	Na
RUTH1	68	1.8	5.1	5	32	42	24	724	444	451	66	66	116	66	0.1
RUTH2	83	1.1	6	31	93	50	26	793	486	493	155	155	182	23	0.1
RUTH3	86	0.9	6.3	18	60	54	28	727	442	449	149	149	116	25	0
RUTH4	79	1.1	5.8	5	47	49	24	1212	737	744	90	90	92	31	0
RUTH5	77	1.4	5.4	4	47	49	24	1434	870	877	93	93	182	66	0.1
RUTH6	86	1.1	6.2	30	87	54	26	1329	804	811	218	218	325	37	0.1
RUTH7	86	1.1	5.9	5	74	47	35	1277	778	785	89	89	145	24	0

Appendix D.2 Soil report for Mount Airy research plot (NCDA&CS Agronomic Division, 2011)

SAMPLE ID	BASE SAT.	AC	pH	P	K	Ca	Mg	Mn	Mn Avail Crop1	Mn Avail Crop2	Zn	Zn Avail	Cu	S	Na
SURRY															
LRG01	67	2.1	5	128	158	40	15	666	409	409	85	85	90	52	0.1
LRG02	98	0.2	7.3	86	145	82	10	653	389	389	80	80	115	31	0.1
LRG03	62	2	5.2	55	75	42	14	573	353	353	53	53	110	35	0.1
LRG04	89	1	6.2	28	126	60	21	689	423	423	73	73	165	49	0.1
TR001	95	0.5	6.9	74	79	62	30	771	466	466	90	90	90	35	0
TR002	95	0.6	6.9	84	75	63	30	665	402	402	103	103	95	39	0
TR003	92	0.8	6.6	73	83	59	29	534	328	328	92	92	95	36	0.1

Appendix D.3 Soil report for Faison research plot (NCDA&CS Agronomic Division, 2011)

SAMPLE ID	BASE SAT.	AC	pH	P	K	Ca	Mg	Mn	Mn Avail Crop1	Mn Avail Crop2	Zn	Zn Avail	Cu	S	Na
FAI01	98	0.3	7.1	572	154	82	12	141	78	78	1192	1192	417	48	0
FAI02	93	0.8	6.6	410	145	67	21	77	47	47	477	477	209	29	0
FAI03	93	1	6.5	448	173	66	21	84	53	53	428	428	231	37	0
FAI04	85	1.4	6.3	393	109	56	23	77	52	52	214	214	151	45	0
FAI05	92	0.9	6.6	366	158	61	24	79	48	48	271	271	159	36	0
FAI06	95	0.7	6.7	505	174	66	22	82	49	49	561	561	252	43	0

Appendix D.4 Soil report for Knightdale research plot (NCDA&CS Agronomic Division, 2011)

SAMPLE ID	BASE SAT.	AC	pH	P	K	Ca	Mg	Mn	Mn Avail Crop1	Mn Avail Crop2	Zn	Zn Avail	Cu	S	Na
RAL01	100	0	8	85	96	86	9	126	55	55	66	66	72	39	0
RAL02	97	0.2	7	52	89	63	27	154	87	87	48	48	39	57	0.1
RAL03	85	0.7	5.8	29	69	58	19	225	148	148	32	32	29	88	0
RAL04	68	1.6	5	21	93	44	16	34	30	30	33	33	19	294	0
RAL05	100	0	8.1	17	215	94	4	45	5	5	246	246	90	831	0.4
RAL06	100	0	8.1	38	104	84	12	77	24	24	118	118	47	101	0

Appendix C: North Carolina CRONOS Rainfall Data

Data retrieval from NC-DP-3 - Mount Olive (Faison) 2.4 SW past 24 months
25 records for this period of record
NC CRONOS Database version 2.7.2

Date/Time (EST)	Number of Records Compiled	monthly SUM of 2m Daily Precipitation (in)
Jul-09	31 (100%)	4.65
Aug-09	31 (100%)	11.5
Sep-09	30 (100%)	2.35
Oct-09	29 (93.5%)	1.14
Nov-09	30 (100%)	5.09
Dec-09	31 (100%)	5.6
Jan-10	31 (100%)	4.1501
Feb-10	28 (100%)	4.31
Mar-10	31 (100%)	4.3102
Apr-10	30 (100%)	0.88
May-10	31 (100%)	4.2801
Jun-10	30 (100%)	2.73
Jul-10	31 (100%)	5.7102
Aug-10	31 (100%)	5.48
Sep-10	30 (100%)	9.0001
Oct-10	31 (100%)	2.9701
Nov-10	30 (100%)	0.7702
Dec-10	31 (100%)	2.27
Jan-11	29 (93.5%)	0.9603
Feb-11	27 (96.4%)	2.15
Mar-11	30 (96.8%)	3.5802
Apr-11	24 (80%)	4.67
May-11	23 (74.2%)	2.67
Jun-11	28 (93.3%)	0.9901
Jul-11	19 (61.3%)	1.05

Data retrieval from NC-WK-48 - Knightdale 1.9 WSW past 24 months
25 records for this period of record
NC CRONOS Database version 2.7.2

Date/Time (EST)	Number of Records Compiled	monthly SUM of 2m Daily Precipitation (in)
Jul-09	29 (93.5%)	3.3705
Aug-09	31 (100%)	3.74
Sep-09	27 (90%)	3.2702
Oct-09	30 (96.8%)	1.5104
Nov-09	30 (100%)	5.7302
Dec-09	29 (93.5%)	5.2501
Jan-10	31 (100%)	4.62
Feb-10	28 (100%)	3.1001
Mar-10	31 (100%)	4.0401
Apr-10	30 (100%)	2.3301
May-10	28 (90.3%)	5.4503
Jun-10	30 (100%)	3.98
Jul-10	18 (58.1%)	1.4
Aug-10	31 (100%)	7.66
Sep-10	30 (100%)	7.11
Oct-10	31 (100%)	1.3402
Nov-10	29 (96.7%)	0.9601
Dec-10	28 (90.3%)	1.89
Jan-11	16 (51.6%)	1.77
Feb-11	21 (75%)	1.5401
Mar-11	18 (58.1%)	4.3302
Apr-11	21 (70%)	4.0301
May-11	24 (77.4%)	3.11
Jun-11	16 (53.3%)	2.2401
Jul-11	22 (71%)	1.9101

STATE CLIMATE OFFICE OF NORTH CAROLINA
NC STATE UNIVERSITY
CRONOS Database
Station ID: 315890 Station type: COOP Station name: Mt Airy 2 W
City, State: Mount Airy, NC County: Surry County
Latitude: 36.49917 Longitude: -80.65083
Elevation: 1041 feet above sea level
Climate division: NC02 - Northern Mountains
Supported by: NOAA National Weather Service
Data retrieval from 315890 - Mt Airy 2 W past 24 months
25 records for this period of record

Date/Time (EST)	Number of Records Compiled	monthly SUM of 2m Daily Precipitation (in)
Jul-09	31 (100%)	6.67
Aug-09	31 (100%)	4.85
Sep-09	30 (100%)	2.97
Oct-09	31 (100%)	2.36
Nov-09	30 (100%)	5.76
Dec-09	31 (100%)	7.7
Jan-10	31 (100%)	6.09
Feb-10	28 (100%)	2.88
Mar-10	31 (100%)	5.05
Apr-10	30 (100%)	1.9
May-10	30 (96.8%)	6.02
Jun-10	30 (100%)	2.41
Jul-10	31 (100%)	3.51
Aug-10	31 (100%)	4.49
Sep-10	30 (100%)	4.1
Oct-10	31 (100%)	3.2
Nov-10	30 (100%)	1.59
Dec-10	31 (100%)	4.09
Jan-11	31 (100%)	1.13
Feb-11	28 (100%)	1.63
Mar-11	31 (100%)	7.04
Apr-11	30 (100%)	4.6
May-11	31 (100%)	6.36
Jun-11	30 (100%)	6.59
Jul-11	24 (77.4%)	2.89

