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16. Abstract

The production of flowering oilseeds along highway right-of-ways provides land managers with a unique opportunity to meet safety and vegetation management objectives while providing enhance roadside aesthetics for motorists. Additionally, these operations provide an economically valuable grain commodity that can either be used to offset the management costs or provide a feedstock that can be used in the biodiesel production process. This two-year research effort, sponsored by the North Carolina Department of Transportation (NCDOT) investigated the cultivation of oilseed crops along North Carolina highway rights-of-way (ROWs) which would ultimately be destined for conversion to biodiesel and use in their fleet of motor vehicles. 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. Results of this study showed that canola and sunflowers are the most eligible oilseeds for production along highway right-of-ways in North Carolina. Both crops generated grain yields similar to yields produced in traditional agronomic settings. Additionally, no-till establishment produced yields similar to plots established with clean, conventional tillage systems. Based on GIS analysis, 14, 962 mi (24,079 km) of eligible ROW was identified in North Carolina.

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EXECUTIVE SUMMARY

The production of flowering oilseeds along highway right-of-ways provides land managers with a unique opportunity to meet safety and vegetation management objectives while providing enhance roadside aesthetics for motorists. Additionally, these operations provide an economically valuable grain commodity that can either be used to offset the management costs or provide a feedstock that can be used in the biodiesel production process. Examples of flowering oilseeds that provide aesthetic value and vegetable oils for biodiesel production are canola, camelina, mustard varieties, safflower, and sunflowers. This two-year research effort, sponsored by the North Carolina Department of Transportation (NCDOT) investigated the cultivation of oilseed crops along North Carolina highway rights-of-way (ROWs) which would ultimately be destined for 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 the project 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 average seasonal rainfall and temperature observations, ROW widths and slopes, highway characteristics and adjacent traffic volumes, and wildlife and motorist safety regulations.

Beginning in early June 2009 and concluding in June mid 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 possible main and interaction effects among tillage, location, and year of cultivation (initial cultivation or subsequent cultivation) on crop productivity in a three by three by 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 were not found to have 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 of 1108 lb ac^{-1} (1241 kg ha^{-1}) followed by minimum tillage and no-till, at 827 lb ac^{-1} (926 kg ha^{-1}) and 766 lb ac^{-1} (858 kg ha^{-1}), respectively (Table 2.4). 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 2409 lb ac^{-1} (2698 kg ha^{-1}), followed sequentially by maximum tillage and no-tillage, at 2399 lb ac^{-1} (2687 kg ha^{-1}) and 1750 lb ac^{-1} (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 the 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 width, GIS analysis was utilized in identifying 14, 962 mi (24,079 km) of eligible ROW, thus totaling approximately 18,136 ac (7,340 ha) of total eligible land base.

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Introduction

Statement of Need and Benefit for NCDOT

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.

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, 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 overall goal of the project 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 fleet of diesel motor vehicles. 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; 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; and 4) perform economic and logistical analyses associated with the implementation of each tillage method.

Organization

This report is organized into two main sections detailing the activities and results of the research conducted under this project. The first section, entitled "Production of oilseed crops on marginal land", focuses on the effects of the various treatments year, tillage, site on the crop yield. The scope of this work is to determine the optimal conditions for growing crops along the roadside. The second major section, entitled "Production of canola along North Carolina highway right-of-ways" will focus on the potential of canola production on the highways and the total amount of land that could be available for production along NC highways. Canola produced the best, most repeatable results so it is discussed in greater detail in this section.

Result of Literature Review

<u>Need for Fuels Produced from Renewable Resources</u>

Driven by world population growth and continuous technological advancement, the worldwide energy demand continues to grow while fossil fuels, which currently constitute the majority of that energy source, are being depleted rapidly. As of 2010, there exist a total of 1,354 billion barrels (bbs) of petroleum oil (a non-renewable fossil fuel and main source from which gasoline and diesel transportation fuels are derived) in the proved world reserves (IEO-a, 2010). In 2009, worldwide annual oil consumption totaled 30.67 bbs (84 million barrels per day (mb/d)), and this demand is expected to continue to increase, reaching 36.14 bbs annually (99 mb/d) by the year 2035 (WEO, 2010). As the demand for fossil fuels for energy production continues to rise, the need for renewable fuels continues to be of paramount importance not only to improve environmental impact but also to ensure 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 energy 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 2.1% of the world supply (28.4 bbs) and consumed 6.82 bbs that year alone (BP, 2010). The supply of world petroleum reserves being controlled predominantly by these Middle Eastern countries creates a virtual monopoly of these resources by their governments and compromises the economic well-being of countries such as ours. Because of deficits such as these and our continued increasing 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 are in place 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 government mandates such as these, 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.

Biodiesel vs. Diesel

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 maintains 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.

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. In addition, 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).

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 low-acid, cold season cultivar of canola (*Brassica napus L*), provides similar soil-building properties to those of soybeans, 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 and Maier et al., 1998) This makes canola the highest oil-yielding oilseed crop in the United States, averaging an oil yield of 122 gal ac^{-1} (1,141 L ha^{-1}) (Kurki et al., 2006). Safflower and sunflower, both warm season crops, also provide 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 an increase in weed and erosion control (Canola Council of Canada, 2009; 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 30 million gallonsof 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.

<u>Agricultural Operations in Highway Rights-of-Way</u>

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 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.

Rights-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 contruction 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).

Soil Compaction and Tillage Effects on Soil Properties and Crop Production

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, 2009).

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).

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 involves a low tillage depth of less than 30 cm while deep tillage (including practices such as subsoiling and chisel plowing) involves more intense soil structure disturbance to greater soil depths. If performed improperly or scheduled poorly, deep tillage 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. Minimum tillage has relatively lower cost requirement, but may leave subsoils compacted. No-tillage involves planting with a no-till drill directly into the soil through any existing ground cover and provides minimal compaction relief. The machinery operation and labor requirements to perform no-till treatments are minimal, thus incurring low input costs compared with all other tillage methods.

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 ac^{-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 lb ac^{-1} vs. 1909 lb ac^{-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 a 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. They indicated that this allowed for the soybean roots to penetrate 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.

