THESIS

MODELING THE PROFITABILITY OF *CAMELINA SATIVA* AS A BIOFUEL FEEDSTOCK IN EASTERN COLORADO

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ABSTRACT

MODELING THE PROFITABILITY OF *CAMELINA SATIVA* AS A BIOFUEL FEEDSTOCK IN EASTERN COLORADO

This study evaluates the economic feasibility of growing *Camelina Sativa* as a biofuel feedstock on farms in northeastern Colorado. *Camelina Sativa* is an oilseed feedstock that can be used to generate straight vegetable oil that has the potential to displace a large percentage of the diesel fuel used by farmers. Offsetting significant portions of diesel fuel allows for a hedge against disruptions in the supply of diesel fuel, as well as unexpected diesel fuel price hikes. This helps ensure the continuation of the food system.

The specific intention of this study is to evaluate the likelihood of economic profitability for a farmer who chooses to integrate camelina in the preexisting crop rotation cycle common in northeastern Colorado. This economic evaluation is measured against various per gallon diesel fuel price levels. The crop rotation cycle includes a corn planting, a fallow period, and a wheat planting. Camelina is grown exclusively during the fallow portion of the rotation and will not be grown at a time when commodity crops would otherwise be grown.

This study is conducted using simulations to help create a realistic agronomic and economic scenario in northeastern Colorado. The variables in the crop rotation budget are chosen from stochastic draws using simulations and 50,000 iterations. The variables are assigned ranges and distributions based on sound economic principles as well as literature recommendations. The variables are also tied to the various diesel fuel price scenarios. The 50,000 iterations are aggregated and assigned a cumulative density function to determine the likelihood of profitability for each diesel price scenario.

The results of the simulated crop rotation budget suggest that camelina has a 50% likelihood of profitable returns when the price of diesel fuel exceeds $4.30/gallon. The study also determines that revenue generation from the sale of camelina meal is the most important factor in determining the profitability of camelina in northeastern Colorado.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

AIC: Akaike's Information Criterion

CDF: Cumulative Density Function

CSU: Colorado State University

CUSD: Correlated Uniform Standard Deviate

DAP: Diammonium Phosphates Fertilizer

EISA: Energy Independence and Security Act

ERS: Economic Research Service

GBP: Great British Pound

GHG: Greenhouse Gas

LBS: Pounds

MSBG: Mississippi State Budget Generator

NASS: National Agricultural Statistics Service

OLS: Ordinary Least Squares

PDF: Probability Density Function

PDSI: Palmer Drought Severity Index

RFS: Renewable Fuel Standards

RMSE: Root Mean Square Error

SPI: Standardized Precipitation Index

SVO: Straight Vegetable Oil

USD: United States Dollar

USDA: United States Department of Agriculture

WTI: West Texas Intermediate

WRSI: Water Requirement Satisfaction Index

CHAPTER 1. INTRODUCTION.

In 2008, the real price of West Texas Intermediate (WTI) crude oil briefly surpassed $145/barrel while setting a new record high price.[1] This rise in the real price of WTI crude oil ushered in a new round of discussions regarding the uncertainty faced by American farmers when projecting on-farm fuel costs. It also exposed the vulnerability faced by farmers if petroleum-based diesel fuel escalates to prices well beyond what is today considered typical, or even becomes unavailable due to an unexpected supply disruption. Rising and volatile petroleum prices have led to escalating variable production costs for farmers throughout the western United States and Canada (Capareda et al., 2010). Regarding fuel costs, a farmer located in the plains of eastern Colorado remarked, “We have to have some control over our fuel costs. You can’t have farmers carpool a swather”.[2] The need for on-farm fuel to power machinery is currently unavoidable, one of the reasons why biofuel research is relevant to the American farmer. Farmers have the ability to control on-farm costs related to fuel consumption through the use of biofuels because they can produce their own fuel.

The Economic Research Service (ERS), an agency in the United States Department of Agriculture (USDA), publishes annual reports explaining the share of input costs that are spent on the typical American farm. According to the ERS, the average farmer growing both

[1] U.S. Energy Information Agency, Independent Statistics and Analysis. Accessed 09 December 2011. http://www.eia.gov/petroleum/gasdiesel/.

[2] Personal communication with Mr. Joel Lundquist, Lundquist Farms, In-person interview with author, July 14, 2011.

wheat and corn can expect to spend about 7% of total farm expenses on fuel procurement.[3] When fuel is grown instead of purchased, the risk of production disruptions from unexpectedly high fuel costs has the potential to be greatly decreased, resulting in more stability for the farm bottom line.