Appendix D: SAS® Analyses of Canola Seed Yield Data for Research Sites

Appendix D1 SAS® Analysis Program Output

```
                                   Site Fixed, Tillage Fixed, By Year

--------------------------------------------------------- year=2010 ----------------------------------------------------------------

                                       The Mixed Procedure

                                        Model Information

                              Data Set                  WORK.BOTH
                              Dependent Variable          yld
                              Covariance Structure        Diagonal
                              Estimation Method           REML
                              Residual Variance Method     Profile
                              Fixed Effects SE Method      Model-Based
                              Degrees of Freedom Method    Residual


                                      Class Level Information

                            Class              Levels    Values

                            site                   3    FAIS RAL SURR
                            TillageTreatment         3    Max Min No
                            plot                  11    1 2 3 4 5 6 7 8 9 11 12
                            year                   1    2010


                                          Dimensions

                                 Covariance Parameters            1
                                 Columns in X                   16
                                 Columns in Z                    0
                                 Subjects                     1
                                 Max Obs Per Subject            28


                                     Number of Observations

                               Number of Observations Read            28
                               Number of Observations Used            28
                               Number of Observations Not Used          0


                                      Covariance Parameter
```

```
                                        Estimates

                                   Cov Parm     Estimate

                                   Residual       104670

                                       Fit Statistics

                          -2 Res Log Likelihood          283.6
                          AIC (smaller is better)        285.6
                          AICC (smaller is better)       285.8
                          BIC (smaller is better)        286.5


                                 Type 3 Tests of Fixed Effects

                                         Num     Den
                       Effect             DF      DF    F Value    Pr > F

                       site                2      19       7.81    0.0034
                       TillageTreatment    2      19       2.72    0.0912
                       site*TillageTreatmen 4     19       0.19    0.9409


                                        Estimates

                                                   Standard
                  Label                   Estimate      Error      DF    t Value    Pr > |t|

                  notill versus avg of max,min   -201.30   132.08   19    -1.52     0.1440

                                   Least Squares Means

                                 Tillage              Standard
              Effect        site    Treatment    Estimate       Error      DF    t Value    Pr > |t|

              site          FAIS                   980.29     98.4460     19       9.96      <.0001
              site          RAL                    553.03      116.48     19       4.75      0.0001
              site          SURR                  1168.61      107.84     19      10.84      <.0001
              TillageTreatment      Max           1107.99      112.25     19       9.87      <.0001
              TillageTreatment      Min            827.49      103.25     19       8.01      <.0001
              TillageTreatment      No             766.44      107.84     19       7.11      <.0001


                               Differences of Least Squares Means

                                 Tillage            _Tillage             Standard
               Effect       site    Treatment    _site    Treatment    Estimate       Error     DF    t Value    Pr > |t|
Adjustment       Adj P

               site         FAIS            RAL                  427.26      152.51     19      2.80      0.0114    Tukey-
Kramer    0.0293
               site         FAIS            SURR                -188.32      146.02     19     -1.29      0.2126    Tukey-
Kramer    0.4179
               site         RAL             SURR                -615.58      158.74     19     -3.88      0.0010    Tukey-
Kramer    0.0028
```

```
                    TillageTreatment        Max           Min       280.50     152.51     19      1.84      0.0816    Tukey-
Kramer    0.1840
                    TillageTreatment        Max           No        341.55     155.66     19      2.19      0.0409    Tukey-
Kramer    0.0979
                    TillageTreatment        Min           No       61.0494     149.30     19      0.41      0.6872    Tukey-
Kramer    0.9124

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                                          Site Fixed, Tillage Fixed, By Year

-------------------------------------------------------------------------------------------- year=2011 ----------------------------------------

                                               The Mixed Procedure


                                               Model Information

                                    Data Set                  WORK.BOTH
                                    Dependent Variable          yld
                                    Covariance Structure        Diagonal
                                    Estimation Method           REML
                                    Residual Variance Method     Profile
                                    Fixed Effects SE Method      Model-Based
                                    Degrees of Freedom Method    Residual


                                             Class Level Information

                                   Class              Levels    Values

                                   site                    3    FAIS RAL SURR
                                   TillageTreatment        3    Max Min No
                                   plot                   12    1 2 3 4 5 6 7 8 9 10 11 12
                                   year                    1    2011


                                                 Dimensions

                                       Covariance Parameters            1
                                       Columns in X                    16
                                       Columns in Z                     0
                                       Subjects                         1
                                       Max Obs Per Subject             30


                                            Number of Observations

                                     Number of Observations Read             30
                                     Number of Observations Used             30
                                     Number of Observations Not Used          0


                                             Covariance Parameter
                                                  Estimates
```

```
                          Cov Parm     Estimate

                          Residual       351420


                              Fit Statistics

                    -2 Res Log Likelihood          338.5
                    AIC (smaller is better)        340.5
                    AICC (smaller is better)       340.7
                    BIC (smaller is better)        341.6


                         Type 3 Tests of Fixed Effects

                                 Num     Den
              Effect              DF      DF    F Value    Pr > F

              site                 2      21      26.56    <.0001
              TillageTreatment     2      21       3.98    0.0343
              site*TillageTreatmen 4      21       0.35    0.8419


                                  Estimates

                                           Standard
      Label                       Estimate      Error     DF    t Value    Pr > |t|

      notill versus avg of max,min  -653.48     231.71     21      -2.82      0.0103


                              Least Squares Means

                                Tillage             Standard
   Effect             site    Treatment    Estimate      Error     DF    t Value    Pr > |t|

   site               FAIS                  3204.22     171.13     21      18.72      <.0001
   site               RAL                   1353.98     197.60     21       6.85      <.0001
   site               SURR                  2000.12     197.60     21      10.12      <.0001
   TillageTreatment           Max           2398.63     189.19     21      12.68      <.0001
   TillageTreatment           Min           2409.23     189.19     21      12.73      <.0001
   TillageTreatment           No            1750.45     189.19     21       9.25      <.0001


                            Differences of Least Squares Means

                      Tillage           _Tillage            Standard
Effect           site    Treatment    _site    Treatment    Estimate      Error     DF    t Value    Pr > |t|    Adjustment      Adj P

site             FAIS                 RAL                    1850.23     261.40     21       7.08      <.0001    Tukey-Kramer    <.0001
site             FAIS                 SURR                   1204.10     261.40     21       4.61      0.0002    Tukey-Kramer    0.0004
site             RAL                  SURR                   -646.14     279.45     21      -2.31      0.0310    Tukey-Kramer    0.0760
TillageTreatment         Max                   Min          -10.6053     267.55     21      -0.04      0.9688    Tukey           0.9991
TillageTreatment         Max                   No             648.17     267.55     21       2.42      0.0245    Tukey           0.0610
TillageTreatment         Min                   No             658.78     267.55     21       2.46      0.0225    Tukey           0.0563
```

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                         Site Fixed, Tillage Fixed, Years Combined

                                  The Mixed Procedure

                                   Model Information

                   Data Set                     WORK.BOTH
                   Dependent Variable           yld
                   Covariance Structure         Variance Components
                   Estimation Method            REML
                   Residual Variance Method     Profile
                   Fixed Effects SE Method      Model-Based
                   Degrees of Freedom Method    Containment



                                Class Level Information

                 Class               Levels    Values

                 site                     3    FAIS RAL SURR
                 TillageTreatment         3    Max Min No
                 plot                    12    1 2 3 4 5 6 7 8 9 10 11 12
                 year                     2    2010 2011


                                      Dimensions

                          Covariance Parameters             6
                          Columns in X                     16
                          Columns in Z                     62
                          Subjects                          1
                          Max Obs Per Subject              58


                                 Number of Observations

                      Number of Observations Read              58
                      Number of Observations Used              58
                      Number of Observations Not Used           0


                                   Iteration History

                 Iteration    Evaluations    -2 Res Log Like       Criterion

                         0              1       828.68197472
                         1              4       839.46928304            .
                         2              1       838.31112552      0.00834153
                         3              3       787.21243344      0.05807900
                         4              3       786.15578659      0.00003835
                         5              3       781.06705700            .
                         6              1       781.06537684            .
                         7              3       781.02110018      0.65439840
```

```
         8           1       780.49675161      0.09681940
         9           1       780.26802721      0.01104868
        10           2       779.45815029      0.00068984
        11           2       777.97392602      0.00014580
        12           2       776.59306898      0.00004620
        13           2       775.30742844      0.00003445
        14           2       774.16144403      0.00007567
        15           2       773.26248194      0.00014292
        16           2       772.80911514      0.00003018
        17           2       772.13101146      0.00000388
        18           2       771.48924340      0.00000131
        19           2       770.89815222      0.00000243
        20           2       770.40743328      0.00000540
        21           2       770.07570751      0.00057193
        22           2       770.01275950      0.00003796
        23           1       769.99795405      0.00000276
        24           1       769.99696547      0.00000002
        25           1       769.99695896      0.00000000


                 Convergence criteria met.


