ABSTRACT

HERNANDEZ, ALONDRA ISAHURA. Assessment of the Feasibility of Using North Carolina Airports to Produce Camelina for Biodiesel. Under the direction of Dr. Matthew Veal, Dr. Consuelo Arellano and Dr. Kelly Zering.

This thesis presents preliminary work in investigating the feasibility of growing camelina on North Carolina airports by examining agronomic practices, phosphorus content of the oil and degumming methods, and finally compiles a list of candidate airports as well as constructs cost models for various scenarios.

The goal of the agronomic study was to find the highest yielding combination of variety: Blaine Creek, Calena, Ligena, and Suneson; seeding rate 8, 13, 18, and 23% open on the grain drill; and fertilization rate: 0, 60, and 120 lb N/ac. Before the harvest the survivability rate of the Ligena variety was found to have an overall mean of 84.35% without significant difference between seeding rates. An ANOVA model found seeding rate, fertilization rate and the interaction between variety and seeding rate to be significant. Most combinations of variety and seeding rate performed statistically similar; the three highest yielding combinations were Suneson 23%, Blaine Creek 18%, and Blaine Creek 23%. For fertilization rate 120 lb N/ac performed best.

AOCS Official Method Ca 12-55 is designed to measure phosphorus content of vegetable oils. Camelina, sunflower, sesame, rapeseed and safflower oils were measured and found to have phosphorus contents of 3.26, 37.92, 60.09, 15.6, and 4.87 ppm respectively. All of these values except for that of camelina were lower than published values which is most likely due to losses inherent to the method. Next, four different varieties of camelina were tested for phosphorus content: Calena had 3.26 ppm, Suneson 55.04 ppm, Celine 50.63 ppm, and Blaine Creek 34.30 ppm. All contents were statistically different. Oil samples from

each variety were then water and acid degummed to determine if either method would remove enough phosphorus to bring the content below 10 ppm. Neither water nor acid degumming individually was able to bring the contents low enough except for acid degumming on Blaine Creek which just made it under 10 ppm. Used in conjunction these methods would be more effective. Calena already has a content below the limit and would not need to be degummed making it an attractive choice for producers wanting to save money by removing the degumming step of the refining process.

Airports across North Carolina that were public, not major airports and within five miles of cropland were considered to be potential sites for camelina production of which there are 57. In total these airports have 4,829 acres available for crop production and on average each has 84.7 acres. Equipment cost models of four scenarios of different scale: small or large, and tillage practice: none or conventional, were constructed. The large scale, no till scenario was the most cost efficient with a total system cost per hour of $697.11 and total cost per acre of $56.07. In these models large scale farms were assumed to have 1,600 acres however since the average farm size in North Carolina is 169 acres, this scenario is unlikely. Another model used the average farm size of the ten counties where the top ten airports with the most available acres are located which was 260 acres. The no till model had a total system cost per hour of $2,025.38 and total cost per acre of $157.07 which are higher than the other models. An enterprise budget for this model assuming a camelina price of $0.27/lb, yield of 1,500 lb/ac, seeding rate of 7 lb/ac and fertilization rate of 20 lb N/ac proved that even with the higher costs this scenario could produce a net return of $208.86/ac.

Assessment of the Feasibility of Using North Carolina Airports to Produce Camelina for Biodiesel

by
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BIOGRAPHY

Alondra Hernandez grew up in Fort Washington, Maryland just outside of Washington D.C. Her parents, David and Arlene, both grew up in Puerto Rico and are both college educated; her father in Chemical Engineering and her mother in Physical Therapy.

After graduating top of her class from Oxon Hill High School in 2007, she began her undergraduate career at the University of Maryland in College Park to pursue a degree in Mechanical Engineering. Four years later she completed her degree requirements and graduated with a Bachelor's degree in May 2011.

A few months before graduation, Alondra applied to North Carolina State University for their Master's program in Agricultural Engineering and was admitted into the program shortly thereafter. In August of that summer she began to work under Dr. Matthew Veal investigating the oilseed camelina and its biofuel potential and after two years of work presents this thesis to present her findings.

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I would like to thank Dr. Matthew Veal for giving me the opportunity to work on this research and to expand my knowledge about camelina and biofuels. I would also like to thank Dr. Consuelo Arellano for sitting with me for hours at a time discussing my data and running statistical analyses.

I also thank my fiancé Jim Thompson, my family and my friends for supporting me during these past two years and encouraging me to push through when times got tough. I love you all.

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INTRODUCTION

As populations worldwide rise and more countries develop industrially the demand for cheap and efficient energy increases rapidly. According to some experts the world now or soon will find itself in the post peak oil era, when global production of crude oil is on the decline and unable to supply demand (Aftabuzzaman and Mazloumi, 2011). Not only is fossil fuel production on a decline, fossil fuels have negative effects on the environment and are supplied by politically unstable countries that present security challenges for the United States (Wald et al., 2009). Because of the political risks involved with these countries the Department of Defense aims to lessen its dependence on foreign oil and adopt new forms of renewable energy (Wald et al., 2009) including non-food based biofuels for the military's many transport vehicles.

Biofuels are alternative fuels made from renewable sources that emit lower amounts of greenhouse gases (Agarwal et al., 2010; An et al., 2011; Blackshaw et al., 2011). Several countries have implemented legislation in order to promote the use of biofuels including the European Union, Canada and the United States. The European Union set a goal to have 5% of transport fuels made from renewable sources by 2005 (Bernardo et al., 2003); similarly, Canada set a goal of having diesel and heating oil have a 2% renewable content by 2010 (Blackshaw et al., 2011). In 2007, the United States Congress passed the US Energy Independence and Security Act (EISA) which establishes the Renewable Fuel Standard that requires the use 136 billion liters of biofuel annually by 2022 (Blackshaw et al., 2011). Reduction of carbon emissions has also been the objective of several legislations, including the Low Carbon Fuel Standard (LCFS) passed by the California Air Resources Board in 2009

(Shonnard et al., 2010). The LCFS requires the state's transportation system to reduce its carbon emissions by 10% by the year 2020 (Shonnard et al., 2010).

In order for biofuels to be a competitive alternative to fossil fuels they must be comparable to or perform better than fossil fuels (Hill et al., 2006). Current biodiesels exceed regular diesel in terms of sulfur content, flash point, aromatic content and cetane number and can be used in existing diesel engines without the need for modification all while having a smaller carbon footprint (Muppaneni et al., 2012; Bernando et al., 2003). Performance is not the only standard to which biofuels must measure; they must also be economical and producible in large quantities (Hill et al., 2006). Since there are many different feedstocks for biofuels such as crops, waste and microalgae, large amounts of fuel can be produced. However not all feedstock are made equal. Some produce higher quality oil than others but more importantly some double as foodstuffs; such crops as corn and soybean cause a moral dilemma in using agricultural land for fuel crop production instead of food production (Aftabuzzaman and Mazloumi, 2011; Campbell et al., 2008; Debolt et al., 2009). Biofuel produced from non-food crops such as *camelina sativa* grown on non-agricultural lands such as airport turf fields presents an innovative solution to producing fuel with low carbon emissions (Shonnard et al., 2010; Reijnders, 2009; Debolt et al., 2009; Campbell et al., 2008).

Camelina sativa is a member of the *Brassicaceae* family with potential to be an influential player in the energy crisis because of its high germination rate and oil yield potential (Agarwal et al., 2010; Shonnard et al., 2010; Bernardo et al., 2003; Carlsson 2009; Lu et al., 2011; Hasheminejad et al., 2011). Camelina is a low input, short season crop (90 days) with a high germination rate which makes it an ideal rotation crop (Agarwal et al., 2010; Blackshaw et al., 2011; Carlsson 2009; Lu et al., 2011; Hasheminejad et al., 2011; Moser and Vaughn 2010). Requiring low input, camelina is also a very economical crop since growing it does not require tillage or large amounts of herbicide or fertilizer (Pilgeram et al., 2007). Camelina has also been found to be allelopathic (Putnam et al., 1993). Camelina seed also has a high oil content of 40% or more (Agarwal et al., 2010) and the plant is low temperature and frost tolerant (Agarwal et al., 2010; Moser and Vaughn, 2010; Muppaneni et al., 2012). The characteristics listed in

Table 1 make camelina a good biodiesel feedstock candidate as well as the fact that its oil can be converted into jet fuel (Shonnard et al., 2010).

Table 1. Characteristics of camelina

Specification	
Oil content	0.42 lb oil/lb seed[1]
Days to maturity	90 days[2]
Seed requirement	~ 3 lb/acre[2]
Average seed yield	~ 1500 lb/acre[2]

[1]Blackshaw et al., 2011

[2]Agarwal et al., 2010

Camelina meal, a byproduct of cold pressed oil, is also profitable. The meal contains 10-12% oil with approximately 5% being omega-3 fatty acids, is 40% protein, and is low in glucosinate which makes it useful as animal feed (Pilgeram, et al., 2007). Pilgeram et al (2007) found that with increasing content of camelina in chicken feed, the omega-3 content in the eggs also increased. As a result of this correlation, 40,000 laying hens in Montana are now being fed camelina.

Camelina-derived fuels have already shown their efficacy as a fuel source. In 2009, Japan Airlines carried out the world's first successful flight of a Boeing aircraft run on camelina-based jet fuel (Agarwal et al., 2010; Shonnard et al., 2010). The fuel was a mixture of three feedstocks: 84% camelina oil, 16% jatropha oil, and less than 1% of algae oil (Tyler, 2009). Bernardo et al (2002) were able to modify a light commercial road vehicle to run on crude camelina oil with lower smog and CO emissions, and similar CO_2 and O_2 emissions as regular diesel. In May 2011, the United States Air Force flew Thunderbird aircraft at their Joint Services Open House on a 50% mixture of camelina based hydrotreated renewable jet fuel and regular jet fuel (Lyle, 2011).

The objective of this thesis is to explore the plausibility of growing camelina at airports across North Carolina for use as biodiesel or jet fuel. Chapter one details the investigation into agronomic practices for growing camelina in North Carolina. The second chapter is about measuring phosphorus content of camelina and other oils using AOCS Official Method Ca 12-55. The final chapter contains a list of airports across North Carolina that have potential to serve as test sites for future on-site camelina production, equipment cost models and a sensitivity analysis of camelina production costs.

CHAPTER 1

Agronomic Practices for Growing Camelina in North Carolina

Introduction

Camelina, also known as false flax and gold of pleasure, production begin in Europe around the Bronze Age but was mostly replaced by canola as time went on (Zubr, 1997; Schillinger et al., 2012). Camelina was introduced in America most likely as a weed in flax seed but was not largely cultivated (Schillinger et al., 2012). Recently interest in camelina has resurged because of its possible role in renewable biodiesel and jet fuel with most production currently taking place in Montana and North Dakota (Schillinger et al., 2012; Shonnard et al., 2012).

Camelina has several unique agronomic traits that add to its potential to be a fuel source that uses minimal energy and pesticides as well as protecting soils from erosion (Putnam et al., 1993; Pilgeram et al., 2007). Camelina is compatible with reduced tillage systems and cover crops and more importantly requires a low seeding rate and is competitive with weeds (Putnam et al., 1993). Seeding rates can range from 5 – 12 lbs/acre (Putnam et al., 1993) or even be as low as 2 lbs/acre (Pilgeram et al., 2007). Low seeding rates makes camelina a very economic crop (Putnam et al., 1993). Camelina can also be sown by drilling or broadcast with similar results (Schillinger et al., 2012). Broadcasting is a more economic and faster method of sowing seed and therefore may be preferable to drilling (Schillinger et al., 2012).

Schillinger et al. (2012) found that for the drier Inland Pacific Northwest a late February to early March planting date produced good stand establishment and seed yield. For locations with more rainfall late-fall and mid-winter planting dates produced the greatest yield (Schillinger et al., 2012). In 2012 North Carolina averaged 1186 mm of precipitation (NOAA) which means that late-fall and mid-winter planting dates may be more suited to the North Carolina climate.

The best defense against weeds is early planting in a clean field to get a good establishment, allowing camelina to be competitive against weeds (Enjalbert and Johnson, 2011). Because camelina is allelopathic (Putnam et al., 1993) it does not require many sprayings, lowering costs and pesticide use. As of now the only herbicide registered for use on camelina is Poast® (sethoxydim) which targets emerged grassy weeds (Enjalbert and Johnson, 2011). The label recommends a maximum rate per acre per application of 2.5 pints. Broadleaf weeds can be controlled with glyphosate prior to planting camelina in mid-to-late winter or early spring (Schillinger et al., 2012). A disadvantage of planting camelina in the fall or early-winter is that there is no opportunity to control fall-germinating broadleaf weeds (Schillinger et al., 2012).

Nitrogen application rate depends on soil nitrogen and organic matter content and expected yield and is therefore site specific (Enjalbert and Johnson, 2011). Phosphorus, potassium and sulfur applications are not needed (Enjalbert and Johnson, 2011).

Camelina can be grown in both conventional and reduced tillage systems as long as there are no residual sulfonylurea or triazine herbicides in the soils that can damage the plants (Enjalbert and Johnson, 2011). For untilled fields with considerable crop residue, seeding rate may have to be increased (Enjalbert and Johnson, 2011).

Camelina production uses the same equipment as for wheat; it can be planted with a wheat drill or broadcast onto moist or frozen soil with similar results (Enjalbert and Johnson, 2011; Putnam et al., 1993). Harvesting should be done when the pods are dark tan or brown and can be done with a combine with similar settings for canola (Ehrensing and Guy, 2008).

Materials and Methods

As camelina is not a common crop in North Carolina part of this study included an experiment to determine the best combination of variety, fertilization rate and seeding rate. This experiment was carried out on a 1-acre plot at the Williamsdale Biofuels Field Laboratory set up in a split-split block design. The varieties used were Ligena, Calena, Blaine Creek, and Suneson. Seeding rate is based on how open the fluted cups on the grain drill are as will be described below; and the percentages used for the large bin were 8%, 13%, 18%, and 23% open. Fertilization rates were 0, 60, and 120 lbs N/acre.