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 lb ac^{-1}) followed by chisel plowing (3100 lb ac^{-1}) and NT (2230 lb ac^{-1}). Dunker and Barnhisel (2000) found that DT also significantly increased soybean yield when performed to a depth of 36-48 in on severely compacted soil. Williams and Weil (2004) found that heavy tillage at 12 in depth had no effect on soybean yield, although the majority of soybean roots remain in the top 6-12 in 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.

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). 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. *Cavalaris and Gemtos (2002) observed a 2998 MJ ha^{-1} energy requirement under conventional tillage for sugar beet production.* A 1.7 – 3.4% reduction of energy requirement was observed under reduced tillage but also a reduction in yield, which may have outweighed the energy savings.

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, 2009).

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.

Energy Requirements and Economics of Tillage Methods

Gilandeh et al. (2006) suggest 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. This indicates 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.

Production of Oilseed Crops on Marginal Land

With the growing demand for production of renewable energy feedstock and the arising sociopolitical controversies regarding the competition between food and energy crops for agricultural cropland, utilization of agriculturally marginal land is emerging as an attractive viable alternative for producing energy crops (Tang et al., 2010; Bardos et al., 2008). 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 are examples of marginal lands. While these types of soils may be inappropriate for food-grade crop production, characteristic lands may be suitable for growing feedstock with end-uses such as the production of biofuels and thus are emerging as an attractive and viable alternative for producing these energy crops (Bardos et al., 2008; Bhardwaj et al., 2011).

In poor or developing countries, marginal lands have been exploited 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 in the throughout the United States. Furthermore, certain types of bioenergy feedstock, such as oilseed crops, have production characteristics that make them especially adaptable to the unfavorable soil conditions of agriculturally marginal land (Bhardwaj et al., 2011). In particular, canola, a cold-season oilseed, has soil-building properties including nitrogen-fixing ability, strong taproots capable of penetrating highly compacted soils, and ground cover characteristics for increasing weed and erosion control (Canola Council of Canada, 2009; Kurki et al., 2006). In addition to its valuable environmental benefits, canola is marketable in several industries, including 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 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 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 indication sthat at least certain areas of the North Carolina ROWs may be suitable to reap the benefits of NT practices.

Materials and Methods

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.

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).

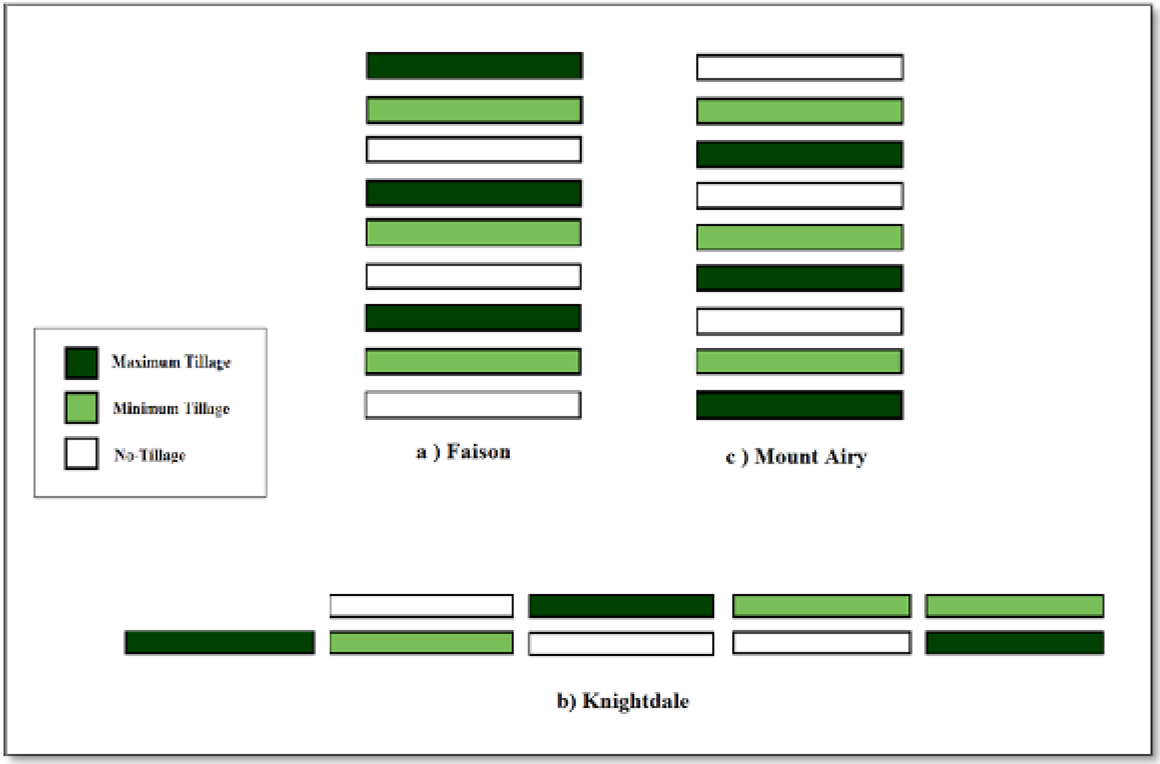

Figure 2.1 a-c Experimental research plot layouts in a) Faison, b) Knightdale, and c) Mount Airy.

Site Descriptions

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 A1.1). See Appendix A1 for aerial imagery indicating location of each research site. The original plot layout in Faison consisted of nine 10 ft x 200 ft (3.05 m x 60.96 m) plots spaced 10 ft (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 5 ft (1.5 m) 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.

Knightdale, Wake County, N.C.

The experimental site of the Piedmont region was established in Knightdale (35°46'N, 78°30'W), located in eastern Wake County, N.C. (Figure A1.2). Nine 10 ft x 200 ft (3.05 m x 60.96 m) plots were arranged in two rows spaced 10 ft (3.05 m) apart, running parallel to each other and to US Highway 540, with in-row plots each spaced 10 ft (3.05 m) 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).