                Covariance Parameter Estimates

                Cov Parm               Estimate

                year                  714742
                site*year               318515
                TillageTreatmen*year       26038
                site*TillageTre*year           0
                plot(site)                     0
                Residual                 219540


                     Fit Statistics

               -2 Res Log Likelihood          770.0
               AIC (smaller is better)        778.0
               AICC (smaller is better)        778.9
               BIC (smaller is better)        772.8


                  Type 3 Tests of Fixed Effects

                          Num     Den
         Effect             DF      DF    F Value    Pr > F

         site                 2       2       1.89    0.3458
         TillageTreatment         2       2       2.69    0.2710
         site*TillageTreatmen       4       4       0.30    0.8649


                         Estimates

                                Standard
 Label                    Estimate       Error      DF    t Value    Pr > |t|
```

```
                    notill versus avg of max,min     -431.71      192.34      2      -2.24      0.1539


                                   Least Squares Means

                               Tillage              Standard
                 Effect          site   Treatment   Estimate      Error     DF    t Value    Pr > |t|

                 site            FAIS               2088.11      728.41      2      2.87      0.1032
                 site            RAL                 953.86      730.79      2      1.31      0.3218
                 site            SURR               1584.36      730.18      2      2.17      0.1622
                 TillageTreatment         Max       1753.67      659.96      2      2.66      0.1172
                 TillageTreatment         Min       1618.36      659.28      2      2.45      0.1335
                 TillageTreatment         No        1254.31      659.64      2      1.90      0.1976


                              Differences of Least Squares Means

                       Tillage            _Tillage            Standard
       Effect            site   Treatment   _site   Treatment   Estimate     Error     DF   t Value   Pr > |t|    Adjustment      Adj P

       site              FAIS              RAL                 1134.25      584.15      2      1.94     0.1917    Tukey-Kramer    0.3259
       site              FAIS              SURR                 503.75      583.37      2      0.86     0.4789    Tukey-Kramer    0.7091
       site              RAL               SURR                -630.50      586.34      2     -1.08     0.3947    Tukey-Kramer    0.6114
       TillageTreatment            Max               Min        135.31      222.01      2      0.61     0.6042    Tukey-Kramer
0.8302
       TillageTreatment            Max               No         499.36      223.09      2      2.24     0.1546    Tukey-Kramer    0.2668
       TillageTreatment            Min               No         364.05      221.05      2      1.65     0.2413    Tukey-Kramer    0.4018


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                          Site Fixed, Tillage Fixed, Year Fixed

                                 The Mixed Procedure

                                  Model Information

                         Data Set                    WORK.BOTH
                         Dependent Variable          yld
                         Covariance Structure        Variance Components
                         Estimation Method           REML
                         Residual Variance Method    Profile
                         Fixed Effects SE Method     Model-Based
                         Degrees of Freedom Method   Containment



                                Class Level Information

                       Class              Levels    Values

                       site                   3    FAIS RAL SURR
                       TillageTreatment       3    Max Min No
                       plot                  12    1 2 3 4 5 6 7 8 9 10 11 12
```

```
year                2    2010 2011


                    Dimensions

          Covariance Parameters          2
          Columns in X                  48
          Columns in Z                  30
          Subjects                       1
          Max Obs Per Subject           58


                 Number of Observations

       Number of Observations Read             58
       Number of Observations Used             58
       Number of Observations Not Used          0


                   Iteration History

Iteration    Evaluations    -2 Res Log Like       Criterion

        0              1       628.88260989
        1              1       628.88260989      0.00000000


                Convergence criteria met.


                 Covariance Parameter
                      Estimates

                 Cov Parm       Estimate

                 plot(site)            0
                 Residual         234214

                    Fit Statistics

          -2 Res Log Likelihood           628.9
          AIC (smaller is better)         630.9
          AICC (smaller is better)        631.0
          BIC (smaller is better)         632.3





                Type 3 Tests of Fixed Effects

                      Num     Den
 Effect                DF      DF    F Value    Pr > F
```

```
site                   2     25      26.59    <.0001
TillageTreatment         2     15       5.18    0.0194
site*TillageTreatmen      4     15       0.29    0.8807
year                   1     15      99.39    <.0001
site*year                2     15      14.50    0.0003
TillageTreatmen*year      2     15       1.83    0.1944
site*TillageTre*year      4     15       0.32    0.8576


                          Least Squares Means

                       Tillage                        Standard
Effect               site   Treatment   year       Estimate     Error     DF    t Value    Pr > |t|

site                 FAIS                      2092.25     101.49     25     20.61     <.0001
site                 RAL                        953.50     118.73     25      8.03     <.0001
site                 SURR                      1584.36     114.07     25     13.89     <.0001
TillageTreatment            Max                    1753.31     114.07     15     15.37     <.0001
TillageTreatment            Min                    1618.36     109.21     15     14.82     <.0001
TillageTreatment            No                     1258.45     111.67     15     11.27     <.0001
site*TillageTreatmen   FAIS    Max                     2243.58     171.10     15     13.11     <.0001
site*TillageTreatmen   FAIS    Min                     2181.28     171.10     15     12.75     <.0001
site*TillageTreatmen   FAIS    No                      1851.89     184.81     15     10.02     <.0001
site*TillageTreatmen   RAL     Max                     1142.19     220.89     15      5.17     0.0001
site*TillageTreatmen   RAL     Min                      963.54     197.57     15      4.88     0.0002
site*TillageTreatmen   RAL     No                       754.78     197.57     15      3.82     0.0017
site*TillageTreatmen   SURR    Max                     1874.16     197.57     15      9.49     <.0001
site*TillageTreatmen   SURR    Min                     1710.26     197.57     15      8.66     <.0001
site*TillageTreatmen   SURR    No                      1168.67     197.57     15      5.92     <.0001
year                                2010     900.64     93.1374     15      9.67     <.0001
year                                2011    2186.10     89.1723     15     24.52     <.0001
site*year            FAIS               2010     980.29     147.26     15      6.66     <.0001
site*year            FAIS               2011    3204.21     139.71     15     22.94     <.0001
site*year            RAL                2010     553.03     174.24     15      3.17     0.0063
site*year            RAL                2011    1353.98     161.32     15      8.39     <.0001
site*year            SURR               2010    1168.61     161.32     15      7.24     <.0001
site*year            SURR               2011    2000.12     161.32     15     12.40     <.0001
TillageTreatmen*year          Max          2010    1107.99     167.91     15      6.60     <.0001
TillageTreatmen*year          Max          2011    2398.63     154.45     15     15.53     <.0001
TillageTreatmen*year          Min          2010     827.49     154.45     15      5.36     <.0001
TillageTreatmen*year          Min          2011    2409.23     154.45     15     15.60     <.0001
TillageTreatmen*year          No           2010     766.44     161.32     15      4.75     0.0003
TillageTreatmen*year          No           2011    1750.45     154.45     15     11.33     <.0001
site*TillageTre*year   FAIS    Max          2010    1168.10     241.98     15      4.83     0.0002
site*TillageTre*year   FAIS    Max          2011    3319.07     241.98     15     13.72     <.0001
site*TillageTre*year   FAIS    Min          2010     837.45     241.98     15      3.46     0.0035
site*TillageTre*year   FAIS    Min          2011    3525.12     241.98     15     14.57     <.0001
site*TillageTre*year   FAIS    No           2010     935.33     279.41     15      3.35     0.0044
site*TillageTre*year   FAIS    No           2011    2768.46     241.98     15     11.44     <.0001
site*TillageTre*year   RAL     Max          2010     727.12     342.21     15      2.12     0.0506
site*TillageTre*year   RAL     Max          2011    1557.26     279.41     15      5.57     <.0001
site*TillageTre*year   RAL     Min          2010     542.25     279.41     15      1.94     0.0713
site*TillageTre*year   RAL     Min          2011    1384.84     279.41     15      4.96     0.0002
site*TillageTre*year   RAL     No           2010     389.72     279.41     15      1.39     0.1834
site*TillageTre*year   RAL     No           2011    1119.85     279.41     15      4.01     0.0011
site*TillageTre*year   SURR    Max          2010    1428.76     279.41     15      5.11     0.0001
site*TillageTre*year   SURR    Max          2011    2319.55     279.41     15      8.30     <.0001
site*TillageTre*year   SURR    Min          2010    1102.79     279.41     15      3.95     0.0013
site*TillageTre*year   SURR    Min          2011    2317.74     279.41     15      8.30     <.0001
site*TillageTre*year   SURR    No           2010     974.29     279.41     15      3.49     0.0033
site*TillageTre*year   SURR    No           2011    1363.06     279.41     15      4.88     0.0002
```