Calibration of grain drill

The grain drill used in this experiment has two seeding bins, a small one and a large one. The bins each feed thirteen fluted cups as shown in Figure 1 which have a slotted wheel that can move on a horizontal axis to control how much seed is released. The position of the wheels is controlled by hand levers that the user sets to the desired percentage open.

Figure 1. Fluted cup from small bin

To calibrate the drill a one liter beaker was placed at the opening of the tube to catch the seed falling out and the hand crank turned 65 times according to the instruction manual. After the 65 turns the beaker of seed was weighed and converted to pounds per acre. The 65 turns were equivalent to 1/10 of an acre. The following equation was used to convert from grams to pounds per acre:

Equation 1. Calibration conversion

$$\frac{g}{cup \cdot 65\,turns} \times \frac{1\,lb}{453\,g} \times 13\,cups \times \frac{65\,turns}{1/10\,acre} \times 10 = \frac{lbs}{acre}$$

After testing the small bin completely open it was found that the small bin would not achieve the desired seeding rates and therefore the large bin on the drill was used instead. Four data points were collected and are tabulated and plotted below.

Table 2. Grain drill calibration data

% Open	Weight (g)	Lbs/acre
4	6.74	1.94
8	13.97	4
16	19.27	5.51
25	31.61	9.08

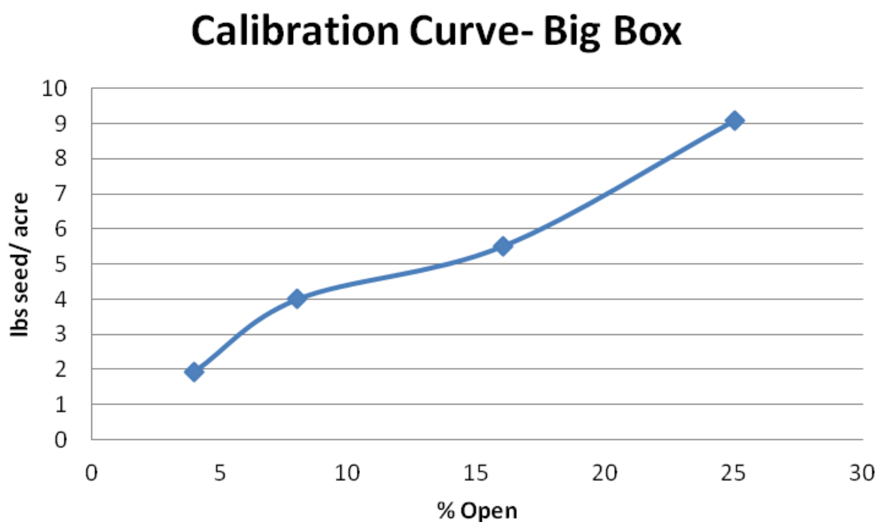

Figure 2. Calibration curve for large bin

For the experiment the desired seeding rates to test were 4, 5, 6, and 7 lbs/acre which correlated to approximately 8%, 13%, 18%, and 23% open on the large bin. Assuming a linear relationship between the percent open and the seeding rate and assuming that all varieties used weigh about the same, the following graph was developed to depict the relationship between the percent open and the seeding rate.

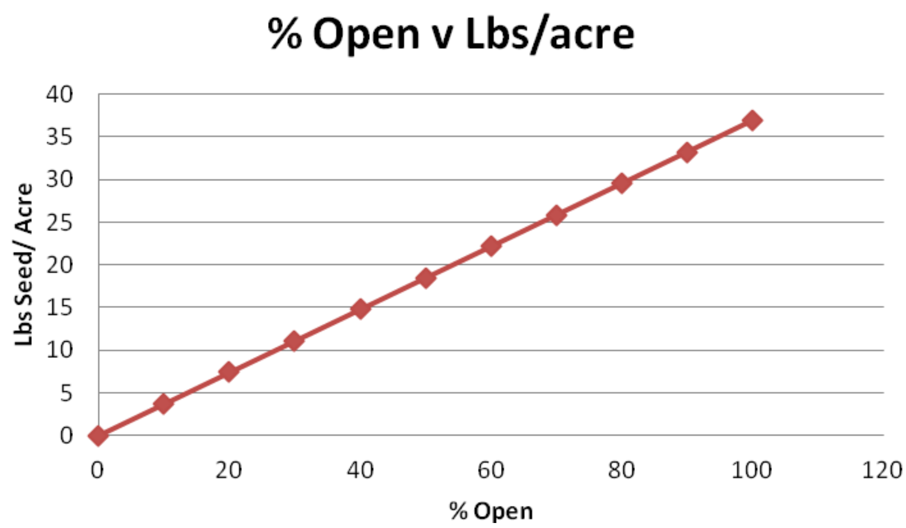

Figure 3. Relationship between % open and seeding rate

Following this relationship, the seeding rates corresponding to 8%, 13%, 18%, and 23% open are 2.96 lb/ac, 4.80 lb/ac, 6.65 lb/ac, and 8.50 lb/ac respectively.

Plot Preparation and Layout

Firstly the plot was tilled to kill off weeds then the plots were marked out with flags. On April 16, 2012 the seeds were planted with the drill press. The following diagram shows the plot layout: where each variety was planted along with the seeding rates.

Each of the larger sixteen subplots is 25 ft x 90 ft, and area of 2,250 ft^2. The in-between rows are 10 ft wide in most cases with some being 8 ft, 3 ft, and 2 ft because of space constraints. Each subplot was further divided into nine smaller plots to test the fertilization with three repetitions within each subplot, a total of 144 test plots.

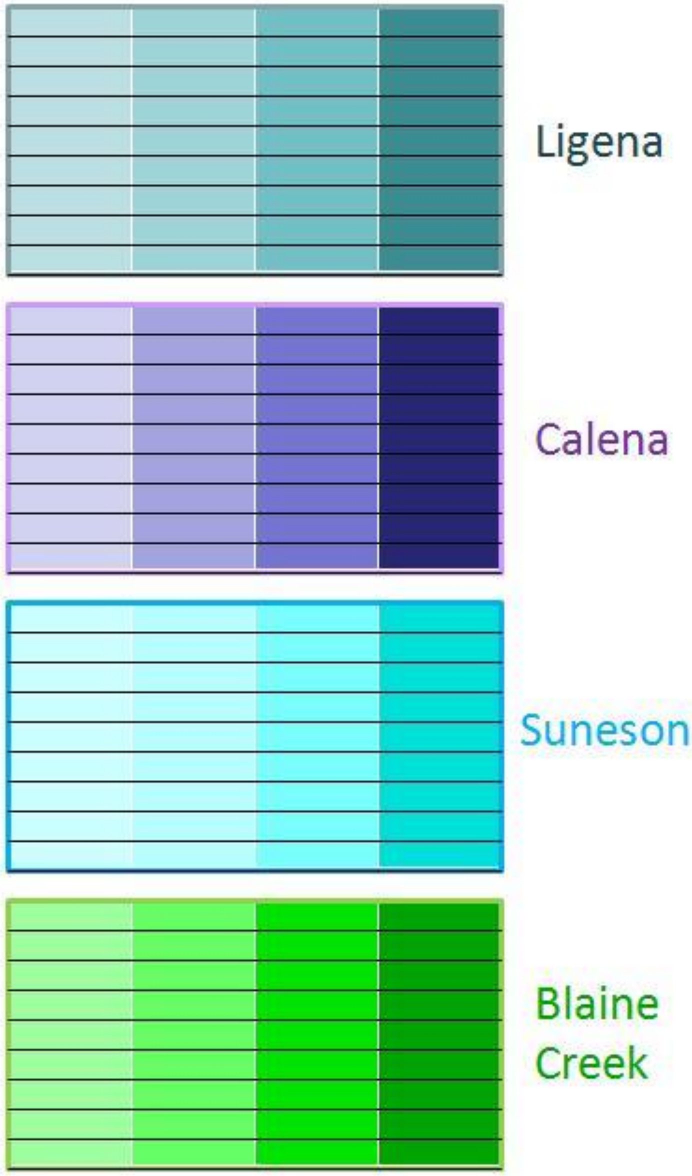

Figure 4. Plot layout with varieties and seeding rates

On the schematic above each block represents a while block with variety as the treatment. These blocks are then divided into four with the darkening colors representing increasing seeding rates as the split plot treatment. The black horizontal lines divide each block into nine split-split plots in which fertilization rates were randomized with each rate on three of the split-split plots within each colored split plot.

Herbicide Application

On May 5, 2012 the field was sprayed with Poast® at 2 pints/acre. Poast® is registered for grass weeds and was therefore ineffective against broadleaf weeds found in the field.

Survivability Rate

In order to determine the survivability rate two pieces of information are needed: the number of seeds in a pound and the number of grown plants within a chosen unit of area. This study employed one square foot wooden frames with which to do the counting. Within each test plot the frame was randomly thrown three times and the number of plants within each frame counted. The survivability rate is the number of plants divided by the number of seeds planted expressed as a percent.

$$\text{Survivability rate} = \frac{\text{\# of plants within 1 ft}^2}{\text{\# of seeds planted within 1 ft}^2}$$

Assuming all of the seed varieties are about the same size and weight, 1,000 seeds weigh about 1.5 g. Based on this figure one pound of seed contains approximately 302,400 seeds which then translates into the following values for number of seeds per square foot.

Table 3. Number of seeds planted per square foot

Percent Open	Seeding Rate (lb/ac)	Seeds/ sq.ft.
8	2.96	21
13	4.8	33
18	6.65	46
23	8.5	59

Harvest

The plants were harvested on June 22, 2012 using a harvester to cut the plants which were then raked and placed into trash bags and labeled. Seeds sown on the eastern side of the field (mostly Suneson and some Calena) did not grow well and were not harvested.

Results and Discussion

Survivability Rate

For this experiment the plants were counted when they had reached a height of about two feet. Only the Ligena variety was counted because of time constraints caused by inclement weather.

Table 4. Survivability rates for Ligena

Percent Open	Mean No. of Plants/ sq. ft.	Std. Error	Survivability Rate (%)
8	18.5	2.53	88.10
13	29.7	3.06	90.00
18	38.5	4.35	83.70
23	44.6	3.75	75.59

An ANOVA test of the data produced a p-value of 0.6915 meaning that there is no significant difference between the survivability counts for each seeding rate. It can be concluded therefore that the seeding rates alone did not have a significant effect on survivability rate. The box plot in Figure 5 shows the relative closeness of the observed means. The average survivability rate across all seeding rates was 84.35% which is high compared to canola which has a survivability rate between 40 and 60% (Canola Watch, 2013). Some observations yielded rates above 100% because during the first attempt at planting , the tractor got stuck after the first run, therefore on the second attempt this area was seeded a second time.

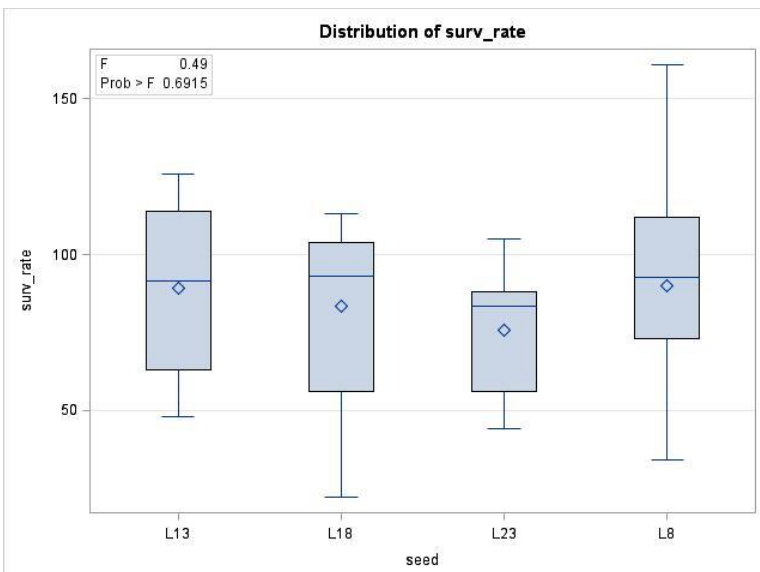

Figure 5. Box plot of survivability rates

The figure below is the SAS diagnostics panel for the ANOVA procedure on the survivability rates.

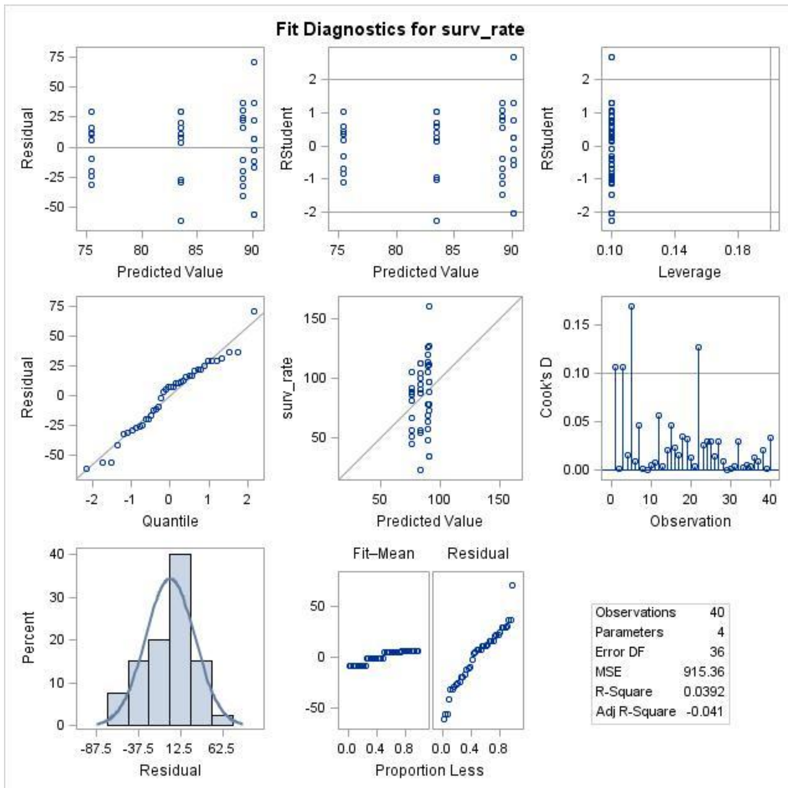

Figure 6. Fit diagnostics for survivability rates

The histogram on the bottom left of the figure shows that the assumption of the normality of the means may have been violated. The residual plot at the top left also shows that the residuals are not normal nor equal, violating two assumptions of the procedure. However, a Kruskal-Wallis test, the non-parametric alternative to ANOVA, also concludes that the mean survivability rates are not significantly different (F= 0.4898, p= 0.6915).