Mount Airy, Surry County, N.C.

In the Mountain region, the experimental site was located in Mount Airy, Surry County, N.C. (36°26'N, 80°36'W). The nine (10 ft x 200 ft) (3.05 m x 60.96 m) plots spaced 10 ft (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 wildflower cultivation practices (NCDOT, 2011).

Tillage Treatments

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 8 in (20.3 cm) (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.

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 (4 – 6 in) (10.16 – 15.24 cm). This was followed by planting with the no-till drill

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 0.5 in (1.27 cm) (Figure A2.3).

Crop Production and Management Schedule

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 6-8 lbs ac^{-1} to recommended depth of approximately .5 in. Fertilizer (10-20-20) at a rate of 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 300 lbs 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 13 ft grain head attachment.

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 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 6-8 lbs ac^{-1} to recommended depth of 0.5 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 217 lb ac^{-1} in Faison and Knightdale and at a rate of 302.5 lbs 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 300 lbs ac^{-1} (NCDOT, 2011). Crops were harvested using a combine (Gleaner K2, AGCO Corporation, Duluth, Ga.) without grain head attachment in early June 2011.

Crop Rotation

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

Table 2.1 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**

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 – 8 lbs ac^{-1} and to the recommended depth of 0.5 in.. Plots received 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 lbs 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 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 (June 2010). The sunflower crops were harvested early October 2010 with a Gleaner K2 combine with 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.

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.

Results

Effects of Site, Tillage, and Year 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

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 2.3), and all locations observed significantly higher yields in the second year of cropping as compared with initial cultivations when averaging across tillage treatment (Table 2.3).

Site Effects

In the 2009 planting season, Faison (980 lbs ac^{-1}) and Mount Airy (1168lb 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). In some instances, 2010 yields were increased more than 300% over 2009 results for respective

locations (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). In Faison, even the lowest yielding tillage 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).

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

	Seed Yield (lbs ac^{-1})	
Site	**2009***	**2010***
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.

Tillage Effects

In the first year of cropping, the maximum tillage treatment produced the highest average yields of 1108 lb ac^{-1} followed by minimum tillage and no-till, at 827 lb ac^{-1} and 766 lb ac^{-1}, respectively (Table 2.4). 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 2409 lb ac^{-1}, followed sequentially by maximum tillage and no-tillage, at 2399 lb ac^{-1}, and 1750 lb ac^{-1}, respectively (Table 2.4). 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; Table F.2), the pairwise comparisons between tillage treatments did not support this finding (Table 2.5)

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

	Seed Yield (lbs ac^{-1})	
Site	**2009***	**2010***
Maximum	1108a	2399a
Minimum	827a	2409a
No Tillage	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.

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, they produced differences in yields of 648 and 659 lbs 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 more intensive methods than no-tillage. Nonetheless, there was no significant difference in the effects of maximum versus minimum tillage in the 2010 planting season; therefore, it may not be justifiable to recommend implementation of a more energy-expending maximum tillage treatment.

Discussion of Results

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 Programs Wildflower Planting Instructions in a procedural handbook (NCDOT, 2011). Unlike those plots, the Knightdale crops were cultivated on land prepared for future roadway expansion of Interstate 540, and thus composed of exceptionally low quality soil. 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 observation of yields on highly-compacted, low-nutrient 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 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.

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.

Production of Canola on North Carolina Highway Rights-of-Way

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 base 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. While the North Carolina Department of Transportation maintains a reputable wildflower program, providing beautification of several statewide roadsides, there is no economic advantage or 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 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.

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.

Site Descriptions

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 3.1)

Figure 3.1. Faison large, maximum tillage canola research plot location (Google Imagery, 2011).

In 2009, the 2000 ft by 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 120 ft to the east to avoid poorly drained areas of the field prior to subsequent canola planting.

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 western 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 Knightdale research plot location (Google Imagery, 2011).

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 10 ft by 2000 ft plot was established approximately 0.5 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. Mount Airy large, maximum tillage plot location (Google Imagery, 2011).

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. Rutherfordton research plot locations (Google Imagery, 2011).

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^{o}44'N, 79^{o}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 10 ft width strip extending the length of ROW totaling approximately 6 mi, partitioned only by previously-defined breaks in ROW caused by the presence of on-ramps, exit ramps, and overpasses (Figure 3.5).

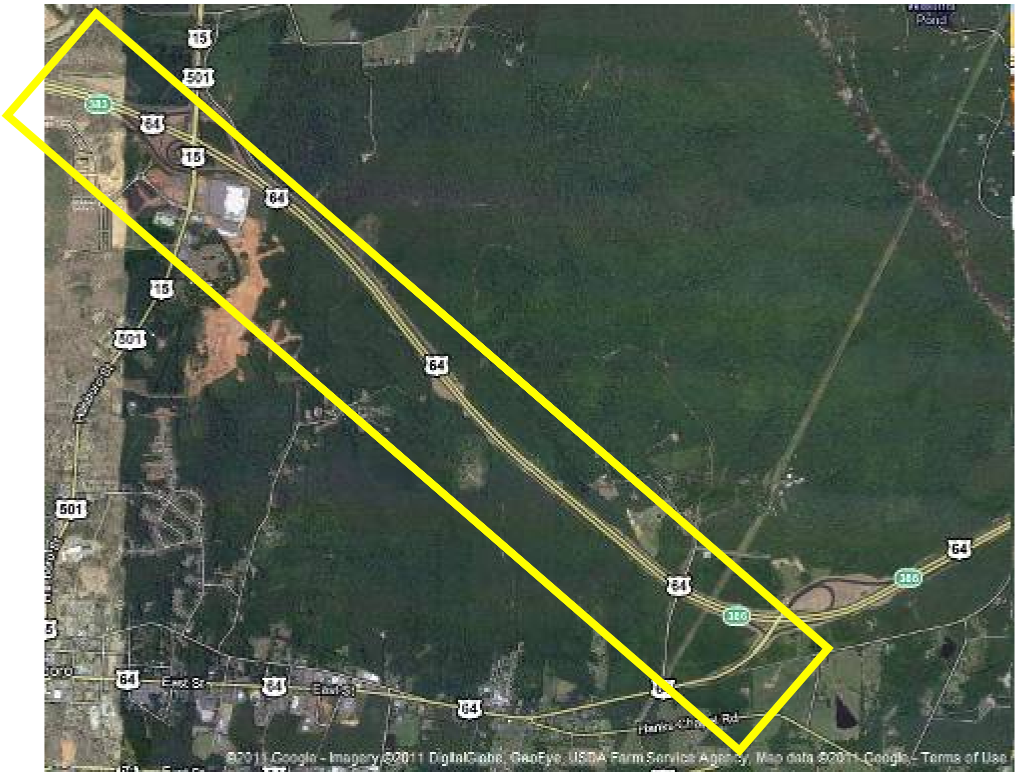

Figure 3.5. Pittsboro research plot locations (Google Imagery, 2011).