```
                                   Differences of Least Squares Means

                          Tillage                  _Tillage                    Standard
        Effect         site   Treatment   year       _site   Treatment   _year      Estimate     Error    DF    t Value    Pr > |t|
Adjustment      Adj P

        site              FAIS                    RAL                         1138.75     156.20     25      7.29     <.0001    Tukey-Kramer
<.0001
        site              FAIS                    SURR                         507.89     152.69     25      3.33     0.0027    Tukey-Kramer
0.0074
        site              RAL                     SURR                        -630.86     164.65     25     -3.83     0.0008    Tukey-Kramer
0.0021
        TillageTreatment            Max                     Min                     134.95     157.92     15      0.85      0.4063    Tukey-
Kramer    0.6760
        TillageTreatment            Max                     No                      494.86     159.63     15      3.10      0.0073    Tukey-
Kramer    0.0189
        TillageTreatment            Min                     No                      359.91     156.20     15      2.30      0.0359    Tukey-
Kramer    0.0860
        site*TillageTreatmen    FAIS    Max              FAIS    Min                 62.2988     241.98     15      0.26      0.8003
Tukey-Kramer    1.0000
        site*TillageTreatmen    FAIS    Max              FAIS    No                  391.69     251.86     15      1.56      0.1407
Tukey-Kramer    0.8136
        site*TillageTreatmen    FAIS    Max              RAL     Max                 1101.39     279.41     15      3.94      0.0013
Tukey-Kramer    0.0263
        site*TillageTreatmen    FAIS    Max              RAL     Min                 1280.04     261.37     15      4.90      0.0002
Tukey-Kramer    0.0044
        site*TillageTreatmen    FAIS    Max              RAL     No                  1488.80     261.37     15      5.70      <.0001
Tukey-Kramer    0.0010
        site*TillageTreatmen    FAIS    Max              SURR    Max                  369.42     261.37     15      1.41      0.1779
Tukey-Kramer    0.8762
        site*TillageTreatmen    FAIS    Max              SURR    Min                  533.32     261.37     15      2.04      0.0593
Tukey-Kramer    0.5412
        site*TillageTreatmen    FAIS    Max              SURR    No                  1074.91     261.37     15      4.11      0.0009
Tukey-Kramer    0.0191
        site*TillageTreatmen    FAIS    Min              FAIS    No                  329.39     251.86     15      1.31      0.2106
Tukey-Kramer    0.9140
        site*TillageTreatmen    FAIS    Min              RAL     Max                 1039.09     279.41     15      3.72      0.0021
Tukey-Kramer    0.0396
        site*TillageTreatmen    FAIS    Min              RAL     Min                 1217.74     261.37     15      4.66      0.0003
Tukey-Kramer    0.0069
        site*TillageTreatmen    FAIS    Min              RAL     No                  1426.50     261.37     15      5.46      <.0001
Tukey-Kramer    0.0016
        site*TillageTreatmen    FAIS    Min              SURR    Max                  307.13     261.37     15      1.18      0.2583
Tukey-Kramer    0.9503
        site*TillageTreatmen    FAIS    Min              SURR    Min                  471.02     261.37     15      1.80      0.0917
Tukey-Kramer    0.6807
        site*TillageTreatmen    FAIS    Min              SURR    No                  1012.61     261.37     15      3.87      0.0015
Tukey-Kramer    0.0297
        site*TillageTreatmen    FAIS    No               RAL     Max                  709.70     288.01     15      2.46      0.0263
Tukey-Kramer    0.3196
        site*TillageTreatmen    FAIS    No               RAL     Min                  888.35     270.54     15      3.28      0.0050
Tukey-Kramer    0.0863
        site*TillageTreatmen    FAIS    No               RAL     No                  1097.11     270.54     15      4.06      0.0010
Tukey-Kramer    0.0213
        site*TillageTreatmen    FAIS    No               SURR    Max                 -22.2646     270.54     15     -0.08      0.9355
Tukey-Kramer    1.0000
        site*TillageTreatmen    FAIS    No               SURR    Min                  141.63     270.54     15      0.52      0.6083
Tukey-Kramer    0.9997
        site*TillageTreatmen    FAIS    No               SURR    No                   683.22     270.54     15      2.53      0.0233
Tukey-Kramer    0.2931
        site*TillageTreatmen    RAL     Max              RAL     Min                  178.65     296.36     15      0.60      0.5556
Tukey-Kramer    0.9993
        site*TillageTreatmen    RAL     Max              RAL     No                   387.41     296.36     15      1.31      0.2108
Tukey-Kramer    0.9142
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        site*TillageTreatmen    RAL     Max                 SURR     Max                    -731.97      296.36      15      -2.47      0.0260
Tukey-Kramer    0.3171
        site*TillageTreatmen    RAL     Max                 SURR     Min                    -568.07      296.36      15      -1.92      0.0745
Tukey-Kramer    0.6137
        site*TillageTreatmen    RAL     Max                 SURR     No                     -26.4817     296.36      15      -0.09      0.9300
Tukey-Kramer    1.0000
        site*TillageTreatmen    RAL     Min                 RAL      No                     208.76      279.41      15      0.75      0.4665
Tukey-Kramer    0.9969
        site*TillageTreatmen    RAL     Min                 SURR     Max                    -910.61      279.41      15      -3.26      0.0053
Tukey-Kramer    0.0901
        site*TillageTreatmen    RAL     Min                 SURR     Min                    -746.72      279.41      15      -2.67      0.0174
Tukey-Kramer    0.2359
        site*TillageTreatmen    RAL     Min                 SURR     No                     -205.13      279.41      15      -0.73      0.4742
Tukey-Kramer    0.9972
        site*TillageTreatmen    RAL     No                  SURR     Max                    -1119.37     279.41      15      -4.01      0.0011
Tukey-Kramer    0.0233
        site*TillageTreatmen    RAL     No                  SURR     Min                    -955.48      279.41      15      -3.42      0.0038
Tukey-Kramer    0.0679
        site*TillageTreatmen    RAL     No                  SURR     No                     -413.89      279.41      15      -1.48      0.1592
Tukey-Kramer    0.8478
        site*TillageTreatmen    SURR    Max                 SURR     Min                    163.89      279.41      15      0.59      0.5662
Tukey-Kramer    0.9994
        site*TillageTreatmen    SURR    Max                 SURR     No                     705.48      279.41      15      2.52      0.0233
Tukey-Kramer    0.2933
        site*TillageTreatmen    SURR    Min                 SURR     No                     541.59      279.41      15      1.94      0.0716
Tukey-Kramer    0.6011
        year                                2010                        2011    -1285.46      128.94      15      -9.97      <.0001    Tukey-Kramer
<.0001
        site*year            FAIS                 2010    FAIS                 2011    -2223.93      202.99      15      -10.96      <.0001    Tukey-
Kramer    <.0001
        site*year            FAIS                 2010    RAL                  2010    427.26      228.14      15      1.87      0.0807    Tukey-
Kramer    0.4534
        site*year            FAIS                 2010    RAL                  2011    -373.69      218.43      15      -1.71      0.1077    Tukey-
Kramer    0.5455
        site*year            FAIS                 2010    SURR                 2010    -188.32      218.43      15      -0.86      0.4022    Tukey-
Kramer    0.9499
        site*year            FAIS                 2010    SURR                 2011    -1019.83      218.43      15      -4.67      0.0003    Tukey-
Kramer    0.0034
        site*year            FAIS                 2011    RAL                  2010    2651.19      223.34      15      11.87      <.0001    Tukey-
Kramer    <.0001
        site*year            FAIS                 2011    RAL                  2011    1850.23      213.40      15      8.67      <.0001    Tukey-
Kramer    <.0001
        site*year            FAIS                 2011    SURR                 2010    2035.60      213.40      15      9.54      <.0001    Tukey-
Kramer    <.0001
        site*year            FAIS                 2011    SURR                 2011    1204.10      213.40      15      5.64      <.0001    Tukey-
Kramer    0.0005
        site*year            RAL                  2010    RAL                  2011    -800.95      237.45      15      -3.37      0.0042    Tukey-
Kramer    0.0397
        site*year            RAL                  2010    SURR                 2010    -615.58      237.45      15      -2.59      0.0204    Tukey-
Kramer    0.1592
        site*year            RAL                  2010    SURR                 2011    -1447.09      237.45      15      -6.09      <.0001    Tukey-
Kramer    0.0002
        site*year            RAL                  2011    SURR                 2010    185.37      228.14      15      0.81      0.4292    Tukey-
Kramer    0.9607
        site*year            RAL                  2011    SURR                 2011    -646.14      228.14      15      -2.83      0.0126    Tukey-
Kramer    0.1059
        site*year            SURR                 2010    SURR                 2011    -831.51      228.14      15      -3.64      0.0024    Tukey-
Kramer    0.0238
        TillageTreatmen*year          Max              2010            Max              2011    -1290.64      228.14      15      -5.66      <.0001
Tukey-Kramer    0.0005
        TillageTreatmen*year          Max              2010            Min              2010    280.50      228.14      15      1.23      0.2378
Tukey-Kramer    0.8162
        TillageTreatmen*year          Max              2010            Min              2011    -1301.24      228.14      15      -5.70      <.0001