Yield

The yield data were modeled as a split-split plot with variety as a randomized block with a whole plot treatment of variety, seeding rate as the split-plot treatment, and fertilization rate as the split-split plot treatment with three repetitions. These repetitions however were not completely independent because they were located on the same subplot which means that parts of the field with more weeds would affect certain treatment combinations more than others. Ideally the plots would have been completely randomized; however because of equipment constraints it was not practical to do so. In order to randomize each plot the grain drill would have had to be completely cleaned out after each plot was planted. To make up for this violation of the assumptions for ANOVA, the error terms used to calculate the F-statistics were specified for each term instead of using the Mean Square Error which would have been low due to the lack of independence. The data were also unbalanced because some plots did not produce a recoverable yield due to excessive weed growth. The table below shows the equations with which each Mean Square Error term was calculated with “var” meaning variety, “fert” is fertilization rate, and “seed” is the seeding rate.

Table 5. Mean Square Error equations

Source	Type III Expected Mean Square
var	Var(Error) + 2.6153 Var(var*fert(seed)) + 10.461 Var(var*fert) + 7.8458 Var(var*seed) + 31.383 Var(var)
seed	Var(Error) + 2.6011 Var(var*fert(seed)) + 7.8034 Var(var*seed) + Q(seed,seed*fert)
var*seed	Var(Error) + 2.6726 Var(var*fert(seed)) + 8.0177 Var(var*seed)
fert	Var(Error) + 2.5729 Var(var*fert(seed)) + 10.291 Var(var*fert) + Q(fert,seed*fert)
var*fert	Var(Error) + 2.6252 Var(var*fert(seed)) + 10.501 Var(var*fert)
seed*fert	Var(Error) + 2.6042 Var(var*fert(seed)) + Q(seed*fert)
var*fert(seed)	Var(Error) + 2.6836 Var(var*fert(seed))

The overall ANOVA test found that seeding rate ($F = 14.69$, $p = 0.0008$), fertilization rate ($F = 35.44$, $p = 0.0004$) and the interaction between variety and seeding rate ($F = 5.87$, $p = 0.0007$) to be significant. Variety on its own was not significant ($F = 1.29$, $p = 0.3281$), neither were the interaction between variety and fertilization rate ($F = 2.25$, $p = 0.0832$), the interaction between seeding rate and fertilization rate ($F = 1.94$, $p = 0.1264$), nor the interaction between all three factors ($F = 1.31$, $p = 0.2014$).

The least square means for the different seeding rates are shown in the following plot.

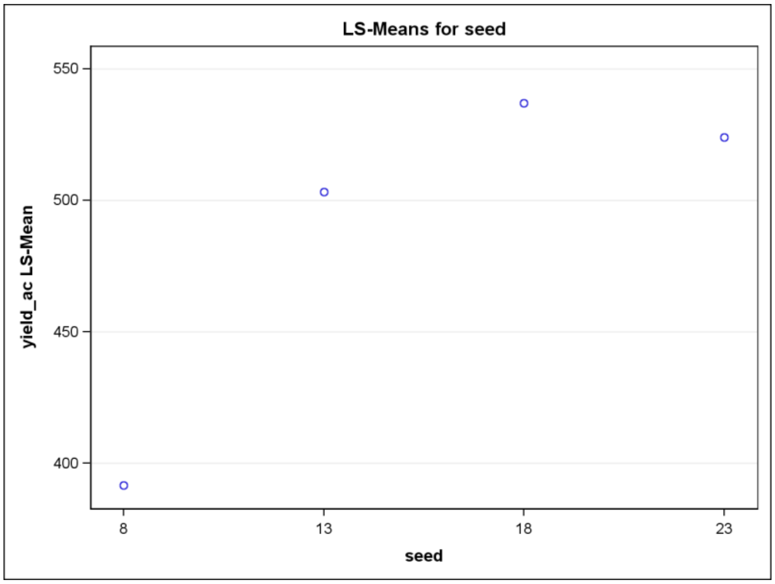

Figure 7. LS means for seeding rates

From the plot it can be noted that 18% open on the grain drill produced the highest mean yield per acre (536.91 lb/ac). Compared to the other means it is significantly higher than the mean yield per acre produced by 8% open (391.56 lb/ac, p= 0.0012) though not significantly different from 13% open (503.12 lb/ac, p= 0.5701) nor 23% open (523.87 lb/ac, p= 0.9621).

Although seeding rate was significant in and of itself the interaction between it and variety must be considered in order to find the highest yielding combination of the factors. Figure 8 shows the plotted means of each variety and seeding rate combination.

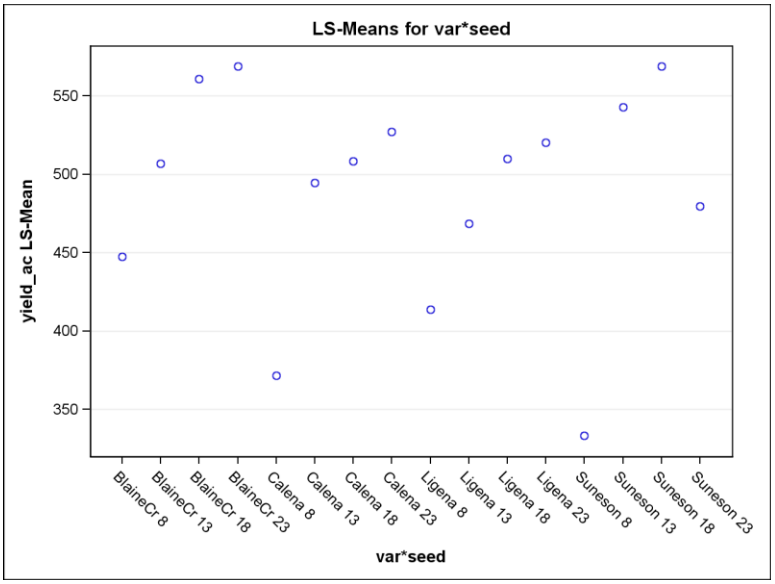

Figure 8. LS means for variety and seeding rate interaction

The combination with the highest mean yield per acre is Suneson 18% (568.82 lb/ac). From the pairwise comparisons however, the only combinations that were significantly different were between Suneson 8% (333.23 lb/ac) and Blaine Creek 18% (560.71 lb/ac, p= 0.0370); Blaine Creek 23% (568.70 lb/ac, p= 0.0301); and Suneson 23% (568.82 lb/ac, p= 0.0472). The mentioned three combinations to which Suneson 8% is different are the top three most yielding variety and seeding rate combinations.

Figure 9 shows the relationship between seeding rate and variety.

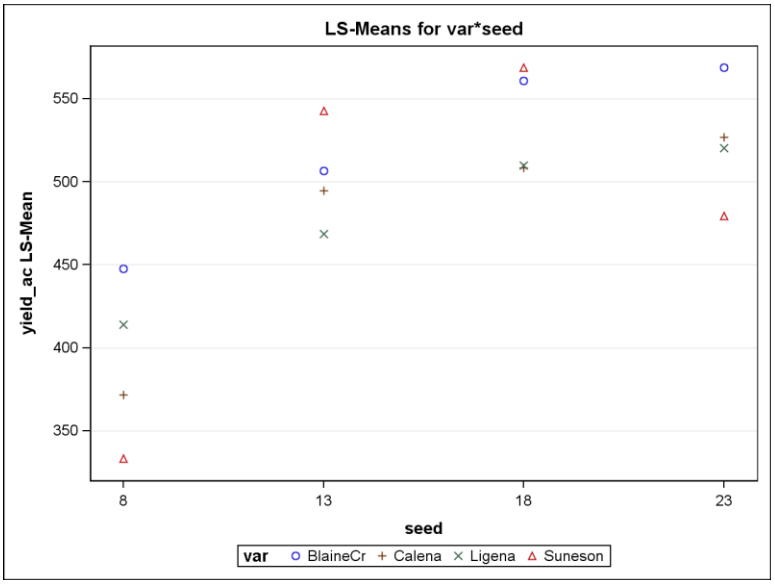

Figure 9. Relationship between seeding rate and variety

Blaine Creek produced the highest yields when the drill was 8% open, Suneson for both 13% and 18% and Blaine Creek for 23%. All of the varieties exhibit an increasing trend except for Suneson which drops off at the end because of the presence of weeds in the part of the field where this treatment combination was located. This upward trend indicates that higher seeding rates produce higher yields but as they get higher the difference in yield becomes smaller.

For fertilization rates, 120 lb N/ac produced the highest mean yields (536.51 lb/ac) as seen in Figure 10.

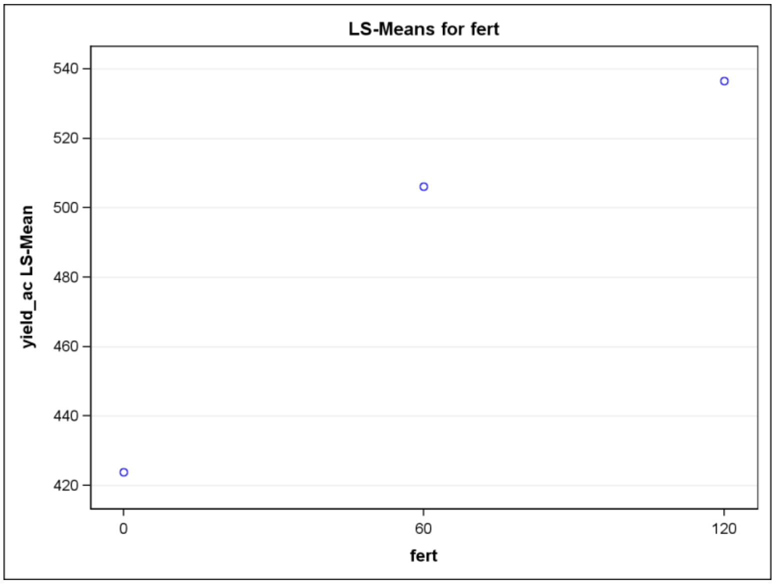

Figure 10. LS means for fertilization rates

The mean yield for the 120 lb N/ac treatment was significantly higher than that of 0 lb N/ac (423.89 lb/ac, $p<0.0001$) and 60 lb N/ac (506.18 lb/ac, $p= 0.0114$).

Extraneous Variables

A possible reason the camelina did not grow well in some areas of the field versus others is because of competition with weeds such as the ones seen in Figure 11. The specific weeds were not identified but there were different types in the field. Those that were shorter and grew thickly were the most destructive.

Figure 11. Weeds in camelina field

Another reason for the lower yields of some varieties is too much rainfall. In April of 2012, Sampson County received 1.63 inches of precipitation and 7.91 inches in May, more than four inches above the norm for May (NOAA Annual Climatological Summary, 2012). Excessively wet soil condition could have rotted some of the seed leading to a poor stand development, especially for the Suneson and Calena varieties.

Conclusions

This study found that seeding rate had no effect on survivability rate for the Ligena variety however data for the other varieties are unavailable. The mean survivability rate across all seeding rates was 84.35%.

All of the seeding rates tested except for 8% produced comparable yields and therefore setting the grain drill to 13% open will not cause heavy losses but will lower production costs. However because the interaction between variety and seeding rate was significant one should not be considered without the other, especially since variety on its own was not significant. Most of the combinations of seeding rate and variety were not significantly different and thus whichever variety is most available to the producer can be used with similar yields to the other varieties. The top three combinations were Suneson 23%, Blaine Creek 18% and Blaine Creek 23%. Blaine Creek or Suneson would be good variety choices since they are in the three most yielding combinations.

The differences in performance between the three different fertilization rates were obvious with 120 lb N/ac performing best, the, 60 lb N/ac then 0 lb N/ac. Even though 120 lb N/ac produced the highest yields in this experiment, the amount of fertilization needed varies from field to field and soil tests are needed to accurately calculate the amount needed. Over-fertilization can be harmful to the plants and can contaminate local water sources through run-off.

Problems with weeds affecting only certain spots of the field and the practical impossibility of complete randomization may have had a significant effect on the results of this experiment. Future replications are needed in order to confirm or refute these results.

References

Canola Watch. 2013. How to increase seed survival rates. Canola Council of Canada. Available at: http://www.canolawatch.org/2013/03/06/how-to-increase-seed-survival-rates/. Accessed 24 April 2013.

Ehrensing, D. T. & S. O. Guy. 2008. Camelina. Oil Seed Crops. Oregon State University Extension Service. Available at: http://extension.oregonstate.edu/catalog/pdf/em/em8953-e.pdf. Accessed 18 March 2013.

Enjalbert, J. N. and J. J. Johnson. 2011. Guide for Producing Dryland Camelina in Eastern Colorado. Colorado State University Extension. Available at: http://www.ext.colostate.edu/pubs/crops/00709.html. Accessed 18 February 2013.

NOAA. National Climatic Data Center. Available at: http://www.ncdc.noaa.gov/cag/time-series/us. Accessed 13 March 2013.

Pilgeram, A. L., D. C. sands, D. Boss, N. Dale, D. Wichman, P. Lamb, C. Lu, R. Barrows, M. Kirkpatrick, B. Thompson and D. L. Johnson. 2007. Camelina Sativa, A Montana Omega-3 and Fuel Crop. Issues in new crops and new uses. Available at: www.extsoilcrop.colostate.edu/CropVar/documents/oilseeds.camelina/montana_omega3_fuelcrop.pdf. Accessed 4 March 2013.