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.

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 6-8 lbs ac^{-1} to depth of approximately 0.5 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.

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 6-8 lbs ac^{-1} and depth of 0.5 in. Sulfur was applied immediately following planting in Faison and Knightdale, and fertilizer (18-24-12) was broadcast at a rate of 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, The Scotts Company, LLC) 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.

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**

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).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).

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

Shapefile	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 levels of 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**

The shapefiles containing precipitation maps, temperature maps and roads characteristics maps were added to the model for selection based on project-specific criteria (Table 3.3).

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	90
Precipitation (in.)	15	---

Roadway and ROW Characteristics

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). 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 79,002,082.66 ft was multiplied by the assumed 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).

Climatic Factors

Eligible 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 for a 9 month growing season (October to June). 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).

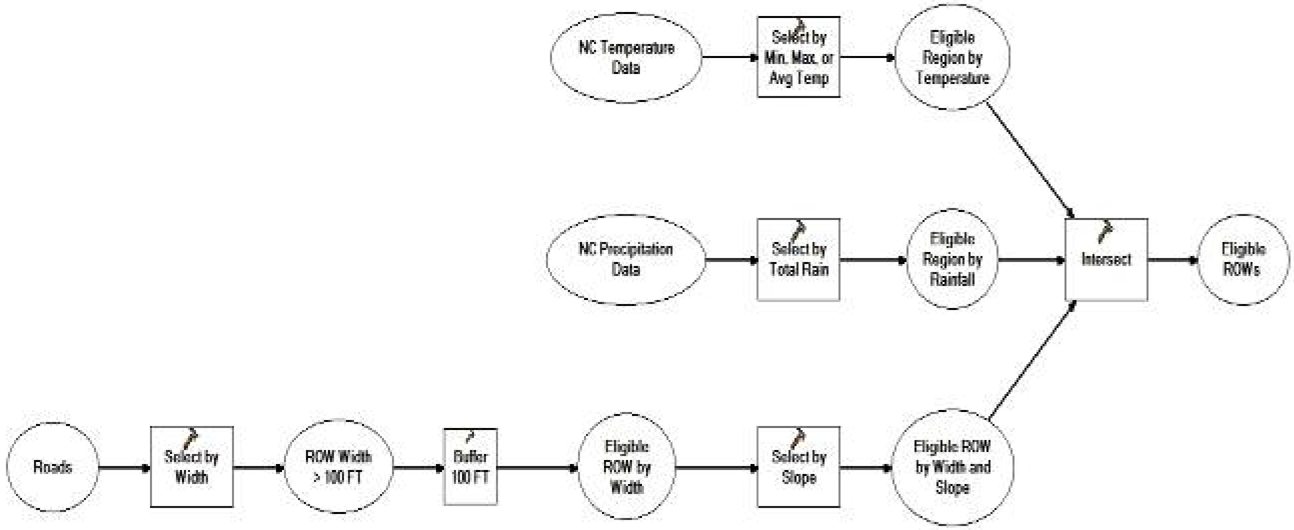

Figure 3.6. ArcGIS Model: Eligible ROW selection process

Regions of North Carolina experiencing appropriate temperature ranges [i.e., 0-37^{o}C)] were selected using the "Select by Attribute" tool and mapped separately. 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.