Tukey-Kramer    0.0005
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          TillageTreatmen*year          Max              2010          No              2010     341.55      232.84      15      1.47      0.1631
Tukey-Kramer    0.6887
          TillageTreatmen*year          Max              2010          No              2011     -642.46      228.14      15      -2.82      0.0130
Tukey-Kramer    0.1089
          TillageTreatmen*year          Max              2011          Min              2010     1571.13      218.43      15      7.19      <.0001
Tukey-Kramer    <.0001
          TillageTreatmen*year          Max              2011          Min              2011     -10.6053      218.43      15      -0.05      0.9619
Tukey-Kramer    1.0000
          TillageTreatmen*year          Max              2011          No              2010     1632.18      223.34      15      7.31      <.0001
Tukey-Kramer    <.0001
          TillageTreatmen*year          Max              2011          No              2011     648.17      218.43      15      2.97      0.0096
Tukey-Kramer    0.0834
          TillageTreatmen*year          Min              2010          Min              2011     -1581.74      218.43      15      -7.24      <.0001
Tukey-Kramer    <.0001
          TillageTreatmen*year          Min              2010          No              2010     61.0494      223.34      15      0.27      0.7883
Tukey-Kramer    0.9997
          TillageTreatmen*year          Min              2010          No              2011     -922.96      218.43      15      -4.23      0.0007
Tukey-Kramer    0.0078
          TillageTreatmen*year          Min              2011          No              2010     1642.79      223.34      15      7.36      <.0001
Tukey-Kramer    <.0001
          TillageTreatmen*year          Min              2011          No              2011     658.78      218.43      15      3.02      0.0087
Tukey-Kramer    0.0765
          TillageTreatmen*year          No              2010          No              2011     -984.01      223.34      15      -4.41      0.0005
Tukey-Kramer    0.0055
          site*TillageTre*year    FAIS    Max              2010    FAIS    Max              2011    -2150.97      342.21      15      -6.29      <.0001
Tukey-Kramer    0.0012
          site*TillageTre*year    FAIS    Max              2010    FAIS    Min              2010      330.65      342.21      15      0.97      0.3493
Tukey-Kramer    0.9998
          site*TillageTre*year    FAIS    Max              2010    FAIS    Min              2011    -2357.03      342.21      15      -6.89      <.0001
Tukey-Kramer    0.0004
          site*TillageTre*year    FAIS    Max              2010    FAIS    No              2010      232.77      369.63      15      0.63      0.5383
Tukey-Kramer    1.0000
          site*TillageTre*year    FAIS    Max              2010    FAIS    No              2011    -1600.36      342.21      15      -4.68      0.0003
Tukey-Kramer    0.0193
          site*TillageTre*year    FAIS    Max              2010    RAL      Max              2010      440.97      419.12      15      1.05      0.3094
Tukey-Kramer    0.9993
          site*TillageTre*year    FAIS    Max              2010    RAL      Max              2011      -389.16      369.63      15      -1.05      0.3091
Tukey-Kramer    0.9993
          site*TillageTre*year    FAIS    Max              2010    RAL      Min              2010      625.85      369.63      15      1.69      0.1111
Tukey-Kramer    0.9406
          site*TillageTre*year    FAIS    Max              2010    RAL      Min              2011      -216.74      369.63      15      -0.59      0.5663
Tukey-Kramer    1.0000
          site*TillageTre*year    FAIS    Max              2010    RAL      No              2010      778.38      369.63      15      2.11      0.0525
Tukey-Kramer    0.7801
          site*TillageTre*year    FAIS    Max              2010    RAL      No              2011    48.2483      369.63      15      0.13      0.8979
Tukey-Kramer    1.0000
          site*TillageTre*year    FAIS    Max              2010    SURR    Max              2010      -260.67      369.63      15      -0.71      0.4915
Tukey-Kramer    1.0000
          site*TillageTre*year    FAIS    Max              2010    SURR    Max              2011    -1151.46      369.63      15      -3.12      0.0071
Tukey-Kramer    0.2592
          site*TillageTre*year    FAIS    Max              2010    SURR    Min              2010    65.3083      369.63      15      0.18      0.8621
Tukey-Kramer    1.0000
          site*TillageTre*year    FAIS    Max              2010    SURR    Min              2011    -1149.65      369.63      15      -3.11      0.0072
Tukey-Kramer    0.2611
          site*TillageTre*year    FAIS    Max              2010    SURR    No              2010      193.81      369.63      15      0.52      0.6077
Tukey-Kramer    1.0000
          site*TillageTre*year    FAIS    Max              2010    SURR    No              2011      -194.96      369.63      15      -0.53      0.6056
Tukey-Kramer    1.0000
          site*TillageTre*year    FAIS    Max              2011    FAIS    Min              2010    2481.62      342.21      15      7.25      <.0001
Tukey-Kramer    0.0002
          site*TillageTre*year    FAIS    Max              2011    FAIS    Min              2011      -206.05      342.21      15      -0.60      0.5561
Tukey-Kramer    1.0000
          site*TillageTre*year    FAIS    Max              2011    FAIS    No              2010    2383.74      369.63      15      6.45      <.0001
Tukey-Kramer    0.0009
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        site*TillageTre*year   FAIS   Max          2011   FAIS   No           2011    550.61    342.21    15    1.61    0.1285
Tukey-Kramer   0.9593
        site*TillageTre*year   FAIS   Max          2011   RAL    Max          2010    2591.95   419.12    15    6.18    <.0001
Tukey-Kramer   0.0014
        site*TillageTre*year   FAIS   Max          2011   RAL    Max          2011    1761.81   369.63    15    4.77    0.0002
Tukey-Kramer   0.0165
        site*TillageTre*year   FAIS   Max          2011   RAL    Min          2010    2776.82   369.63    15    7.51    <.0001
Tukey-Kramer   0.0002
        site*TillageTre*year   FAIS   Max          2011   RAL    Min          2011    1934.23   369.63    15    5.23    0.0001
Tukey-Kramer   0.0072
        site*TillageTre*year   FAIS   Max          2011   RAL    No           2010    2929.35   369.63    15    7.93    <.0001
Tukey-Kramer   <.0001
        site*TillageTre*year   FAIS   Max          2011   RAL    No           2011    2199.22   369.63    15    5.95    <.0001
Tukey-Kramer   0.0021
        site*TillageTre*year   FAIS   Max          2011   SURR   Max          2010    1890.31   369.63    15    5.11    0.0001
Tukey-Kramer   0.0089
        site*TillageTre*year   FAIS   Max          2011   SURR   Max          2011    999.51    369.63    15    2.70    0.0163
Tukey-Kramer   0.4461
        site*TillageTre*year   FAIS   Max          2011   SURR   Min          2010    2216.28   369.63    15    6.00    <.0001
Tukey-Kramer   0.0019
        site*TillageTre*year   FAIS   Max          2011   SURR   Min          2011    1001.33   369.63    15    2.71    0.0162
Tukey-Kramer   0.4435
        site*TillageTre*year   FAIS   Max          2011   SURR   No           2010    2344.78   369.63    15    6.34    <.0001
Tukey-Kramer   0.0011
        site*TillageTre*year   FAIS   Max          2011   SURR   No           2011    1956.01   369.63    15    5.29    <.0001
Tukey-Kramer   0.0065
        site*TillageTre*year   FAIS   Min          2010   FAIS   Min          2011    -2687.68  342.21    15    -7.85   <.0001
Tukey-Kramer   <.0001
        site*TillageTre*year   FAIS   Min          2010   FAIS   No           2010    -97.8817  369.63    15    -0.26   0.7948
Tukey-Kramer   1.0000
        site*TillageTre*year   FAIS   Min          2010   FAIS   No           2011    -1931.01  342.21    15    -5.64   <.0001
Tukey-Kramer   0.0035
        site*TillageTre*year   FAIS   Min          2010   RAL    Max          2010    110.32    419.12    15    0.26    0.7960
Tukey-Kramer   1.0000
        site*TillageTre*year   FAIS   Min          2010   RAL    Max          2011    -719.81   369.63    15    -1.95   0.0705
Tukey-Kramer   0.8545
        site*TillageTre*year   FAIS   Min          2010   RAL    Min          2010    295.20    369.63    15    0.80    0.4370
Tukey-Kramer   1.0000
        site*TillageTre*year   FAIS   Min          2010   RAL    Min          2011    -547.39   369.63    15    -1.48   0.1593
Tukey-Kramer   0.9792
        site*TillageTre*year   FAIS   Min          2010   RAL    No           2010    447.73    369.63    15    1.21    0.2445
Tukey-Kramer   0.9969
        site*TillageTre*year   FAIS   Min          2010   RAL    No           2011    -282.40   369.63    15    -0.76   0.4567
Tukey-Kramer   1.0000
        site*TillageTre*year   FAIS   Min          2010   SURR   Max          2010    -591.32   369.63    15    -1.60   0.1305
Tukey-Kramer   0.9611
        site*TillageTre*year   FAIS   Min          2010   SURR   Max          2011    -1482.11  369.63    15    -4.01   0.0011
Tukey-Kramer   0.0619
        site*TillageTre*year   FAIS   Min          2010   SURR   Min          2010    -265.34   369.63    15    -0.72   0.4839
Tukey-Kramer   1.0000
        site*TillageTre*year   FAIS   Min          2010   SURR   Min          2011    -1480.30  369.63    15    -4.00   0.0011
Tukey-Kramer   0.0624
        site*TillageTre*year   FAIS   Min          2010   SURR   No           2010    -136.84   369.63    15    -0.37   0.7164
Tukey-Kramer   1.0000
        site*TillageTre*year   FAIS   Min          2010   SURR   No           2011    -525.61   369.63    15    -1.42   0.1755
Tukey-Kramer   0.9854
        site*TillageTre*year   FAIS   Min          2011   FAIS   No           2010    2589.79   369.63    15    7.01    <.0001
Tukey-Kramer   0.0004
        site*TillageTre*year   FAIS   Min          2011   FAIS   No           2011    756.66    342.21    15    2.21    0.0430