Putnam, D.H., J.T. Budin, L.A. Field, and W.M. Breene. 1993. Camelina: A promising low-input oilseed. p. 314-322. In: J. Janick and J.E. Simon (eds.), New crops. Wiley, New York.

Schillinger, W. F., D. J. Wysocki, T. G. Chastain, S. O. Guy, and R. S. Karow. 2012. Camelina: Planting date and method effects on stand establishment and seed. *Field Crops Research* 130(2012): 138-144.

Shonnard, D. R., L. Williams and T. N. Kalnes. 2010. Camelina-Derived Jet Fuel and Diesel: Sustainable Advanced Biofuels. *Environmental Progress & Sustainable Energy* 29(3): 382-392.

Zubr, J. 1997. Oil seed crop: Camelina Sativa. *Industrial Crops and Products* 6(2) 113-119.

CHAPTER 2

Usefulness of AOCS Official Method Ca 12-55 on Measuring Phosphorus Content of Camelina Oil

Introduction

Global attention has turned to biofuels and their potential to replace fossil fuels in today's energy market. Camelina sativa, a member of the Brassicaceae family produces oil that can be converted into diesel as well as jet fuel (Shonnard et al, 2010). Camelina possesses many characteristics that make it almost ideal for oil production: it has a high germination rate, high oil yield potential, is a low input, short season crop, is low temperature and frost tolerant as well as drought tolerant (Agarwal et al, 2010, Blackshaw et al, 2011; Carlsson, 2009, Hasheminejad et al, 2011; Lu et al, 2011; Moser and Vaughn, 2010). As with all plant derived oils, refining the crude oil is important to the quality of the finished product.

Phosphorus, in the form of phosphatides also known as gums, in vegetable oils lowers the oil quality and can plug engine filters, lines and injectors (Zufarov et al., 2008, Ma and Hanna, 1999). As such, the EPA has set a limit on phosphorus content in biodiesels of 10 ppm (National Renewable Energy Laboratory, 2009).

Degumming is an important step in the vegetable oil refining process that removes the gums (Zufarov et al., 2008). Knowledge of the characteristics of the raw oil, specifically the phosphorus content, is important to selecting the most appropriate and cost efficient method of degumming (Leung et al., 2010). Hydratable phosphatides can be removed with water degumming while non-hydratable phosphatides require more complex methods with higher temperature requirements and the use of acids or other degumming substances

(Zufarov et al., 2008). Common methods include water degumming and acid (micelles) degumming (Zufarov et al., 2008, Leung et al., 2010).

The simplest method to remove phosphatides from vegetable oils is water degumming, a method that uses water to remove the hydratable phospholipids in the oil (Zufarov et al., 2008). The basic procedure is to heat the oil, add water, stir, and let the phosphatides settle naturally or by centrifugation (Zufarov et al., 2008, Leung et al., 2010). Despite the fact that this method is quite simple, easily operated and results in high yields (Leung et al., 2010), water degumming does not sufficiently remove enough gums for most vegetable oils (Zufarov et al., 2008) but it is useful as a first step in the removal process.

Oil that has been water degummed can be further refined with an acid degumming step to remove the non-hydratable phospholipids. First a dilute acid is added to the oil and mixed in for some time then a base is added to the mixture (Dijkstra and Opstal, 1989, Zufarov et al., 2008). The acid breaks the metal-phosphatidic acid bonds resulting in insoluble metal salts and phosphatidic acid (Zufarov et al., 2008). The base then hydrates the acid and the phosphatides are removed by centrifugation (Zufarov et al., 2008). The acids most commonly used are citric or phosphoric acid and the bases used are include sodium hydroxide (NaOH), sodium carbonate (Na_2CO_3), or sodium silicate (Na_2SiO_3) (Leung et al., 2010, Zufarov et al., 2008).

As the phosphorus content of the oil is proportionate to the phosphatide content (Ma and Hanna, 1999), the difference between the initial phosphorus content and the post-degumming phosphorus content quantifies the efficiency of the process. One method to measure phosphorus content in vegetable oils is the AOCS Official Method Ca 12-55, a relatively simple process. Phosphorus is measured by first calcining the oil in the presence of zinc oxide, forming phosphomolybdate which is then reduced and the molybdenum blue is finally measured with a spectrophotometer (Tosi et al., 1998).

This method requires charring and ashing the samples which is a long process and can lead to losses and contamination (Dijkstra and Meert, 1982). Other disadvantages of the method include heating at boiling point, including once with concentrated hydrochloric acid, cooling before absorbance is measured, and the use of hydrazine sulfate, a carcinogen (Tosi et al., 1998).

Materials and Methods

The oils used in these experiments were cold pressed using a KernKraft KK40F Universal Screw Press. Absorbancies were measured using a Shimadzu UV-1770 PharmaSpec spectrophotometer.

Type

In order to compare the efficacy of AOCS Method Ca 12-55 different crude oils were tested and the observed phosphorus contents compared to those found in literature. Sunflower, sesame, safflower and rape seeds were pressed for the crude oils used in this experiment.

Variety

Paulsen et al. (2011) found crude camelina oil to have a phosphorus content between 0.6 -35 $mgkg^{-1}$, a rather large range. The purpose of this experiment was to investigate whether or not phosphorus content changes significantly across different varieties of camelina. The varieties investigated include Suneson, Celine, Calena, and Blaine Creek.

Blaine Creek is a short-season, high yield line developed by breeders at Montana State University (Ehrensing and Guy, 2008). Suneson is also a variety bred by Montana State University and is a mid-season, average-yield line, typically with higher oil content than Blaine Creek (Ehrensing & Guy, 2008). Celine is a spring, high yielding variety developed by Group Limagrain in France (Enjalbert and Johnson, 2011; Ehrensing and Guy, 2008).

Degumming

This portion this study investigates whether or not AOCS Method Ca 12-55 can detect and measure the phosphorus content of degummed camelina oil and compares water degumming to acid degumming. The oil was heated to 80˚C on a hot plate and distilled water was then added at 5% volume and the mixture was stirred for 15 minutes with a magnetic stirrer. After stirring the mixture was allowed to naturally settle and separate. The same procedure was followed for acid degumming but 30% citric acid solution was used instead of water.

Results and Discussion

Type

The means are standard errors of the results of these experiments are tabulated below.

Table 6. Means, standard errors of observed P contents

Seed Type	P Content (ppm)	Expected (ppm)	Difference
Camelina	3.26 ± 0.15	0.6 - 35[1]	within range
Sunflower	37.92 ± 0.31	95.7 ± 4.3[2]	57.78
Sesame	60. 09 ± 0.78	8720 ± 350[3]	8659.91
Rapeseed	15.6 ± 0.08	156.4 ± 6.2[2]	140.8
Safflower	4.87 ± 0.12	19.4 ± 1.2[4]	14.53

[1]Paulsen et al., 2011

[2]Zufarov et al., 2008

[3]Deosthale, 1981

[4]Lee et al., 2004

As can be seen from the table, the observed values for all the oils expect camelina were lower than those found in literature. A fact worth noting is that only Zufarov et al. (2008) used AOCS Method Ca 12-55 to obtain the phosphorus contents of sunflower and rapeseed oils.

The observed values for sesame and rapeseed oils were both at least an order of magnitude lower than those found in literature. For this reason these oils were tested again and the following table compares the means along with the standard errors of P content from trial one and two.

Table 7. Sesame and rapeseed P contents- trials 1 and 2

Type	Trial 1 P-content (ppm)	Trial 2 P-content (ppm)
Sesame	60. 09 ± 0.78	56.65 ± 1.51
Rapeseed	15.6 ± 0.08	11.1 ± 0.70[a]

[a]Mean and SE exclude outlying observation

The mean for the rapeseed P content in trial two excludes an outlying observation caused by an error during the experiment. A t-test with unequal variances and including the outlier found that the means from trial one and trial two are not significantly different ($p=0.0615$) and the same test without the outlier produced the same conclusion that the means are the same ($p=0.095$). A t-test with equal variances produced a p-value of 0.1137, leading to the conclusion that the means from trial one and trial two are not significantly different.

An explanation as to why the observed values of this experiment are consistently lower than those found in literature relates to a difficulty involving the crucibles used for the experiments. The AOCS method calls for clear glass crucibles which have been discontinued by Fisher Scientific thus porcelain crucibles were used instead. The obstacle these pose is in the step requiring the boiling of the ash/hydrochloric acid/water mixture for five minutes. With the porcelain crucibles it is impossible to know when the samples have started boiling and peering under the watch glass would only release heat and affect the boiling. For these experiments the mixture was left to heat on a hot place at heat level 5 for 10 minutes, allowing five minutes to reach boiling point. At that setting the hot plate exceeds 100˚C after five minutes. The uncertainty is whether or not the samples actually begin boiling after five minutes. The observed phosphorus contents could be low because the sample was not boiled long enough in order to adequately extract from the ash sample. This follow up experiment increased the time on the hot plate to 15 minutes in order to assess whether the added five minutes will produce significantly different results.

Table 8. Comparison of samples on hot plate for 10 min. v. 15 min.

	Time on Hot Plate (min)	P content (ppm)	P-value
Sunflower Oil	10	37.92 ± 0.31	0.2063
	15	38.62 ± 0.34	

An equality of variance test concluded that the variances of the samples on the hot plate for 10 minutes and 15 minutes are the same (F=1.23, P=0.8950). A t-test using the Pooled variance produced a t-statistic of -1.51 and a p-value of 0.2063. From these values it can be concluded that the mean P contents are not significantly different and therefore extended time on the hot plate did not affect the resultant P content.

The reason the observed values are lower could be because of the method itself and the losses it incurs although this does not explain the difference in values that Zufarov et al. (2008) obtained. In general the values from literature are quite variable and the true values cannot be obtained from any one article and requires more repetitions.

Variety

The following table shows the means and standard errors of the phosphorus contents of the different varieties of camelina seed.

Table 9. Mean and standard errors of P contents by variety

Variety	Mean P content (ppm)
Blaine Creek	34.30 ± 0.20
Celine	50.63 ± 0.29
Suneson	55.04 ± 1.04
Calena	3.26 ± 0.15

Suneson had the highest phosphorus content and Calena the lowest. An overall ANOVA F-test output a p-value of less than 0.0001 and an F-statistic of 1778.64, meaning that the null hypothesis that the mean P contents of the different varieties are the same is rejected. Thus, at least one of the varieties is different. A Least Squares with Tukey Adjustment comparison resulted in the following matrix of p-values:

Table 10. Least Squares matrix for varieties

i/j	**1**	**2**	**3**	**4**
1		<.0001	<.0001	<.0001
2	<.0001		<.0001	<.0001
3	<.0001	<.0001		0.0023
4	<.0001	<.0001	0.0023	

where 1= Blaine Creek, 2= Calena, 3= Celine and 4= Suneson. All of the values in the matrix are below 0.05, indicating that all of the varieties of different from each other. This can be seen graphically in the following box plot.

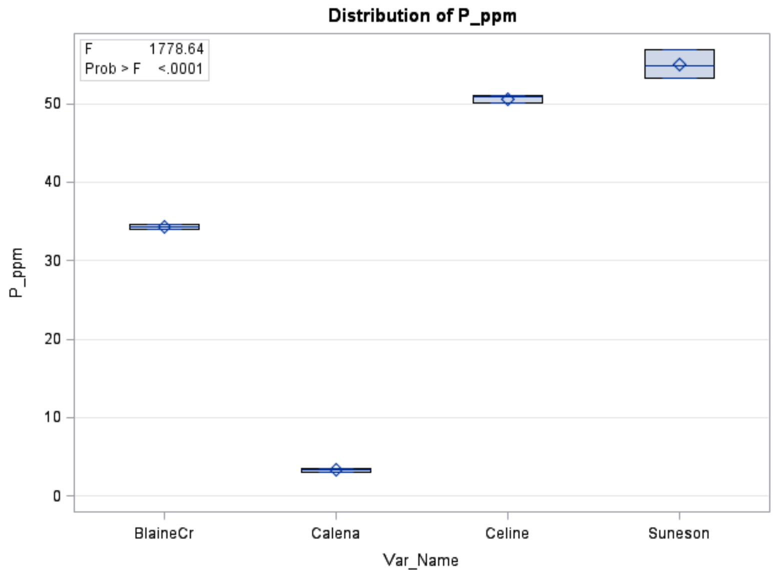

Figure 12. Box plot of variety P contents

Degumming

The following graph shows the phosphorus contents of the oils from different varieties before and after degumming.

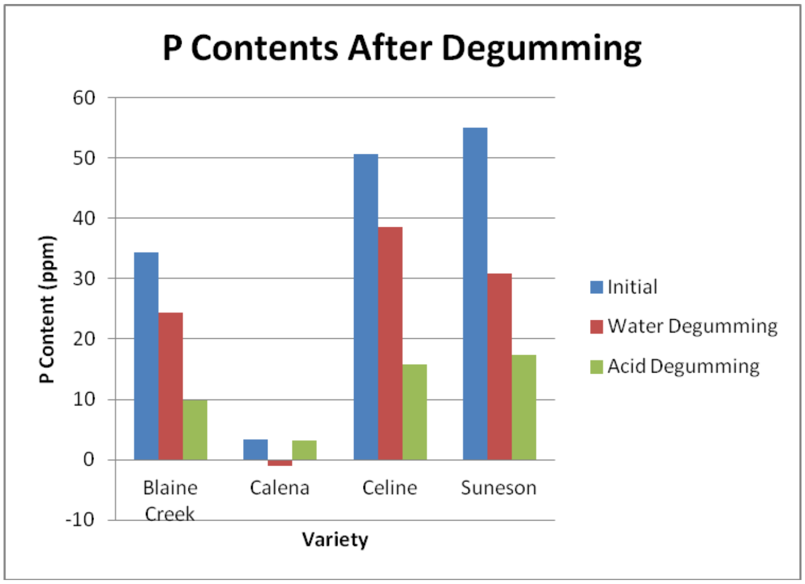

Figure 13. Degumming results

Although water degumming did remove some of the phosphorus from the oils, it was ineffective in bringing the content below 10 ppm, as the figure above shows. The degummed Calena sample yielded a negative phosphorus content which indicates that the method does not measure low contents accurately. In this case the negative value can be counted as zero since a negative content makes no practical sense. Water degumming worked best for Calena, essentially removing 100% of the gums, however it was not needed because the phosphorus content was already below 10 ppm. Water degumming also worked well for Suneson, removing 44% of the gums as opposed to 29% for Blaine Creek and 24% for Celine. All of the varieties except Calena would need additional degumming in order to comply with the EPA limit.