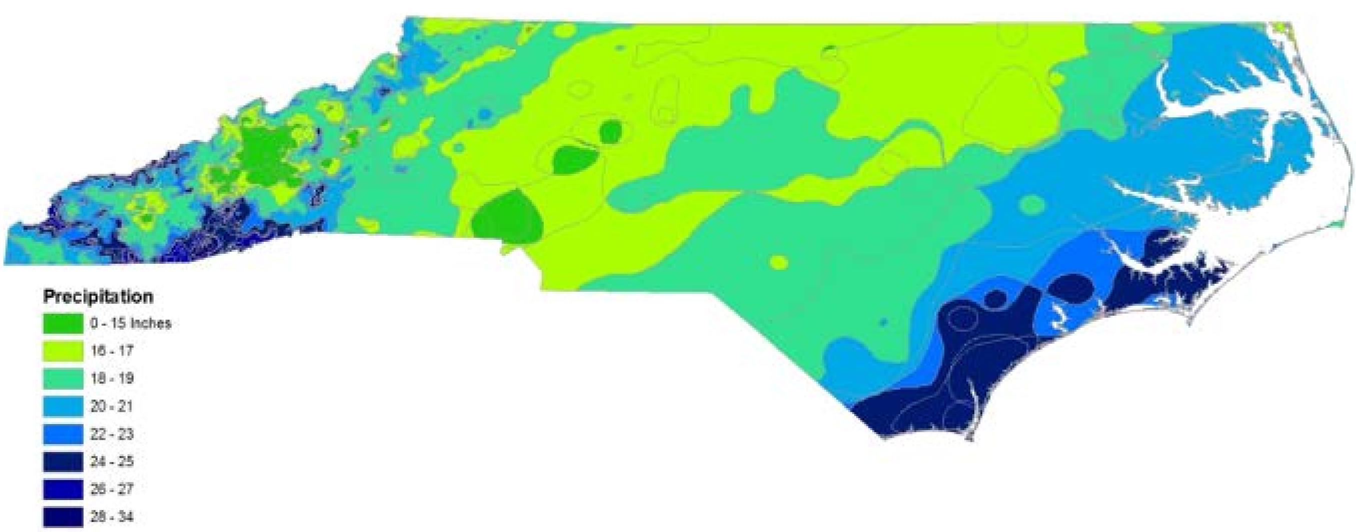

Figure 3.7 Average annual precipitation observations across North Carolina

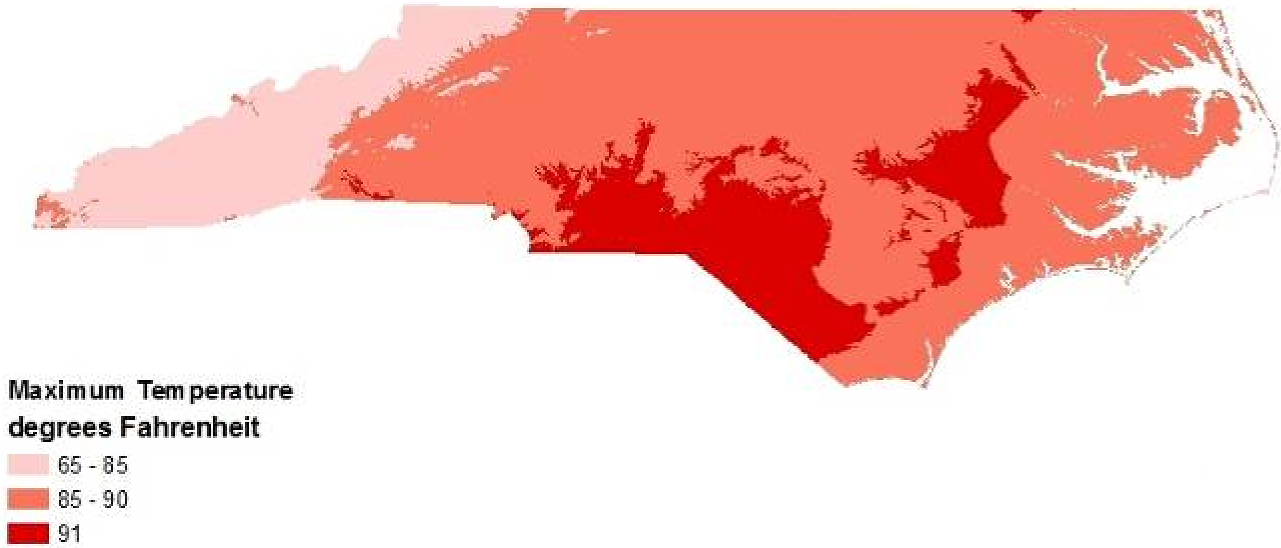

Figure 3.8 Average annual temperature observations across North Carolina

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).

Figure 3.9 Eligible regions and ROWs of North Carolina for canola crop production

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. If the primary constraints correspond to soil conditions, level of compaction, or highway safety measures, then areas of marginal land other than ROWs could be suggested for further evaluation.

Discussion of Results

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 (Figures 3.10 and 3.11 In both years, the Knightdale plots experienced the lowest yields compared with all other locations (Figures 3.10 and 3.11). It is 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 seasonin 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, 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 in successive seasons (i.e. Faison and Knightdale), the results of plot trials show obvious trends of increased canola yields with successive 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 can be achieved in both instances of previous wildflower cultivation practices and project-specific oilseed crop cultivation.