Tukey-Kramer   0.7241
        site*TillageTre*year   FAIS   Min          2011   RAL    Max          2010    2798.00   419.12    15    6.68    <.0001
Tukey-Kramer   0.0006
        site*TillageTre*year   FAIS   Min          2011   RAL    Max          2011    1967.86   369.63    15    5.32    <.0001
Tukey-Kramer   0.0062
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        site*TillageTre*year    FAIS    Min         2011    RAL     Min         2010    2982.87     369.63    15     8.07     <.0001
Tukey-Kramer    <.0001
        site*TillageTre*year    FAIS    Min         2011    RAL     Min         2011    2140.28     369.63    15     5.79     <.0001
Tukey-Kramer    0.0027
        site*TillageTre*year    FAIS    Min         2011    RAL     No          2010    3135.40     369.63    15     8.48     <.0001
Tukey-Kramer    <.0001
        site*TillageTre*year    FAIS    Min         2011    RAL     No          2011    2405.27     369.63    15     6.51     <.0001
Tukey-Kramer    0.0008
        site*TillageTre*year    FAIS    Min         2011    SURR    Max         2010    2096.36     369.63    15     5.67     <.0001
Tukey-Kramer    0.0034
        site*TillageTre*year    FAIS    Min         2011    SURR    Max         2011    1205.57     369.63    15     3.26     0.0053
Tukey-Kramer    0.2090
        site*TillageTre*year    FAIS    Min         2011    SURR    Min         2010    2422.33     369.63    15     6.55     <.0001
Tukey-Kramer    0.0008
        site*TillageTre*year    FAIS    Min         2011    SURR    Min         2011    1207.38     369.63    15     3.27     0.0052
Tukey-Kramer    0.2074
        site*TillageTre*year    FAIS    Min         2011    SURR    No          2010    2550.83     369.63    15     6.90     <.0001
Tukey-Kramer    0.0004
        site*TillageTre*year    FAIS    Min         2011    SURR    No          2011    2162.06     369.63    15     5.85     <.0001
Tukey-Kramer    0.0025
        site*TillageTre*year    FAIS    No          2010    FAIS    No          2011    -1833.13    369.63    15     -4.96    0.0002
Tukey-Kramer    0.0117
        site*TillageTre*year    FAIS    No          2010    RAL     Max         2010    208.21      441.79    15     0.47     0.6442
Tukey-Kramer    1.0000
        site*TillageTre*year    FAIS    No          2010    RAL     Max         2011    -621.93     395.15    15     -1.57    0.1364
Tukey-Kramer    0.9657
        site*TillageTre*year    FAIS    No          2010    RAL     Min         2010    393.08      395.15    15     0.99     0.3356
Tukey-Kramer    0.9997
        site*TillageTre*year    FAIS    No          2010    RAL     Min         2011    -449.51     395.15    15     -1.14    0.2731
Tukey-Kramer    0.9984
        site*TillageTre*year    FAIS    No          2010    RAL     No          2010    545.61      395.15    15     1.38     0.1876
Tukey-Kramer    0.9888
        site*TillageTre*year    FAIS    No          2010    RAL     No          2011    -184.52     395.15    15     -0.47    0.6472
Tukey-Kramer    1.0000
        site*TillageTre*year    FAIS    No          2010    SURR    Max         2010    -493.43     395.15    15     -1.25    0.2309
Tukey-Kramer    0.9958
        site*TillageTre*year    FAIS    No          2010    SURR    Max         2011    -1384.23    395.15    15     -3.50    0.0032
Tukey-Kramer    0.1436
        site*TillageTre*year    FAIS    No          2010    SURR    Min         2010    -167.46     395.15    15     -0.42    0.6777
Tukey-Kramer    1.0000
        site*TillageTre*year    FAIS    No          2010    SURR    Min         2011    -1382.41    395.15    15     -3.50    0.0032
Tukey-Kramer    0.1447
        site*TillageTre*year    FAIS    No          2010    SURR    No          2010    -38.9600    395.15    15     -0.10    0.9228
Tukey-Kramer    1.0000
        site*TillageTre*year    FAIS    No          2010    SURR    No          2011    -427.73     395.15    15     -1.08    0.2961
Tukey-Kramer    0.9991
        site*TillageTre*year    FAIS    No          2011    RAL     Max         2010    2041.34     419.12    15     4.87     0.0002
Tukey-Kramer    0.0137
        site*TillageTre*year    FAIS    No          2011    RAL     Max         2011    1211.20     369.63    15     3.28     0.0051
Tukey-Kramer    0.2042
        site*TillageTre*year    FAIS    No          2011    RAL     Min         2010    2226.21     369.63    15     6.02     <.0001
Tukey-Kramer    0.0018
        site*TillageTre*year    FAIS    No          2011    RAL     Min         2011    1383.62     369.63    15     3.74     0.0020
Tukey-Kramer    0.0971
        site*TillageTre*year    FAIS    No          2011    RAL     No          2010    2378.74     369.63    15     6.44     <.0001
Tukey-Kramer    0.0009
        site*TillageTre*year    FAIS    No          2011    RAL     No          2011    1648.61     369.63    15     4.46     0.0005
Tukey-Kramer    0.0283
        site*TillageTre*year    FAIS    No          2011    SURR    Max         2010    1339.70     369.63    15     3.62     0.0025
Tukey-Kramer    0.1180
        site*TillageTre*year    FAIS    No          2011    SURR    Max         2011    448.90      369.63    15     1.21     0.2433
Tukey-Kramer    0.9968
        site*TillageTre*year    FAIS    No          2011    SURR    Min         2010    1665.67     369.63    15     4.51     0.0004
Tukey-Kramer    0.0261
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        site*TillageTre*year   FAIS   No        2011   SURR   Min        2011    450.72    369.63    15    1.22    0.2415
Tukey-Kramer   0.9967
        site*TillageTre*year   FAIS   No        2011   SURR   No         2010   1794.17    369.63    15    4.85    0.0002
Tukey-Kramer   0.0141
        site*TillageTre*year   FAIS   No        2011   SURR   No         2011   1405.40    369.63    15    3.80    0.0017
Tukey-Kramer   0.0880
        site*TillageTre*year   RAL    Max       2010   RAL    Max        2011   -830.14    441.79    15   -1.88    0.0798
Tukey-Kramer   0.8820
        site*TillageTre*year   RAL    Max       2010   RAL    Min        2010    184.87    441.79    15    0.42    0.6815
Tukey-Kramer   1.0000
        site*TillageTre*year   RAL    Max       2010   RAL    Min        2011   -657.72    441.79    15   -1.49    0.1573
Tukey-Kramer   0.9782
        site*TillageTre*year   RAL    Max       2010   RAL    No         2010    337.40    441.79    15    0.76    0.4569
Tukey-Kramer   1.0000
        site*TillageTre*year   RAL    Max       2010   RAL    No         2011   -392.73    441.79    15   -0.89    0.3881
Tukey-Kramer   0.9999
        site*TillageTre*year   RAL    Max       2010   SURR   Max        2010   -701.64    441.79    15   -1.59    0.1331
Tukey-Kramer   0.9632
        site*TillageTre*year   RAL    Max       2010   SURR   Max        2011  -1592.43    441.79    15   -3.60
0.0026   Tukey-Kramer   0.1219
        site*TillageTre*year   RAL    Max       2010   SURR   Min        2010   -375.67    441.79    15   -0.85    0.4085
Tukey-Kramer   1.0000
        site*TillageTre*year   RAL    Max       2010   SURR   Min        2011  -1590.62    441.79    15   -3.60    0.0026
Tukey-Kramer   0.1228
        site*TillageTre*year   RAL    Max       2010   SURR   No         2010   -247.17    441.79    15   -0.56    0.5841
Tukey-Kramer   1.0000
        site*TillageTre*year   RAL    Max       2010   SURR   No         2011   -635.94    441.79    15   -1.44    0.1706
Tukey-Kramer   0.9837
        site*TillageTre*year   RAL    Max       2011   RAL    Min        2010   1015.01    395.15    15    2.57    0.0214
Tukey-Kramer   0.5202
        site*TillageTre*year   RAL    Max       2011   RAL    Min        2011    172.42    395.15    15    0.44    0.6688
Tukey-Kramer   1.0000
        site*TillageTre*year   RAL    Max       2011   RAL    No         2010   1167.54    395.15    15    2.95    0.0098
Tukey-Kramer   0.3244
        site*TillageTre*year   RAL    Max       2011   RAL    No         2011    437.41    395.15    15    1.11    0.2857
Tukey-Kramer   0.9988
        site*TillageTre*year   RAL    Max       2011   SURR   Max        2010    128.50    395.15    15    0.33    0.7495
Tukey-Kramer   1.0000
        site*TillageTre*year   RAL    Max       2011   SURR   Max        2011   -762.29    395.15    15   -1.93    0.0729
Tukey-Kramer   0.8622
        site*TillageTre*year   RAL    Max       2011   SURR   Min        2010    454.47    395.15    15    1.15    0.2681
Tukey-Kramer   0.9982
        site*TillageTre*year   RAL    Max       2011   SURR   Min        2011   -760.48    395.15    15   -1.92    0.0735
Tukey-Kramer   0.8641
        site*TillageTre*year   RAL    Max       2011   SURR   No         2010    582.97    395.15    15    1.48    0.1608
Tukey-Kramer   0.9799
        site*TillageTre*year   RAL    Max       2011   SURR   No         2011    194.20    395.15    15    0.49    0.6302
Tukey-Kramer   1.0000
        site*TillageTre*year   RAL    Min       2010   RAL    Min        2011   -842.59    395.15    15   -2.13    0.0499
Tukey-Kramer   0.7664
        site*TillageTre*year   RAL    Min       2010   RAL    No         2010    152.53    395.15    15    0.39    0.7049
Tukey-Kramer   1.0000
        site*TillageTre*year   RAL    Min       2010   RAL    No         2011   -577.60    395.15    15   -1.46    0.1644
Tukey-Kramer   0.9814
        site*TillageTre*year   RAL    Min       2010   SURR   Max        2010   -886.51    395.15    15   -2.24    0.0404
Tukey-Kramer   0.7062
        site*TillageTre*year   RAL    Min       2010   SURR   Max        2011  -1777.31    395.15    15   -4.50    0.0004
Tukey-Kramer   0.0265
        site*TillageTre*year   RAL    Min       2010   SURR   Min        2010   -560.54    395.15    15   -1.42    0.1765
Tukey-Kramer   0.9857
        site*TillageTre*year   RAL    Min       2010   SURR   Min        2011  -1775.49    395.15    15   -4.49    0.0004
Tukey-Kramer   0.0267
        site*TillageTre*year   RAL    Min       2010   SURR   No         2010   -432.04    395.15    15   -1.09    0.2915
Tukey-Kramer   0.9990
```