For Calena, acid degumming removed very little phosphorus indicating that most of the phosphatides in the oil are hydratable. For the other varieties acid degumming removed more phosphorus than water degumming but was only able to bring the phosphorus content of Blaine Creek below 10 ppm. Acid degumming removed only 1% of the gums from the Calena oil but was more effective in the other varieties, removing 68% from Suneson, 71% from Blaine Creek and 69% from Celine. Camelina oil from varieties other than Calena would need to be degummed in a two-step combined process of water and acid degumming or by some other method.

Considering the differences between method and not variety, the following plot shows that both water and acid degumming removed significant amounts of phosphorus from the initial values (F= 32.77, p< 0.0001).

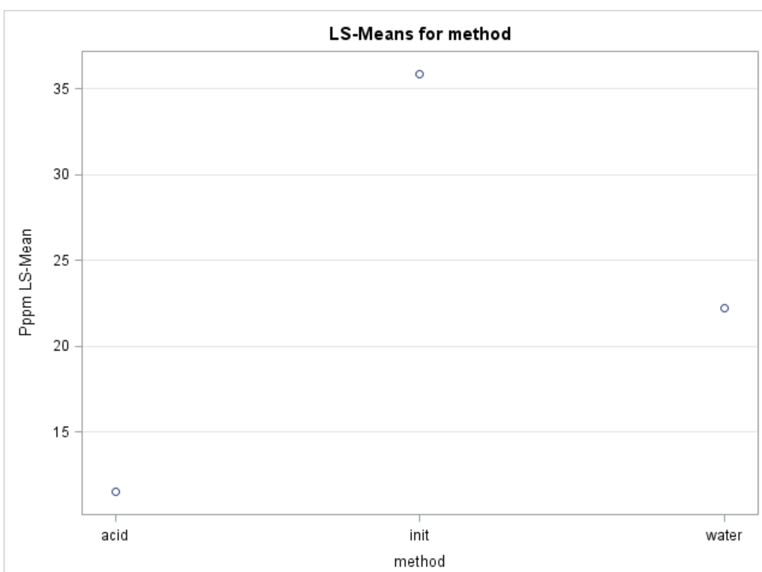

Figure 14. LS means for degumming method

Overall, acid degumming removed more phosphatides than water degumming.

Conclusions

Type

Measuring the phosphorus contents of sunflower, safflower, rapeseed, sesame and camelina all produced lower contents than those found in literature, except for camelina. These low values could be a consequence of the losses inherent in the method and are not a result of a shorter boiling time than the method calls for. A study with more repetitions could come closer to obtaining a true value of the phosphorus contents of these oils.

Variety

Phosphorus content is dependent on variety type. Suneson had the highest content of 55.04 ppm ± 1.04; Celine the second highest with 50.63 ppm ± 0.29; then Blaine Creek with 34.30 ppm ± 0.20, and Calena had the lowest with 3.26 ppm ± 0.15. Calena would work best for onsite fuel production operations because with its low P content it requires little to no degumming, lowering production costs. However, planners should also consider the agronomic characteristics of each of the varieties along with the oil phosphorus contents in order to determine the ideal variety for their specific purposes and location.

Degumming

AOCS Method Ca 12-55 was able to detect decreases in phosphorus content after the oils were degummed. For all the varieties tested except for Calena which had initial phosphorus content below 10 ppm, water degumming did not remove enough phosphorus to meet the EPA limit. For the Calena sample the method yielded a negative phosphorus content which indicates that the method does not accurately measure trace amounts of phosphorus however if complete accuracy is not needed then the negative values can be assumed to be zero. Calena is a good choice for growers who intend to produce biodiesel on-site because they can bypass the degumming step and save time and money.

References

Agarwal, A., T. Pant and Z. Ahmed. 2010. Camelina sativa: a new crop with biofuel potential introduced in India. *Current science 99*(9): 1194-1195.

Blackshaw, R. E., E. N. Johnson, Y. Gan, W. E. May, D. W. McAndrews, V. Barthet, T. McDonald and D. Wispinski. 2011. Alternative oilseed crops for biodiesel feedstock on the Canadian prairies. *Canadian Journal of Plant Science 91*(5): 889-896.

Carlsson, A. S. 2009. Plant oils as feedstock alternatives to petroleum - A short survey of potential oil crop platforms. *Biochimie 91*(6): 665-670.

Deosthale, Y. G. 1981. Trace Element Composition of Common Oilseeds. *JAOCS 58*(11): 988-990.

Dijkstra, A. J. and D. Meert. 1982. Determination of Trace Elements in Oils by Plasma Emission Spectroscopy. *JAOCS 59*(4): 199-204.

Dijkstra, A. J. and M. V. Opstal. 1989. The total degumming process. *JAOCS. 66*(7)*:* 1002-1009.

Ehrensing, D. T. & S. O. Guy. 2008. Camelina. Oil Seed Crops. Oregon State University Extension Service. Available at: http://extension.oregonstate.edu/catalog/pdf/em/em8953-e.pdf. Accessed 18 March 2013.

Enjalbert, J. N. and J. J. Johnson. 2011. Guide for Producing Dryland Camelina in Eastern Colorado. Colorado State University Extension. Available at: http://www.ext.colostate.edu/pubs/crops/00709.html. Accessed 18 February 2013.

Hasheminejad, M., M. Tabatabaei, Y. Mansourpanah, M. K. Far and A. Javani. 2011. Upstream and downstream strategies to economize biodiesel production. *Bioresource technology 102*(2): 461-468.

Lee, Y. C., S. W. Oh, J. Chang and I. H. Kim. 2004. Chemical composition and oxidative stability of safflower oil prepared from safflower seed roasted with different temperatures. *Food Chemistry 84*(1): 1-6.

Leung, D. Y. C., X. Wu and M. K. H. Leung. 2010. A review on biodiesel production using catalyzed transesterification. *Applied Energy 87*(4): 1083-1095.

Lu, C., J. A. Napier, T. E. Clemente and E. B. Cahoon. 2011. New frontiers in oilseed biotechnology: meeting the global demand for vegetable oils for food, feed, biofuel, and industrial applications. *Current opinion in biotechnology 22*(2): 252-259.

Ma, F. and Hanna M. A. 1999. Biodiesel production: a review. *Bioresource Technology 70*(1): 1- 15.

Moser, B. R. and S. F. Vaughn. 2010. Evaluation of alkyl esters from Camelina sativa oil as biodiesel and as blend components in ultra low-sulfur diesel fuel. *Bioresource technology 101*(2): 646-653.

National Renewable Energy Laboratory. 2009. Biodiesel Handling and Use Guide Fourth Edition. Available at: www. osti.gov/bridge. Accessed 8 January 2013.

NOAA. National Climatic Data Center. Available at: http://www.ncdc.noaa.gov/cag/time-series/us. Accessed 13 March 2013.

Paulsen, H. M., V. Wichmann, U. Schuemann and B. Richter. 2011. Use of straight vegetable oil mixtures of rape and camelina as on farm fuels in agriculture. *Biomass & Bioenergy 35*(9): 4015-4024.

Shonnard, D. R., L. Williams and T. N. Kalnes. 2010. Camelina-Derived Jet Fuel and Diesel: Sustainable Advanced Biofuels. *Environmental Progress & Sustainable Energy 29*(3): 382-392.

Tosi, E. A., A. F. Cazzoli and L. M. Tapiz. 1998. Phosphorus in Oil. Production of Molybdenum Blue Derivative at Ambient Temperature Using Noncarcinogenic Reagents. *JAOCS 75*(1): 41-44.

Zufarov, O., S. Schmidt and S. Sekretár. 2008. Degumming of rapeseed and sunflower oils. *Acta Chimica Slovaca 1*(1):321-328.

CHAPTER 3

North Carolina Airports with Potential for Camelina Production and Modeling Their Costs

Introduction

In the face of rising global fuel demand and decreasing production, non-food crop derived biofuels present a more environmentally friendly alternative than fossil fuels (Shonnard et al., 2010). Camelina sativa, an oilseed similar to canola, is one such non-food crop with applications in fuel. A unique aspect of camelina is that its oil can be refined into jet fuel; in fact, in early 2009 Japan Airlines completed the first successful test flight using an 84% camelina, 16% jatropha and less than 1% of algae fuel mixture (Shonnard et al., 2010; Lane, 2012). The big question facing plant based biofuel production is where to grow the feedstock? Taking agricultural land from food production to fuel production causes a moral dilemma as well as threatens food supplies while clearing forest lands would emit the carbon reserves in the soil into the atmosphere (Campbell et al., 2008).

Many airports in the United States lease out portions of their land for crop production, usually for corn and wheat (DeVault et al., 2012). Depending on yields, associated costs and demand, producing biofuel feedstock could become a lucrative endeavor for some airports (DeVault et al., 2012). Growing camelina in particular on airport turf fields presents a unique opportunity as its oil can be refined into jet fuel.

By producing their own camelina on site individual airports could gain supplemental income by selling the seeds to biodiesel manufacturers, universities, or even farmers. The airports could also fuel their ground fleets with biodiesel made on-site which would make the airports more self sustaining and could possibly save them money on fuel.

Machinery costs are a large portion of the costs associated with any agricultural production. Costs can be divided into two categories: ownership costs and operating costs. Ownership costs occur regardless of amount of use and include depreciation, interest, taxes and insurance (Edwards, 2009).

Depreciation

Depreciation is the loss of value, or cost, from age of the machine (Edwards, 2009). In order to calculate the depreciation, the remaining value of machine after its economic life with an average number of hours of annual use. In a cost estimate model the economic life is the number of years for which costs are estimated; typically 15 years for tractors and 10 to 12 years for other farm machines (Edwards, 2009). The annual use of a machine in hours is the quotient of the average annual use in acres divided by the field capacity:

$$Annual\ Use\ (hr) = \frac{Annual\ Use\ (ac)}{Field\ \ Capacity\ \ (ac/hr)}.$$

Field capacity of an implement is defined as:

$$Field\ \ Capacity\ \ (ac/hr) = \frac{Avg\ \ Speed \times Width}{8.25 \times (Avg\ Utilization/100)}$$

where average speed is in mph and average utilization is a percentage. Both values can be found in Table 3 of ASAE Standard D497.4. The field capacity of a power unit is assumed to be 120% of the field capacity of an implement.

Total depreciation is then calculated as the different between purchase price and remaining value. Purchase price in this model is estimated as 92% of the list price for power units and 97% of the list price for implements. In summary,

Total Depreciation = Purchase Price – Remaining Value.

Capital Recovery

Capital recovery is the amount of money required to repay the value lost due to depreciation and to pay interest, which is calculated using a Capital Recovery Factor (CRF) (Edwards, 2009). The CRF is calculated using the Real Rate of Return (RRR) and the economic life:

$$CRF = \frac{RRR \times (1 + RRR)^{EL}}{(1 + RRR)^{EL} - 1},$$

where EL is the economic life in years and the RRR is calculated as:

$$RRR = \frac{Interest\ \ Rate - Inflation\ \ Rate}{1 + Inflation\ \ Rate}.$$

Capital Recovery is then calculated as

(Total Depreciation x CRF) + (RRR x Remaining Value).

Taxes, Insurance, and Housing (TIH)

In this model the costs of taxes, insurance and housing was estimated as

TIH= 0.015 x Purchase Price.

Total Ownership Cost

The total ownership cost per year is

Total Ownership Cost/yr = Capital Recovery + TIH.

Operating costs are directly correlated with amount of use and include repairs and maintenance, fuel, lubrication and labor (Edwards, 2009).

The total ownership cost per hour is the total ownership cost divided by the hours of annual use.

Total Operating Cost

Total operating cost includes repair, fuel, labor, and lubrication costs. The cost of repairs over the life of a machine is the difference between the repair cost at the end of the machine's life and the repair cost at the time of purchase:

$$\textit{Total Accumulated Repair Cost} = \textit{End of Life Repair Cost} - \textit{Purchase Repair Cost}.$$

The average repair cost per hour is the total accumulated repair cost (above) divided by the difference of the total accumulated hours at the end of life and the accumulated hours at purchase. Repair cost in general is calculated as

$$\textit{Repair Cost} = \textit{RF1} \times \textit{Purchase Price} \times (\textit{Accumulated hrs of use}/1000)^{RF2},$$

where RF1 and RF2 are constants found in Table 3 of ASAE Standard D497.4.

Fuel cost is a function of maximum PTO horsepower and fuel price,

$$\textit{Fuel cost/hr} = 0.044 \times \textit{PTO HP} \times \textit{Fuel Price},$$

where 0.044 is constant to estimate the average fuel consumption of a diesel engine (Edwards, 2009).

Lubrication cost is estimated by multiplying the fuel cost per hour by 15%:

$$\textit{Lubrication Cost/hr} = 0.15 \times \textit{Fuel Cost/hr}.$$

Labor cost per hour is estimated by multiplying the labor value per hour (wage rate) by a factor of 1.1:

$$\textit{Labor Cost/hr} = 1.1 \times \textit{Labor Value/hr}.$$

Total operating cost per hour is the sum of the repair, fuel, lubrication, and labor costs per hour:

Total Operating Cost/hr = Repair Cost/hr + Fuel Cost/hr + Lubrication Cost/hr + Labor Cost/hr.