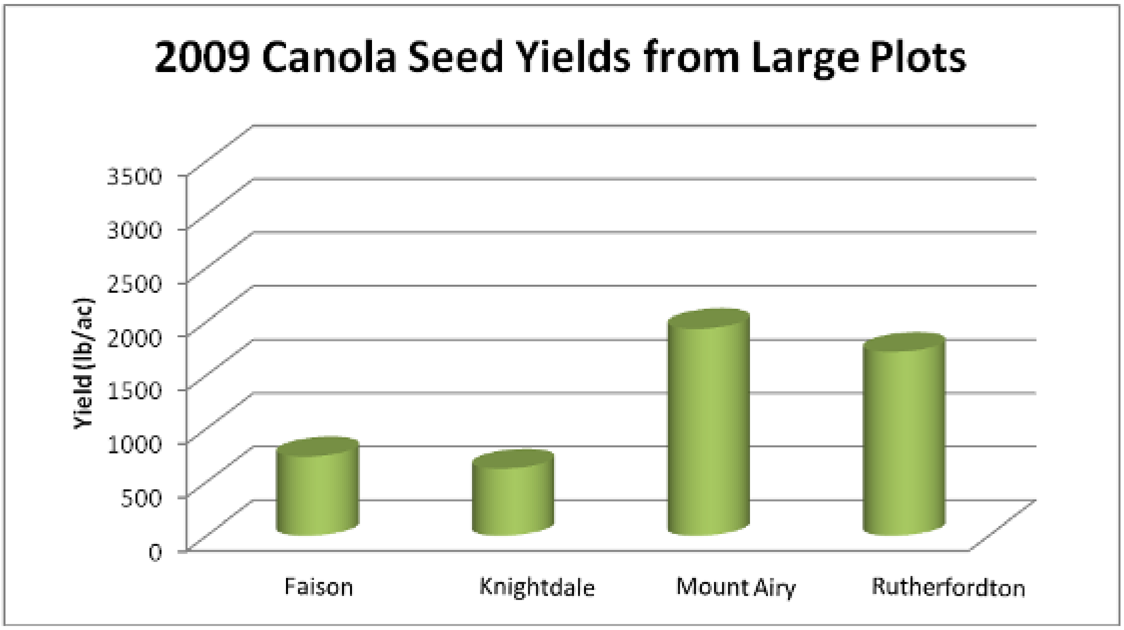

Figure 3.10 2009 Canola seed yields (lb ac^{-1}) by location

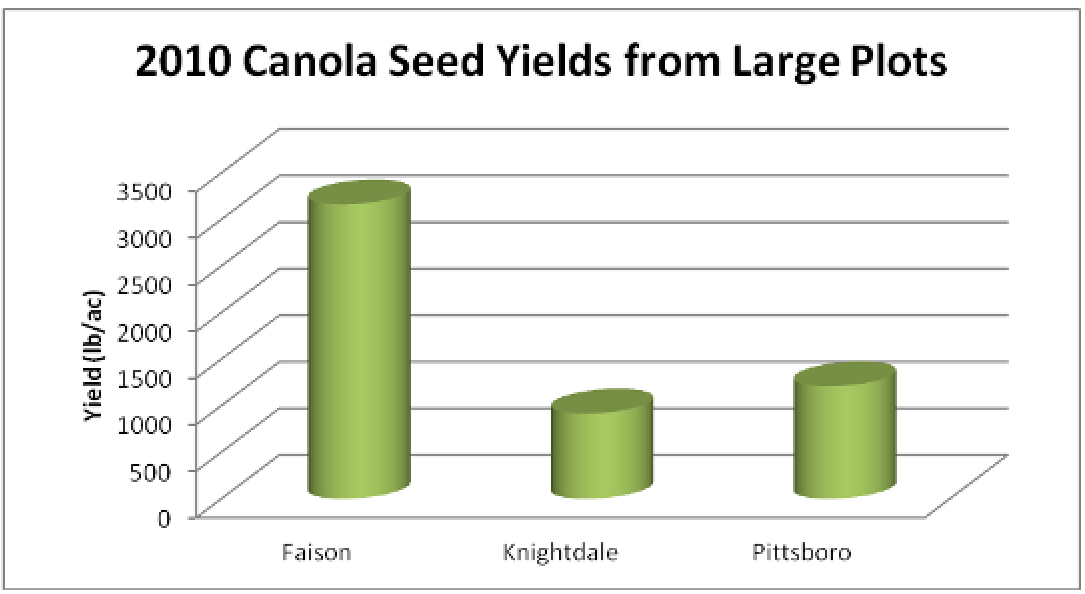

Figure 3.11 2010 Canola seed yields (lb ac^{-1}) by location

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. Planting date is also an important factor in oilseed productivity and yield. Plantings and harvests were often delayed due to scheduling conflicts for availability of equipment necessary to perform planting and harvesting operations. Since incidences of abnormal climatic conditions should 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), yields may increase with earlier planting dates for canola in North Carolina.

GIS Analysis Results

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 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; however, important 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.

Findings and Conclusions

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 were often delayed to due scheduling conflicts for availability of equipment necessary to perform planting and harvesting operations. Since incidences of abnormal climatic conditions should 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), yields

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.

Recommendations

Based on the activities associated with this research project the following recommendations have been developed.

- ***Canola is a suitable crop for right-of-way crop production in North Carolina***. Yields were not significantly different from grain yields generated in traditional, agronomic settings. The crop could be grown along all highways in the state.

- Sunflowers are a marginal crop for right-of-way production in North Carolina.   Yields were heavily dependent on rainfall and temperatures. ***Sunflowers grown west of I-85 and planted in late June/early July were comparable to yields generated under agronomic settings***.

- Tillage in the first year is necessary to insure a well-established, uniform stand that will produce a better aesthetic effect than no-till establishment. Tillage is not as important in subsequent years and the ***tillage will not guarantee improved crop yield***.

- Crop management should occur in 10 ft strips or less to provide easy transport of the equipment and allow for maneuverability along the roadside. This is essentially the smallest cutting width of a modern grain combine.

- Further coordination with an oilseed crushing facility is required for growth of the program. Extracting the oil from the harvest crop at the anticipated scale of the project would overwhelm biodiesel production facilities. A dedicated crush facility is needed.

- Signage along roadsides is recommended to provide information to motorist and traditional contract mowing crews. Plots were accidently mowed during the project performance period. Also, motorist were witnessed stopped along the roadside to harvest crops for their own consumption.

- Further research is needed to identify sustainable agronomic practices along the roadside as a ***continuous canola-sunflower rotation will invite plant diseases in the soil***. Most likely, non-oilseed crops, such as winter legumes, could be planted.

- Additional research is also required to quantify the environmental impact of these operations, particularly the impact on storm water runoff from the roadway. Also, if soils along the roadway are high in heavy metals it could impact the marketability of the grain products. Marketing impacts would involve the feed, not the oil used for biodiesel.

- The contract crop production strategy is also unknown at this time. If a grower decides to cultivate crops along the highway as part of a DOT program it is logical to make them responsible for mowing operations along the same stretch of road.

Implementation and Technology Transfer Plan

The primary research tool developed from this project is the GIS modeling algorithm that can be used in ESRI ArcGIS. This tool could be used by GIS and roadside environmental managers to make decisions regarding the eligibility of lands for crop production. A brief written tutorial would be sufficient to train those with experience in ArcGIS on how to implement the GIS model. This research activity also laid the foundation for the development of a roadside crop production guide, however, this guide cannot be fully developed at this time. Both environmental impacts of this activity and the development of long-term crop rotational strategies have not been developed.

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Appendix A: Agricultural Roadside Operations