```
        site*TillageTre*year    RAL    Min          2010    SURR    No          2011    -820.81     395.15    15    -2.08     0.0554
Tukey-Kramer    0.7945
        site*TillageTre*year    RAL    Min          2011    RAL    No          2010    995.12     395.15    15    2.52     0.0236
Tukey-Kramer    0.5488
        site*TillageTre*year    RAL    Min          2011    RAL    No          2011    264.99     395.15    15    0.67     0.5127
Tukey-Kramer    1.0000
        site*TillageTre*year    RAL    Min          2011    SURR    Max          2010    -43.9233     395.15    15    -0.11     0.9130
Tukey-Kramer    1.0000
        site*TillageTre*year    RAL    Min          2011    SURR    Max          2011    -934.72     395.15    15    -2.37     0.0319
Tukey-Kramer    0.6368
        site*TillageTre*year    RAL    Min          2011    SURR    Min          2010    282.05     395.15    15    0.71     0.4863
Tukey-Kramer    1.0000
        site*TillageTre*year    RAL    Min          2011    SURR    Min          2011    -932.90     395.15    15    -2.36     0.0322
Tukey-Kramer    0.6395
        site*TillageTre*year    RAL    Min          2011    SURR    No          2010    410.55     395.15    15    1.04     0.3153
Tukey-Kramer    0.9994
        site*TillageTre*year    RAL    Min          2011    SURR    No          2011    21.7800     395.15    15    0.06     0.9568
Tukey-Kramer    1.0000
        site*TillageTre*year    RAL    No          2010    RAL    No          2011    -730.13     395.15    15    -1.85     0.0845
Tukey-Kramer    0.8936
        site*TillageTre*year    RAL    No          2010    SURR    Max          2010    -1039.04     395.15    15    -2.63     0.0190
Tukey-Kramer    0.4864
        site*TillageTre*year    RAL    No          2010    SURR    Max          2011    -1929.84     395.15    15    -4.88     0.0002
Tukey-Kramer    0.0134
        site*TillageTre*year    RAL    No          2010    SURR    Min          2010    -713.07     395.15    15    -1.80     0.0913
Tukey-Kramer    0.9084
        site*TillageTre*year    RAL    No          2010    SURR    Min          2011    -1928.02     395.15    15    -4.88     0.0002
Tukey-Kramer    0.0135
        site*TillageTre*year    RAL    No          2010    SURR    No          2010    -584.57     395.15    15    -1.48     0.1597
Tukey-Kramer    0.9794
        site*TillageTre*year    RAL    No          2010    SURR    No          2011    -973.34     395.15    15    -2.46     0.0263
Tukey-Kramer    0.5804
        site*TillageTre*year    RAL    No          2011    SURR    Max          2010    -308.91     395.15    15    -0.78     0.4465
Tukey-Kramer    1.0000
        site*TillageTre*year    RAL    No          2011    SURR    Max          2011    -1199.71     395.15    15    -3.04     0.0083
Tukey-Kramer    0.2900
        site*TillageTre*year    RAL    No          2011    SURR    Min          2010    17.0600     395.15    15    0.04     0.9661
Tukey-Kramer    1.0000
        site*TillageTre*year    RAL    No          2011    SURR    Min          2011    -1197.89     395.15    15    -3.03     0.0084
Tukey-Kramer    0.2919
        site*TillageTre*year    RAL    No          2011    SURR    No          2010    145.56     395.15    15    0.37     0.7177
Tukey-Kramer    1.0000
        site*TillageTre*year    RAL    No          2011    SURR    No          2011    -243.21     395.15    15    -0.62     0.5475
Tukey-Kramer    1.0000
        site*TillageTre*year    SURR    Max          2010    SURR    Max          2011    -890.79     395.15    15    -2.25
0.0396    Tukey-Kramer    0.7002
        site*TillageTre*year    SURR    Max          2010    SURR    Min          2010    325.97     395.15    15    0.82     0.4223
Tukey-Kramer    1.0000
        site*TillageTre*year    SURR    Max          2010    SURR    Min          2011    -888.98     395.15    15    -2.25     0.0399
Tukey-Kramer    0.7027
        site*TillageTre*year    SURR    Max          2010    SURR    No          2010    454.47     395.15    15    1.15     0.2681
Tukey-Kramer    0.9982
        site*TillageTre*year    SURR    Max          2010    SURR    No          2011    65.7033     395.15    15    0.17     0.8702
Tukey-Kramer    1.0000
        site*TillageTre*year    SURR    Max          2011    SURR    Min          2010    1216.77     395.15    15    3.08
0.0076    Tukey-Kramer    0.2729
        site*TillageTre*year    SURR    Max          2011    SURR    Min          2011    1.8133     395.15    15    0.00     0.9964
Tukey-Kramer    1.0000
        site*TillageTre*year    SURR    Max          2011    SURR    No          2010    1345.27     395.15    15    3.40     0.0039
Tukey-Kramer    0.1678
        site*TillageTre*year    SURR    Max          2011    SURR    No          2011    956.50     395.15    15    2.42     0.0286
Tukey-Kramer    0.6050
        site*TillageTre*year    SURR    Min          2010    SURR    Min          2011    -1214.95     395.15    15    -3.07
0.0077    Tukey-Kramer    0.2747
```