Total Cost per Hour

Total cost per hour is the sum of the total operating cost per hour and the total ownership cost per hour:

Total Cost/hr = Total Operating Cost/hr + Total Ownership Cost/hr.

Total System Cost

Total system cost is the sum of the power unit total cost per hour and the implement total cost per hour:

Total System Cost/hr = Power Unit Total Cost/hr + Implement Total Cost/hr.

Total Cost per Acre

Total cost per acre is calculated as the total system cost divided by the field capacity:

$$Total\ \ Cost/\,ac = \frac{Total\ System\ Cost}{Field\ \ Capacity}.$$

Materials and Methods

According to airnav.com, there are 110 airports in North Carolina however not all are suitable for crop production programs. This search considered only publicly owned airports under the assumption that any initiative to instill a crop production program would be publicly funded. Major airports were also excluded.

The other criterion for the search was that the airport be located within five miles of existing agricultural land. The benefit of having these lands nearby is that the farmers could form a cooperative with the airports to rent their equipment.

The data files used include the point feature *air.shp* acquired from NCSU Library GIS Data Lookup which identifies the approximate locations of all airports across North Carolina in 2003. Land use data was supplied by the raster *nlcd_nc_utm17.tif* (2006) acquired from the USDA/NRCS Geospatial Data Gateway. The queries were conducted using ArcMap version 10 (Environmental Systems Research Institute, Redlands, California, US).

To approximate the total amount of grassland available on the identified airports (Table 1), the tax parcel polygons of the airports were used as a mask to extract data from the land use raster. Cells representing grassland (NLCD code 71) or pasture (NLCD code 81) were selected. Each cell on the raster has an area of about 0.2223 acres and therefore the selected number of cells was multiplied by a factor of 0.2223 in order to convert the cell number into the area in acres. The same procedure was used to estimate the amount cropland (NLCD code 82) in acres.

Cost Analysis

Using the total acreage available which includes the sum of the acres of grassland, pasture and cropland, the average acreage available for crop production per airport is 84.7 acres. Equipment costs were modeled for four different scenarios: small-scale with no tillage; small-scale with tillage, large-scale with no tillage; and large-scale with tillage. For the estimates of machinery costs it is assumed that the equipment will be shared with a farmer with 800 acres of cropland for the small scale model and 1,600 acres for the large scale model. The annual use of the equipment is the sum of the average airport acreage and the assumed farm acreage. For the small scale models the annual acreage is 884.7, and 1,684.7 acres for the large scale models. The equipment was also assumed to be new with zero accumulated hours to date. The economic life of the power units was set to 15 years and 5 years for the implements. Interest rate was held at 5% and inflation rate at 2.5%. The assumed machinery labor rate was $10 per hour. Current list prices and PTO horsepower were obtained from Lazarus, 2012. Diesel price was estimated to be $3.60 as done by Lazarus, 2012. Draft parameters, field efficiency and repair parameters, rotary power requirements, and salvage parameters are from ASAE Agricultural Machinery Management Data. The total system costs per hour and total costs per acre were obtained using the BAE Machine Rate spreadsheet created by Dr. Matthew Veal.

Results and Discussion

Airport List

This investigation yielded 57 airports across North Carolina that could possibly host an agricultural production program. The table below lists the airports according to the county in which they are located.

Table 11. Prospective airports by county

County	Airport Name	Grassland and Pasture Acreage	Cropland in 2006 (Acres)
Alamance	Burlington-Alamance Regional	113.4	0
Anson	Anson County	58.9	0
Ashe	Ashe County	63.6	0
Avery	Avery County (Morrison Field)	13.6	0
Beaufort	Warren Field	12.4	32.9
Bladen	Elizabethtown (Curtis L. Brown Jr. Field Airport)	0.4	66.7
Brunswick	Brunswick County (Cape Fear Regional Jetport)	9.3	1.6
Cabarrus	Concord Regional	217.0	0
Caldwell	Foothills Regional Airport	64.0	0
Carteret	Michael J. Smith Field	0.7	24.4

Table 11. Continued

Chatham	Siler City Municipal	72.2	0
Cherokee	Western Carolina Regional Airport	76.7	43.3
Chowan	Northeastern Regional	0.4	12.7
Cleveland	Shelby Municipal	101.4	0
Columbus	Columbus County Municipal	38.9	20.5
Currituck	Currituck County	98.3	112.3
Dare	Billy Mitchell*	107.6	0
	First Flight*	1.8	0
	Dare County Regional	7.1	0.7
Davidson	Davidson County	39.1	0
Duplin	Duplin County	5.8	38.9
Edgecombe	Tarboro-Edgecombe	28.7	10.2
Franklin	Franklin County	76.7	0
Gaston	Gastonia Municipal	12.0	0
Granville	Henderson-Oxford	65.6	0.4
Halifax	Halifax County	65.6	32.9
Harnett	Harnett County	53.4	28.0
Hyde	Hyde County	0	282.1
	Ocracoke Island	64.0	36.5
Iredell	Statesville Municipal	45.1	0
Jackson	Jackson County	31.6	0
Johnston	Johnston County	212.1	124.5
Lee	Sanford-Lee County Regional	48.9	0
Lincoln	Lincoln County	73.4	0
Macon	Macon County	72.5	0.7
Martin	Martin County	12.7	29.8
Montgomery	Montgomery County	8.9	0
Orange	Horace-Williams	67.8	0
Pender	Henderson Field	7.6	64.0
Person	Person County	104.5	0
Randolph	Asheboro Municipal	117.4	0
Richmond	Richmond County	85.8	34.2
Robeson	Lumberton Municipal	6.0	44.9
Rockingham	Rockingham County	42.2	0
Rowan	Rowan County	108.0	0
Rutherford	Rutherford County	90.0	0
Sampson	Sampson County	0.9	39.3
Scotland	Laurinburg-Maxton	57.4	217.4
Stanly	Stanly County	62.9	0
Surry	Elkin Municipal	46.0	0
	Mount Airy/ Surry County	61.8	0
Union	Monroe	61.8	0
Washington	Plymouth Municipal	6.9	152.9
Wayne	Goldsboro Wayne Municipal (Wayne Executive Jetport Airport)	4.2	11.3

Table 11. continued

Wayne	Mount Olive Municipal	0	86.2
Wilkes	Wilkes County	210.7	0
Wilson	Wilson Industrial Air Center	142.9	20.9
	Sum	3258.6	1570.2
		Total	4828.8

*Owned by National Park Service

The total amount of acres available for planting is approximately 4,829 acres across the 57 airports found to meet the selection criteria. The average acreage is 84.7 acres per airport. Johnston County Airport has the highest available acreage of 336.6 acres. The following table lists the airports with more than 200 acres available for crop production.

Table 12. Airports with over 200 acres available

County	Airport Name	Available Acres
Johnston	Johnston County	336.6
Hyde	Hyde County	282.1
Scotland	Laurinburg-Maxton	274.8
Cabarrus	Concord Regional	217
Wilkes	Wilkes County	210.7
Currituck	Currituck County	210.6

Cost Analysis

The following tables show the equipment lists, list prices, PTO horsepower, implements, total system cost per hour, and total cost per acre for each of the four scenarios.

Table 13. Small-scale, no till cost model

Power Unit	Current List Price	PTO hp	Implement Type	Current List Price	Total System Cost Per Hour	Total Cost Per Acre
2 wheel drive tractor, between 80 and 150 hp	$114,000.00	130	No till drill (15ft)	$44,000.00	$136.36	$21.43
Boom Sprayer (80ft)	$220,000.00	160	-	-	$624.25	$18.39
Combine, self propelled	$267,000.00	240	Combine, small grains (20 ft)	$21,000.00	$206.22	$43.62
				Total	$966.83	$83.44

Table 14. Small-scale, till cost model

Power Unit	Current List Price	PTO hp	Implement Type	Current List Price	Total System Cost Per Hour	Total Cost Per Acre
2 wheel drive tractor, more than 150 hp	$140,000.00	140	Tandem disk harrow - primary (21 ft)	$35,000.00	$232.18	$19.00
			Field cultivator - primary (18 ft)	$21,000.00	$214.59	$16.53
			Straight point chisel plow (15 ft)	$19,000.00	$144.24	$18.67
			Grain drill (16 ft)	$19,000.00	$128.71	$18.96
Boom Sprayer (80ft)	$220,000.00	160	-	-	$624.25	$18.39
Combine, self propelled	$267,000.00	240	Combine, small grains (30 ft)	$25,000.00	$250.13	$35.28
				Total	$1,594.10	$126.83

Table 15. Large-scale, no till cost model

Power Unit	Current List Price	PTO hp	Implement Type	Current List Price	Total System Cost Per Hour	Total Cost Per Acre
2 wheel drive tractor, between 80 and 150 hp	$114,000.00	130	No till drill (15ft)	$44,000.00	$104.96	$16.49

Table 15. continued

Boom Sprayer (80ft)	$220,000.00	160	-	-	$393.77	$11.60
Combine, self propelled	$267,000.00	240	Combine, small grains (30 ft)	$25,000.00	$198.38	$27.98
				Total	$697.11	$56.07

Table 16. Large-scale, till cost model

Power Unit	Current List Price	PTO hp	Implement Type	Current List Price	Total System Cost Per Hour	Total Cost Per Acre
2 wheel drive tractor, more than 150 hp	$140,000.00	140	Tandem disk harrow - primary (21 ft)	$35,000.00	$144.30	$11.81
			Field cultivator - primary (18 ft)	$21,000.00	$134.60	$10.37
			Straight point chisel plow (15 ft)	$19,000.00	$99.04	$12.82
			Grain drill (25 ft)	$33,000.00	$129.50	$12.21
Boom Sprayer (80ft)	$220,000.00	160	-	-	$393.77	$11.60
Combine, self propelled	$267,000.00	240	Combine, small grains (30 ft)	$25,000.00	$198.38	$27.98
				Total	$1,099.59	$86.79

For both small and large-scale operations, not tilling the field before planting saves a considerable amount of money, $43.39 per acre for small scale and $30.72 per acre for large scale. Of course, tilled operations cost more because they require more equipment.

An alternate model for the small-scale, tilled operation uses a 20 ft combine head instead of a 30 ft and has a lower total system cost per hour than the one above, but a higher cost per acre.

Table 17. Alternate model for small-scale, till

Power Unit	Current List Price	PTO hp	Implement Type	Current List Price	Total System Cost Per Hour	Total Cost Per Acre
2 wheel drive tractor, more than 150 hp	$140,000.00	140	Tandem disk harrow - primary (21 ft)	$35,000.00	$232.18	$19.00
			Field cultivator - primary (18 ft)	$21,000.00	$214.59	$16.53
			Straight point chisel plow (15 ft)	$19,000.00	$144.24	$18.67
			Grain drill (16 ft)	$19,000.00	$128.71	$18.96
Boom Sprayer (80ft)	$220,000.00	160	-	-	$624.25	$18.39
Combine, self propelled	$267,000.00	240	Combine, small grains (20 ft)	$21,000.00	$206.22	$43.62
				Total	$1,550.19	$135.17

The following graph shows the total system cost per hour and total cost per acre of each of the five models.

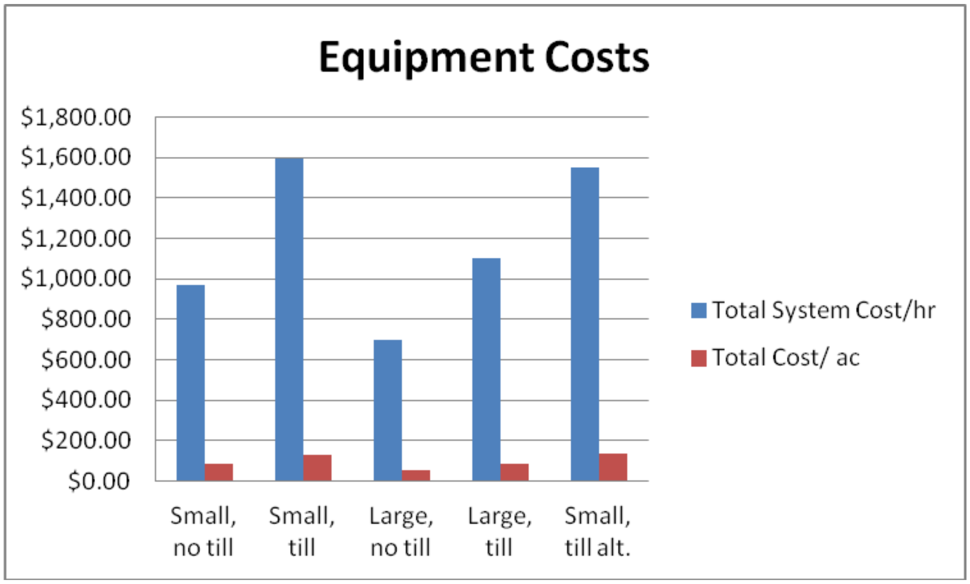

Figure 15. Equipment costs for five models

The large-scale, no till operation is the most economical scenario of the five with the lowest total system cost per hour and total cost per acre. The small-scale, tilled operations are the most costly.

An important question to ask is how many farms in North Carolina are on the scale of 800 or 1,600 acres. According to the 2011 State Agriculture Overview by the USDA (USDA-NASS, 2011) the average farm size in North Carolina was 169 acres. The following tables shows the top ten airports in terms of available acres along with the average farm size of the counties in which they are located as well as their top commodities. Average farm size and top commodities were obtained from the North Carolina Farm Bureau website.