Appendix A1: Research Plot Locations

Appendix A1.1 Faison

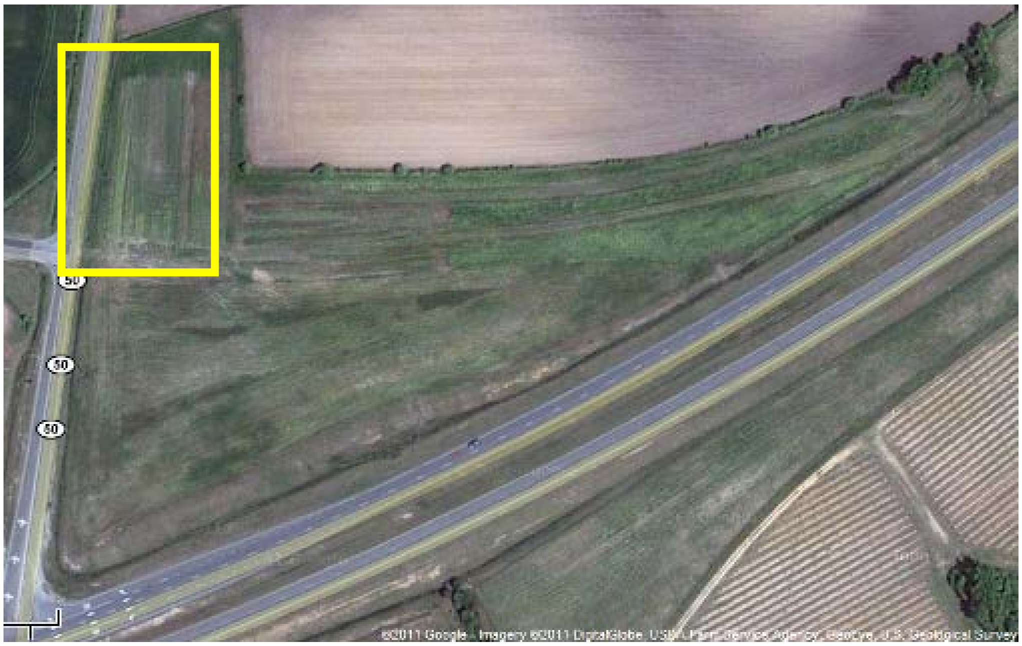

Figure A1.1a. Faison nine small canola research plot location (Google Imagery, 2011).

Figure A1.1b. Faison large, maximum tillage canola research plot location (Google Imagery, 2011).

Appendix A1.2 Knightdale

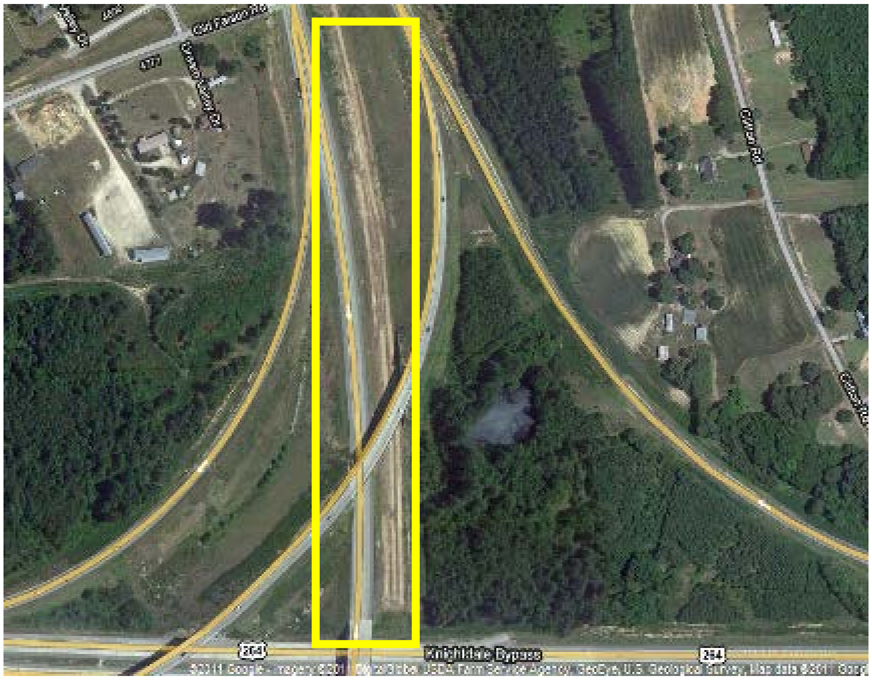

Figure A1.2. Knightdale research plot location (Google Imagery, 2011).

Appendix A1.3 Mount Airy

Figure A1.3a. Mount Airy research plot locations (Google Imagery, 2011).

Figure A1.3b. Mount Airy large, maximum tillage plot location (Google Imagery, 2011).

Appendix A1.4 Pittsboro

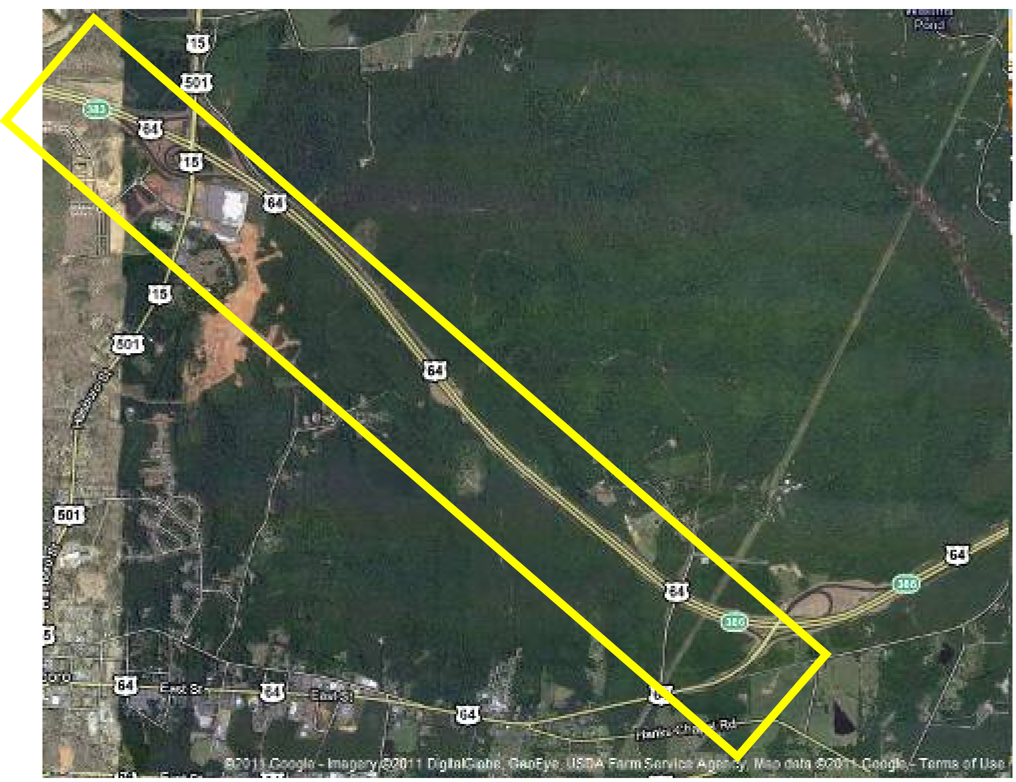

Figure A1.4. Pittsboro research plot locations (Google Imagery, 2011).