```
          site*TillageTre*year    SURR    Min            2010    SURR     No            2010     128.50     395.15      15       0.33      0.7495
Tukey-Kramer    1.0000
          site*TillageTre*year    SURR    Min            2010    SURR     No            2011    -260.27     395.15      15      -0.66      0.5201
Tukey-Kramer    1.0000
          site*TillageTre*year    SURR    Min            2011    SURR     No            2010    1343.45     395.15      15       3.40      0.0040
Tukey-Kramer    0.1690
          site*TillageTre*year    SURR    Min            2011    SURR     No            2011     954.68     395.15      15       2.42      0.0289
Tukey-Kramer    0.6076
          site*TillageTre*year    SURR    No             2010    SURR     No            2011    -388.77     395.15      15      -0.98      0.3408
Tukey-Kramer    0.9997
```

Appendix D2 SAS® Analysis Program Code

```
options ls=200 ps=1000;
/*
data yr2010;
   length location $12;
   infile "yr2010.csv" dlm=";" missover;
   input Location  $ TillageTreatment  $ Field_lbs   Clean_lbs   Length_ft   Area_sqft  h area2 Area_ac  Area_ha  yld;
   year=2010;
run;
data yr2011;
   length location $12;
   infile "yr2011.csv" dlm=";" missover;
   input Location  $ TillageTreatment  $ Field_lbs   Clean_lbs   Length_ft   Area_sqft  h area2 Area_ac  Area_ha  yld;
   year=2011;
run;
data both;
   set yr2010 yr2011;
   plot=scan(location,1," ");
   site=scan(location,2," ");
run;
*/

PROC IMPORT OUT= WORK.Both
            DATAFILE= "E:\Thesis\Appendices\Statistics\Both.csv"
            DBMS=CSV REPLACE;
     GETNAMES=YES;
     DATAROW=2;
RUN;

proc sort;
   by year;
run;

*proc mixed data=both method=type3;
goptions dev=actximg;
ods graphics on;
proc mixed data=both;
title "Site Random, Tillage Fixed, By Year";
by year;
   class site tillagetreatment plot year;
   model yld=tillagetreatment/outp=two ;*residual ;
random site site*tillagetreatment plot(site);
lsmeans tillagetreatment/pdiff adjust=Tukey;
   estimate "notill versus avg of max,min" tillagetreatment -1 -1 2/divisor=2;
run;
```

```
*proc mixed data=both method=type3;
proc mixed data=both ;
by year;
   class site tillagetreatment plot year;
   model yld=site|tillagetreatment/outp=two;* residual ;
              lsmeans site|tillagetreatment/pdiff adjust=Tukey;
   estimate "notill versus avg of max,min" tillagetreatment -1 -1 2/divisor=2;
run;

proc mixed data=both ;
by year;
   class site tillagetreatment plot year;
   model yld=site|tillagetreatment/outp=two ;*residual ;
              lsmeans site tillagetreatment/pdiff adjust=Tukey;
   estimate "notill versus avg of max,min" tillagetreatment -1 -1 2/divisor=2;
run;

*proc mixed data=both method=type3;
proc mixed data=both;
   class site tillagetreatment plot year;
   model yld=site|tillagetreatment/outp=two ;*residual ;
   random year year*site year*tillagetreatment site*year*tillagetreatment plot(site);
              lsmeans site|tillagetreatment/pdiff adjust=Tukey;
   estimate "notill versus avg of max,min" tillagetreatment -1 -1 2/divisor=2;
run;

proc mixed data=both;
   class site tillagetreatment plot year;
   model yld=site|tillagetreatment/outp=two ;*residual ;
   random year year*site year*tillagetreatment site*year*tillagetreatment plot(site);
              lsmeans site tillagetreatment/pdiff adjust=Tukey;
   estimate "notill versus avg of max,min" tillagetreatment -1 -1 2/divisor=2;
run;

*proc mixed data=both method=type3;
proc mixed data=both;
   class site tillagetreatment plot year;
   model yld=tillagetreatment/outp=two ;*residual ;
   random year|site year*tillagetreatment site*tillagetreatment year*site*tillagetreatment plot(site);
              lsmeans year site year*tillagetreatment site*tillagetreatment year*site*tillagetreatment tillagetreatment/pdiff adjust=Tukey;
   estimate "notill versus avg of max,min" tillagetreatment -1 -1 2/divisor=2;
run;
ods graphics off;


proc sort data=both;
by year site replicate;
run;
proc print data=both;
run;


proc print;
   title "canola, both years";
   *var location tillagetreatment yld;
run;

proc gplot data=two;
    plot resid*pred=site;
run;

proc freq;
   by year;
```

```
   tables site*tillagetreatment;
   *tables plot;
run;
proc freq;
   tables site*tillagetreatment;
run;
```