Table 18. Airports, counties with average farm size and top commodities

County	Airport Name	Acres	Average Farm Size in County (acres)	Top Commodities
Johnston	Johnston County	336.6	156	Swine, broilers, flue-cured tobacco
Hyde	Hyde County	282.1	470	Corn, vegetables, soybeans
Scotland	Laurinburg-Maxton	274.8	346	Broilers, Swine, soybeans
Cabarrus	Concord Regional	217	109	Broilers, greenhouse/nursery, beef cattle
Wilkes	Wilkes County	210.7	100	Broilers, eggs, beef cattle
Currituck	Currituck County	210.6	345	Corn, soybeans, livestock
Wilson	Wilson Industrial Air Center	163.8	344	Flue-cured tobacco, greenhouse/nursery, sweet potatoes
Washington	Plymouth Municipal	159.8	518	Swine, soybean, corn
Cherokee	Western Carolina Regional Airport	120	71	Eggs, livestock, greenhouse/nursery
Richmond	Richmond County	120	147	Broilers, swine, fruits

The ten counties listed in the table above have an average farm size of 260.6 acres. Counties whose top commodities include row crops like corn and soybeans are the ones with the most potential to fit airport/farm cooperation proposed in this paper. These counties include: Hyde, Scotland, Currituck and Washington. Of these, Hyde County is the most promising because of its high average farm size of 470 acres.

The models below uses the average farm size of the ten counties listed above (260.6 acres) with either no tillage or tillage. The total number of acres entered into the model was the sum of the 260.6 acres plus the 84.7 acre airport average, or 345.3 acres.

Table 19. Average farm size of 10 counties (345.3 acres), no till model

Power Unit	Current List Price	PTO hp	Implement Type	Current List Price	Total System Cost Per Hour	Total Cost Per Acre
2 wheel drive tractor, between 80 and 150 hp	$114,000.00	130	No till drill (15ft)	$44,000.00	$268.17	$42.14
Boom Sprayer (80ft)	$220,000.00	160	-	-	$1,410.34	$41.55
Combine, self propelled	$267,000.00	240	Combine, small grains (20 ft)	$21,000.00	$346.87	$73.38
				Total	$2,025.38	$157.07

Table 20. Average farm size of 10 counties (345.3), till model

Power Unit	Current List Price	PTO hp	Implement Type	Current List Price	Total System Cost Per Hour	Total Cost Per Acre
2 wheel drive tractor, more than 150 hp	$140,000.00	140	Tandem disk harrow - primary (21 ft)	$35,000.00	$527.74	$43.19
			Field cultivator - primary (18 ft)	$21,000.00	$482.22	$37.15
			Straight point chisel plow (15 ft)	$19,000.00	$299.64	$38.78
			Grain drill (16 ft)	$19,000.00	$258.99	$38.15
Boom Sprayer (80ft)	$220,000.00	160	-	-	$1,410.34	$41.55
Combine, self propelled	$267,000.00	240	Combine, small grains (30 ft)	$25,000.00	$487.60	$68.76
				Total	$3,466.53	$267.58

Compared to the previous cost models a smaller farm as in the two models above increases the equipment costs.

Enterprise Budget

An enterprise budget for the model presented in Table 19 was created and is shown below. The price of nitrogen is the 2012 national average from the National Agricultural Statistics Service (USDA-NASS, 2013). The price of camelina was estimated with the national average price of canola from 2012 (USDA-NASS, 2013) as done by Gesch and Archer, 2013. The price for Poast® was obtained from Painter and Miller, 2009 and the cost of camelina seed from Enjalbert and Johnson, 2011.

Table 21. Enterprise budget for no till, 345.3 acre model

		Unit	Quantity	Price or Cost/ Unit	Total Per Acre
1. Gross Receipts:					
	Camelina seed	lb	1500	$0.27	$405.00
2. Variable Costs:					
	Seed	lb	7	$2.00	$14.00
	Nitrogen	lb	20	$0.25	$5.00
	Herbicide (Poast®)	pt	1.5	$9.38	$14.07
	Aerial Application	appl.	1	$6.00	$6.00
3. Equipment Costs (Variable & Fixed):					
	2 wheel drive tractor, between 80 and 150 hp	No till drill (15ft)			$42.14
	Boom Sprayer (80ft)				$41.55
	Combine, self propelled	Combine, small grains (20 ft)			$73.38
4. Total Costs:					$196.14
5. Net Returns:					**$208.86**

For this particular situation, a yield of 1500 lbs at a price of $0.27/lb, the total net returns is $208.86/acre. Hauling cost was excluded because it was assumed that the camelina will be kept and processed on-site.

The following table shows the net returns for different prices and yields while keep the other factors constant.

Table 22. Returns for various price and yield combinations

	Yield (lbs/ac)			
Price/lb	500	1000	1500	2000
$0.15	-$121.14	-$46.14	$28.86	$103.86
$0.20	-$96.14	$3.86	$103.86	$203.86
$0.25	-$71.14	$53.86	$178.86	$303.86
$0.30	-$46.14	$103.86	$253.86	$403.86

Figure 16 graphically depicts the data presented in

Table 22 and shows that yield has a greater effect on return than price does.

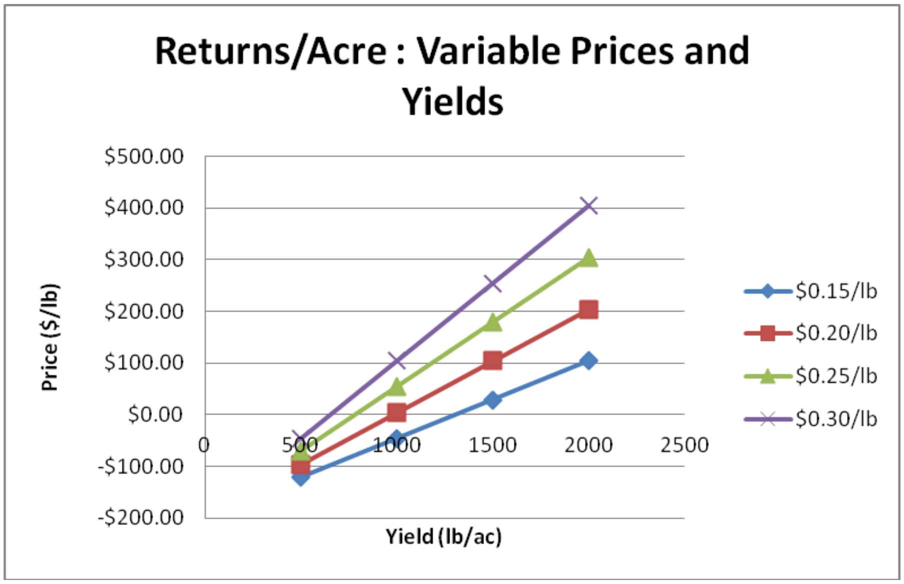

Figure 16. Returns per acre as affected by yield and price

The points at which each line crosses the x-axis are the breakeven yields for each price and they are shown below.

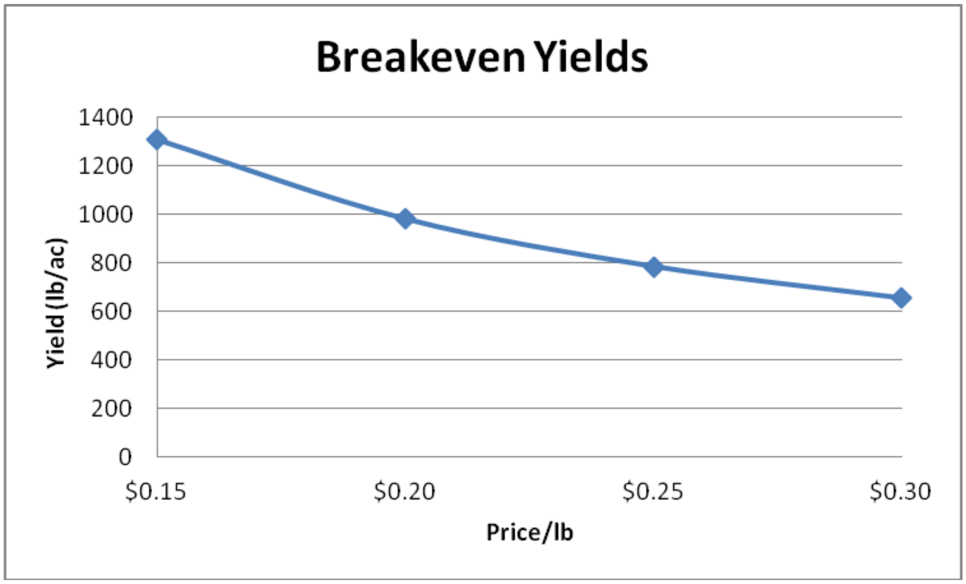

Figure 17. Breakeven yields

Naturally, as price increases breakeven yield decreases. More information on average camelina yields in North Carolina would be helpful in determining how low the price can drop until growing camelina is no longer profitable.

Conclusions

Airport List

North Carolina has the potential to grow more bioenergy crops without converting more land into new cropland by planting on its unused airport fields. With up to 4,828.8 acres available of open land on the fifty seven airports identified, a significant portion of that area could produce crops within safe distances outside the obstacle free zones and object free areas. A more accurate estimate of the acreage would require information from each airport concerning their safety margins and plans for development.

Cost Analysis

Scale and tillage requirements will affect the costs of the operation. Of the models presented, the large-scale operation with no tillage produced the lowest equipment costs. In general, no-till operations are more economical than tilled operations because they require less equipment. Since camelina can grow well in untilled conditions, no-till is a viable option for lowering production costs while still producing a good yield.

The average farm size of the ten counties in which the top ten potential airports are located is 260.6 acres. This smaller farm size model produced higher equipment costs than those modeled with 800 and 1,600 acres. Depending on the possible returns from camelina which as of yet has a small market, buying new equipment for an airport operation and a regular farm may not be cost efficient. A possible alternative is for the airports to rent equipment from farmers. To do this, only airports located in counties that produce wheat could be considered since camelina is harvestable with the same equipment as wheat. A no-till drill may still have to be purchased but it is a small expense compared to purchasing all new equipment. Of the top ten counties mentioned, Hyde County looks to be the most promising because it has a large average farm size and its main commodities are crops as opposed to animals.

Even for smaller scale operations, profits are possible as long as yield and price are high enough. Equipment costs as well as enterprise budgets should be carefully calculated before any operation begins. Since camelina as of yet does not have a stable market, growing it for sale may be financially riskier than growing it and using it directly for biodiesel and thereby lowering fuel costs depending on the price of diesel and the amount needed.

References

ASAE. 2003. Agricultural Machinery Management Data. ASAE. Available at: http://www3.abe.iastate.edu/ae340/2006/ASAE_D497.4.pdf. Accessed 20 March 2013.

Campbell, J. E., D. B. Lobell, R. C. Genova and C. B. Field. 2008. The global potential of bioenergy on abandoned agriculture lands. *Environmental science & technology* 42(15): 5791-5794.

DeVault, T. L., J. L. Belant, B. F. Blackwell, J. A. Martin, J. A. Schmidt, L. W. Burger Jr., and J. W. Patterson Jr. 2012. Airports Offer Unrealized Potential for Alternative Energy Production. E*nvironmental Management* 49: 517-522.

Edwards, W. 2009. Estimating Farm Machinery Costs. Iowa State University Extension. Available at: http://www.extension.iastate.edu/Publications/PM710.pdf. Accessed 11 February 2013.

Gesch, R. W. and D. W. Archer. 2013. Double-cropping with winter camelina in the northern Corn Belt to produce fuel and food. *Industrial Crops and Products* 44: 718-725.

Lane, J. 2012. Aviation biofuels: which airlines are doing what, with whom? Biofuels Digest. Available at: http://www.biofuelsdigest.com/bdigest/2012/06/05/aviation-biofuels-which-airlines-are-doing-what-with-whom/. Accessed 17 December 2012.

Lazarus, W. F. 2012. Machinery Cost Estimates. University of Minnesota Extension. Available at: http://faculty.apec.umn.edu/wlazarus/documents/machdata.pdf. Accessed 11 February 2013.
North Carolina Farm Bureau Federation. 2013. Counties. Available at: http://www.ncfb.org/counties/countyProfile.cfm?countyID=44. Accessed 3 April 2013.

Painter, K. and E. Miller. 2009. 2009 Crop Rotation Budgets, Over 18” Precipitation Zone Under Reduced Tillage, Eastern Washington. Washington State University. Available at: http://www.farm-mgmt.wsu.edu/PDF-docs/budgets/2009_E-WA-Dryland-budgets/2009HighRainfallZoneReducedTillageBudgets_Apr09.pdf. Accessed 4 April 2013.

Shonnard, D. R., L. Williams, and T. N. Kaines. 2010. Camelina-Derived Jet Fuel and Diesel: Sustainable Advanced Biofuels. *Environmental Progress & Sustainable Energy 29* (3): 382-392.

USDA-NASS. 2011 State Agriculture Overview: North Carolina. USDA and National Agricultural Statistics Service. Available at: http://www.nass.usda.gov/Statistics_by_State/Ag_Overview/AgOverview_NC.pdf. Accessed 3 April 2013.

USDA-NASS. 2013. Quick Stats 2.0. USDA and National Agricultural Statistics Service. Available at: http://quickstats.nass.usda.gov/. Accessed 9 April 2013.

SUMMARY OF CHAPTERS

CHAPTER 1: Agronomic Practices for Growing Camelina in North Carolina

The goal of this portion of the study was to find the variety/fertilization rate/seeding rate combination that would produce the highest yield. The varieties tested were: Ligena, Blaine Creek, Suneson, and Calena. Fertilization rates were 0 lb N/ac, 20 lb N/ac, and 120 lb N/ac. Seeding rate corresponded to the percent open on the grain drill and the percentages tested here were 8, 13, 18 and 23% which corresponding to seeding rates of 2.96 lb/ac, 4.8 lb/ac, 6.65 lb/ac and 8.5 lb/ac respectively.

Survivability rate is the number of plants that survive divided by the number of seeds planted expressed as a percent. This study found that survivability rate did not significantly differ by seeding rate ($F= 0.49$, $p= 0.6915$) however data were available only for the Ligena variety because of time constraints imposed by inclement weather. The overall survivability rate across all seeding rates was 84.35%.