Figure A1.5. Rutherfordton research plot locations (Google Imagery, 2011).

Appendix A2: Agricultural Equipment and Seedbed Preparation

Figure A2.1 Rotary tillage with New Holland 6640 tractor (New Holland North America, Inc., New Holland, Pa.) coupled with M&W Dyna-Drive surface cultivator (NCDOT)

Figure A2.2. No-till planting with John Deere 1590 no-till drill (Deere & Company, Moline, Ill.) at Faison research site (NCDOT)

Figure A2.3 Depiction of soil disturbance associated with no-till treatment with John Deere 1590 no-till drill (Deere & Company, Moline, Ill.) at Knightdale research site (photo courtesy of NCDOT Roadside Environmental Unit)

Figure A2.4 Depiction of seedbed preparation for maximum tillage treatment at Knightdale research site (photo courtesy of NCDOT Roadside Environmental Unit)

Appendix B: Soil Properties Test Reports for North Carolina Research Sites

NCDA&CS Agronomic Division Phone: (919)733-2655 Web site: www.ncagr.gov/agronomi/ Report No: 00526

Field Information / Applied Lime / Recommendations

Sample No.	Last Crop	Mo	Yr	T/A	Crop or Year		Lime	N	P_2O_5	K_2O	Mg	S	Cu	Zn	B	Mn	See Note
					1st Crop:	Small Grains		80-100	10-30	0	0	0	0	0	.0	pH$	3
					2nd Crop:	Small Grains		80-100	10-30	0	0	0	0	0	.0	pH$	3

Test Results

Soil Class	HM%	W/V	CEC	BS%	Ac	pH	P-I	K-I	Ca%	Mg%	Mn-I	Mn-AI(1)	Mn-AI(2)	Zn-I	Zn-AI	Cu-I	S-I	SS-I	NO_3-N	NH_4-N	Na
		1.20	6.2	97.0	0.2	7.0	52	89	63.0	27.0	154	87	87	48	48	39					0.1

Field Information / Applied Lime / Recommendations

Sample No.	Last Crop	Mo	Yr	T/A	Crop or Year		Lime	N	P_2O_5	K_2O	Mg	S	Cu	Zn	B	Mn	See Note
					1st Crop:	Small Grains		80-100	60-80	10-30	0	0	0	0	.0	0	3
					2nd Crop:	Small Grains		80-100	60-80	10-30	0	0	0	0	.0	0	3

Test Results

Soil Class	HM%	W/V	CEC	BS%	Ac	pH	P-I	K-I	Ca%	Mg%	Mn-I	Mn-AI(1)	Mn-AI(2)	Zn-I	Zn-AI	Cu-I	S-I	SS-I	NO_3-N	NH_4-N	Na
		1.15	4.6	85.0	0.7	5.8	29	69	58.0	19.0	225	148	148	32	32	29					0.0

Field Information / Applied Lime / Recommendations

Sample No.	Last Crop	Mo	Yr	T/A	Crop or Year		Lime	N	P_2O_5	K_2O	Mg	S	Cu	Zn	B	Mn	See Note
					1st Crop:	Small Grains		80-100	80-100	0	0	0	2	0	.0	0	3
					2nd Crop:	Small Grains		80-100	80-100	0	0	0	$	0	.0	0	3

Test Results

Soil Class	HM%	W/V	CEC	BS%	Ac	pH	P-I	K-I	Ca%	Mg%	Mn-I	Mn-AI(1)	Mn-AI(2)	Zn-I	Zn-AI	Cu-I	S-I	SS-I	NO_3-N	NH_4-N	Na
		1.04	5.0	68.0	1.6	5.0	21	93	44.0	16.0	34	30	30	33	33	19					0.0

Field Information / Applied Lime / Recommendations

Sample No.	Last Crop	Mo	Yr	T/A	Crop or Year		Lime	N	P_2O_5	K_2O	Mg	S	Cu	Zn	B	Mn	See Note
					1st Crop:	Small Grains		80-100	90-110	0	0	0	0	0	.0	$pH	3
					2nd Crop:	Small Grains		80-100	90-110	0	0	0	0	0	.0	$pH	3

Test Results

Soil Class	HM%	W/V	CEC	BS%	Ac	pH	P-I	K-I	Ca%	Mg%	Mn-I	Mn-AI(1)	Mn-AI(2)	Zn-I	Zn-AI	Cu-I	S-I	SS-I	NO_3-N	NH_4-N	Na
		1.11	61.8	100.0	0.0	8.1	17	215	94.0	4.0	45	5	5	246	246	90					0.4

Field Information / Applied Lime / Recommendations

Sample No.	Last Crop	Mo	Yr	T/A	Crop or Year		Lime	N	P_2O_5	K_2O	Mg	S	Cu	Zn	B	Mn	See Note
					1st Crop:	Small Grains		80-100	40-60	0	0	0	0	0	.0	$pH	3
					2nd Crop:	Small Grains		80-100	40-60	0	0	0	0	0	.0	$pH	3

Test Results

Soil Class	HM%	W/V	CEC	BS%	Ac	pH	P-I	K-I	Ca%	Mg%	Mn-I	Mn-AI(1)	Mn-AI(2)	Zn-I	Zn-AI	Cu-I	S-I	SS-I	NO_3-N	NH_4-N	Na
		1.12	11.1	100.0	0.0	8.1	38	104	84.0	12.0	77	24	24	118	118	47					0.0

NC DA&CS Agronomic Division 2011

Appendix C: North Carolina CRONOS Rainfall Data for Research Sites

Data retrieval from NC-DP-3 - Mount Olive 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	29.7604
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	20.0408
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