An ANOVA analysis found that seeding rate ($F=14.69$, $p= 0.0008$), fertilization rate ($F= 35.44$, $p= 0.0004$), and the interaction between variety and seeding ($F= 5.87$, $p= 0.0007$) were significant. Comparing all the different treatment combinations of variety and seeding rate reveals that most are statistically similar and the three highest yielding combinations were Suneson 23%, Blaine Creek 18% and Blaine Creek 23%. Each of the three fertilization rate treatments produced significantly different mean yields with 120 lb N/ac having the highest mean, then 60 lb N/ac, then 0 lb N/ac. Based on the results of this experiment, the choosing Suneson or Blaine Creek with seeding rates of 23% and 18% or 23% respectively along with a fertilization rate of 120 lb N/ac will have better yields than the other possible combinations of the three factors.

Patches of weeds in the field affected some varieties more than others, particularly Suneson and Celine, and therefore possibly affected the accuracy of this analysis. Another repetition of the experiment is advised in order to confirm or refute these results.

CHAPTER 2: Usefulness of AOCS Official Method Ca 12-55 on Measuring Phosphorus Content of Camelina Oil

AOCS Official Method CA 12-55 is designed to measure phosphorus contents of vegetable oils and was utilized in this study to measure the phosphorus content of camelina oil. In order to verify that the method worked it was used to measure the phosphorus contents of camelina (Calena variety), sunflower, sesame, rapeseed and safflower oils and the observed results compared to published results. Camelina oil was found to have a phosphrous content of 3.26 ppm, sunflower 37.92 ppm, sesame 60.09 ppm, rapeseed 15.6 ppm and safflower 4.87 ppm. Except for camelina's content which fell in the published range, all the oils yielded lower phosphorus contents than found in literature. A possible explanation for the low values was that the samples were not boiling long enough however a subsequent experiment found no difference between samples left on the hot plate for 10 minutes and those left for 15 minutes ($t= -1.51$, $p= 0.2063$). Losses inherent to the method possibly lower the final readings in comparison to other methods used in literature.

Zufarov et al. (2008) published a phosphorus content range for camelina of 0.6 to 35 ppm which led to the question of whether or not phosphorus content changes with variety.

Varieties tested here included Calena, Blaine Creek, Celine and Suneson. In order, Suneson had the highest P-content of 55.04 ppm, then Celine with 50.63 ppm, Blaine Creek with 34.30 ppm and last Calena with 3.26 ppm. An ANOVA test with Tukey adjustment for multiple comparisons found that not all of the contents were the same ($F= 1778.64$, $p<0.0001$). Analyzing all pairwise comparisons found that all the varieties were different from one another.

Water degumming did not remove enough phosphorus from the camelina oils to get below a content of 10 ppm. Calena oil however had initially a phosphorus content below 10 ppm and did not require any further degumming although water degumming did reduce the content by 131% which indicated that the method does not accurately measure trace amounts. In essence, water degumming removed all or almost all of the phosphatides in the oil. Water degumming did perform as well with the other varieties, removing 44% of the phosphorus for Suneson, 29% for Blaine Creek and 24% for Celine. Acid degumming was more effective on these varieties, removing 68% for Suneson, 71% for Blaine Creek and 69% for Celine but was rather ineffective on Calena, removing only 1%. This result indicates that most of the phosphatides in Calena oil are hydratable. Even though acid degumming was more effective, it was only able to bring Blaine Creek's phosphorus content just below 10 ppm. A two-step water then acid degumming process or some other degumming process would be needed for most camelina varieties to attain a phosphorus content below 10 ppm.

CHAPTER 3: North Carolina Airports with Potential for Camelina Production and Modeling Their Costs

Of North Carolina's 110 airports, 57 are public, non-major, and within five miles of agricultural land; meeting the criteria to be a possible candidate for a camelina production operation. Together these airports offer about 4,829 acres of available land including grassland, pasture and cropland.

On average each airport has 84.7 acres available and this number was used to make for different equipment cost models: small-scale, no till; small-scale, till; large-scale, no till; and large-scale, till. Small-scale farms were assumed to be 800 acres and large-scale 1,600 acres. These acreages plus the 84.7 acre average were used to calculate equipment costs. Of the four models the large-scale, no till model was the most cost effective a total system cost per hour of $697.11 and a total cost per acre of $56.07. However, because the average farm size in North Carolina is only 169 acres, finding a farm with 1,600 acres is unlikely. To make a better model the average of the airports with the ten highest available acreages, 260 acres, was used instead of the 800 and 1,600 acres. For the no till model the total system cost per hour was $2,025.38 and the total cost per acre $157.07. The conventional tillage model had a total system cost of $3,466.53 and a total cost per acre of $267.58.

Although these costs are higher than the previous four models, net returns are possible depending on price and more so yield. An enterprise budget for the no till model using the top ten airport average acreage with inputs of a 1,500 lb/ac yield, a camelina price equivalent to canola ($0.27), a seeding rate of 7 lb/ac and a fertilization rate of 20 lb/ac produces a net return of $208.86/ac.

In North Carolina solid agronomic practices for growing camelina that would be able to attain yields higher than 1,500 lb/ac and a bigger market for camelina are needed to make camelina production steadily profitable.

COMPLETE REFERENCE LIST

Aftabuzzaman, M. and E. Mazloumi. 2011. Achieving sustainable urban transport mobility in post peak oil era. *Transport Policy* 18(5): 605-702.

Agarwal, A., T. Pant and Z. Ahmed. 2010. Camelina sativa: a new crop with biofuel potential introduced in India. *Current science 99*(9): 1194-1195.

An, H., W. E. Wilhelm and S. W. Searcy. 2011. Biofuel and petroleum-based fuel supply chain research: A literature review. *Biomass & Bioenergy* 35(9): 3763-3774.

ASAE. 2003. Agricultural Machinery Management Data. ASAE. Available at: http://www3.abe.iastate.edu/ae340/2006/ASAE_D497.4.pdf. Accessed 20 March 2013.

Bernardo, A., R. Howard-Hildige, A. O'Connell, R. Nichol, J. Ryan, B. Rice, E. Roche and J. Leahy. 2003. Camelina oil as a fuel for diesel transport engines. *Industrial Crops and Products* 17(3): 191-197.

Blackshaw, R. E., E. N. Johnson, Y. Gan, W. E. May, D. W. McAndrews, V. Barthet, T. McDonald and D. Wispinski. 2011. Alternative oilseed crops for biodiesel feedstock on the Canadian prairies. *Canadian Journal of Plant Science 91*(5): 889-896.

Campbell, J. E., D. B. Lobell, R. C. Genova and C. B. Field. 2008. The global potential of bioenergy on abandoned agriculture lands. *Environmental science & technology* 42(15): 5791-5794.

Canola Watch. 2013. How to increase seed survival rates. Canola Council of Canada. Available at: http://www.canolawatch.org/2013/03/06/how-to-increase-seed-survival-rates/. Accessed 24 April 2013.

Carlsson, A. S. 2009. Plant oils as feedstock alternatives to petroleum - A short survey of potential oil crop platforms. *Biochimie 91*(6): 665-670.

Debolt, S., J. E. Campbell, R. Smith Jr., M. Montross and J. Stork. 2009. Life cycle assessment of native plants and marginal lands for bioenergy agriculture in Kentucky as a model for south-eastern USA. *Global Change Biology Bioenergy* 1(4): 308-316.

Deosthale, Y. G. 1981. Trace Element Composition of Common Oilseeds. *JAOCS 58*(11): 988-990.

DeVault, T. L., Belant, J. L., Blackwell, B. F., Martin, J.A., Schmidt, J. A., Burger Jr, L. W., and Patterson Jr, J. W. 2012. Airports Offer Unrealized Potential for Alternative Energy Production. E*nvironmental Management* 49: 517-522.

Dijkstra, A. J. and D. Meert. 1982. Determination of Trace Elements in Oils by Plasma Emission Spectroscopy. *JAOCS 59*(4): 199-204.

Dijkstra, A. J. and M. V. Opstal. 1989. The total degumming process. *JAOCS. 66*(7)*:* 1002-1009.

Edwards, W. 2009. Estimating Farm Machinery Costs. Iowa State University Extension. Available at: http://www.extension.iastate.edu/Publications/PM710.pdf. Accessed 11 February 2013.

Ehrensing, D. T. & S. O. Guy. 2008. Camelina. Oil Seed Crops. Oregon State University Extension Service. Available at: http://extension.oregonstate.edu/catalog/pdf/em/em8953-e.pdf. Accessed 18 March 2013.

Enjalbert, J. N. and J. J. Johnson. 2011. Guide for Producing Dryland Camelina in Eastern Colorado. Colorado State University Extension. Available at: http://www.ext.colostate.edu/pubs/crops/00709.html. Accessed 18 February 2013.

Hasheminejad, M., M. Tabatabaei, Y. Mansourpanah, M. K. Far and A. Javani. 2011. Upstream and downstream strategies to economize biodiesel production. *Bioresource technology 102*(2): 461-468.

Hill, J., E. Nelson, D. Tilman, S. Polasky and D. Tiffany. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels RID A-8919-2008. *Proceedings of the National Academy of Sciences of the United States of America* 103(30): 11206-11210.

Lane, J. 2012. Aviation biofuels: which airlines are doing what, with whom? Biofuels Digest. Available at: http://www.biofuelsdigest.com/bdigest/2012/06/05/aviation-biofuels-which-airlines-are-doing-what-with-whom/. Accessed 17 December 2012.

Lazarus, W. F. 2012. Machinery Cost Estimates. University of Minnesota Extension. Available at: http://faculty.apec.umn.edu/wlazarus/documents/machdata.pdf. Accessed 11 February 2013.

Lee, Y. C., S. W. Oh, J. Chang and I. H. Kim. 2004. Chemical composition and oxidative stability of safflower oil prepared from safflower seed roasted with different temperatures. *Food Chemistry 84*(1): 1-6.

Leung, D. Y. C., X. Wu and M. K. H. Leung. 2010. A review on biodiesel production using catalyzed transesterification. *Applied Energy 87*(4): 1083-1095.

Lu, C., J. A. Napier, T. E. Clemente and E. B. Cahoon. 2011. New frontiers in oilseed biotechnology: meeting the global demand for vegetable oils for food, feed, biofuel, and industrial applications. *Current opinion in biotechnology 22*(2): 252-259.
Lyle, A. 2011. Thunderbirds to perform first demo with alternative fuel. U.S. Air Force. Available at: http://www.af.mil/news/story.asp?id=123256454. Accessed 1 December 2011.

Ma, F. and Hanna M. A. 1999. Biodiesel production: a review. *Bioresource Technology 70*(1): 1- 15.

Moser, B. R. and S. F. Vaughn. 2010. Evaluation of alkyl esters from Camelina sativa oil as biodiesel and as blend components in ultra low-sulfur diesel fuel. *Bioresource technology 101*(2): 646-653.

Muppaneni, T., H. K. Reddy, P. D. Patil, P. Dailey, C. Aday and S. Deng. 2012. Ethanolysis of camelina oil under supercritical condition with hexane as a co-solvent. *Applied Energy 94*: 84-88.

National Renewable Energy Laboratory. 2009. Biodiesel Handling and Use Guide Fourth Edition. Available at: www.osti.gov/bridge. Accessed 8 January 2013.

Paulsen, H. M., V. Wichmann, U. Schuemann and B. Richter. 2011. Use of straight vegetable oil mixtures of rape and camelina as on farm fuels in agriculture. *Biomass & Bioenergy 35*(9): 4015-4024.

Pilgeram, A. L., D. C. sands, D. Boss, N. Dale, D. Wichman, P. Lamb, C. Lu, R. Barrows, M. Kirkpatrick, B. Thompson and D. L. Johnson. 2007. Camelina Sativa, A Montana Omega-3 and Fuel Crop. Issues in new crops and new uses. Available at: www.extsoilcrop.colostate.edu/CropVar/documents/oilseeds.camelina/montana_omega3_fuelcrop.pdf. Accessed 4 March 2013.

Putnam, D.H., J.T. Budin, L.A. Field, and W.M. Breene. 1993. Camelina: A promising low-input oilseed. p. 314-322. In: J. Janick and J.E. Simon (eds.), New crops. Wiley, New York.

Reijnders, L. 2009. Acute View Transport biofuels: Can they help limiting climate change without an upward impact on food prices? *Journal of Consumer Protection and Food Safety* 4(1): 75-78.

Schillinger, W. F., D. J. Wysocki, T. G. Chastain, S. O. Guy, and R. S. Karow. 2012. Camelina: Planting date and method effects on stand establishment and seed. *Field Crops Research* 130(2012): 138-144.

Shonnard, D. R., L. Williams and T. N. Kalnes. 2010. Camelina-Derived Jet Fuel and Diesel: Sustainable Advanced Biofuels. *Environmental Progress & Sustainable Energy 29*(3): 382-392.

Tosi, E. A., A. F. Cazzoli and L. M. Tapiz. 1998. Phosphorus in Oil. Production of Molybdenum Blue Derivative at Ambient Temperature Using Noncarcinogenic Reagents. *JAOCS 75*(1): 41-44.
Tyler, D. 2009. Japan Airlines 747 Makes First Ever Flight on Camelina Biofuel. Gas2. Available at: http://gas2.org/2009/01/31/japan-airlines-747-makes-first-ever-flight-on-camelina-biofuel/. Accessed 12 November 2011.

Wald, C. F., R. E. Keys, J. B. Nathan, C. B. Boyd, T. J. Lopez, T. R. Oliver Jr., L. P., Farrell Jr., R. Magnus, G. R. Sullivan, P. J. Kern, D. V. McGinn and R. H. Truly. 2009. Powering America's Defense: Energy and the Risks to National Security. Available at: http://www.cna.org/sites/default/files/Powering%20Americas%20Defense.pdf. Accessed 12 November 2011.

Zubr, J. 1997. Oil seed crop: Camelina Sativa. *Industrial Crops and Products* 6(2) 113-119.

Zufarov, O., S. Schmidt and S. Sekretár. 2008. Degumming of rapeseed and sunflower oils. *Acta Chimica Slovaca 1*(1):321-328.