Given the vulnerability to a diesel fuel supply shock as well as the rising costs of production faced by farmers, the main objective of this study is to identify a biofuel option that allows for a hedge against a major disruption in the supply of petroleum-based diesel fuel. Similar to many insurance policies, this study identifies the premium farmers will pay to have an alternative farm-grown fuel option. This premium is measured as the opportunity cost of growing and generating a gallon of homemade biofuel on-farm compared with purchasing a gallon of petroleum-based diesel fuel. This study evaluates the inputs needed to create a gallon of straight vegetable oil (SVO), a biofuel that is a direct diesel alternative. In a real world setting, the inputs used in the creation of SVO often fluctuate in price and quantity. The variability in input factors allows for stochastic simulations to determine the premium farmers will pay to hedge against diesel fuel disruptions. As demonstrated in this study, in many cases the farmer can profitably create SVO on-farm and does not pay a risk premium. The mitigation of the rise of variable costs provides the ancillary objective of this study. While the main motivation is to create an economic model to determine the cost of a hedge against diesel fuel disruption, by implementing a biofuel option farmers are also controlling variable costs (and thus can learn how to improve profitability) even if there is no supply disruption of diesel fuel.

The desire to enhance biofuel production has been a national objective since the passing of the second Renewable Fuel Standards (RFS) in the United States, part of the

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[3] US Department of Agriculture, Economic Research Service. 2011. Farm Income and Costs: 2011 Farm Sector Income Forecast. Accessed 08 October 2011. http://www.ers.usda.gov/Briefing/FarmIncome/.

Energy Independence Security Act of 2007 (EISA). The RFS calls for 36 billion gallons of biofuels to be created annually by the year 2020 (U.S. Congress, 2005). One of the main deliverables of the EISA, and the subsequent RFS, is the USDA's "Regional Roadmap" report. This set of reports creates specific and attainable goals of biofuel development based on knowledge of each region of the United States (U.S. Department of Agriculture, 2010). However, the arid western states were not identified as a region where abundant biofuel development can be expected. The low expectations are due in large part to the difficulty of finding a crop that will have sustained success in an arid setting.

To achieve the goals set forth in the RFS, the development of non-corn-based biofuels will be necessary, as increased emissions and food prices have been attributed to land-use changes caused by growing corn for ethanol (Fargione et al., 2008; Searchinger et al., 2008). Literature sources, such as Heaton, Dohleman, and Long (2008) suggest that only one or two non-corn-based feedstocks will be enough to achieve the goals set forth by the RFS, while many other studies have concluded that regionally varied feedstocks are essential to help contribute to the 36 billion gallons of biofuels called for by 2020 (e.g. Bourgeon and Treguer, 2010; Demirbas, 2010; Sommerville et al., 2010). Despite the limited expected contribution of the arid western region to the national RFS, there are oilseed feedstocks that have shown promise towards their eventual contribution to the national biofuel makeup.

Oilseeds have been identified as attractive biofuel feedstocks in the western region of the United States (i.e. Putnam et al., 1993). Some oilseed crops minimize the need for inputs like water and may be readily adopted into preexisting crop rotations, providing producers with additional revenue. The minimal inputs suggest that the opportunity cost of growing specific oilseeds for SVO is considerably lower than other established biofuel feedstocks. Oilseed crops may also replace significant portions of diesel in engine operations, thus helping to ensure that food production will continue should there be a disruption to petroleum supplies (Vollman et al., 2005; Putnam et al., 1993; Eidhan, Burke, O'Beirne, 2003).

This study evaluates the feasibility of using the oilseed crop *Camelina Sativa* as a biofuel feedstock in northeastern Colorado. *Camelina Sativa* was chosen for four specific reasons. First, the crop fits in the established crop rotation systems utilized by many farmers in northeastern Colorado because camelina can be grown as an opportunity crop on land that otherwise would have been vacant while in fallow (Johnson et al., 2009). Camelina allows farmers to grow three crops in three years, as opposed to only growing two crops in three years, a more common rotation currently utilized in northeastern Colorado. Second, camelina is also considered a relatively low input oilseed crop (Robinson, 1987). This lowers the opportunity cost of creating a gallon of SVO from camelina compared with purchasing a gallon of petroleum-based diesel fuel. Third, camelina has been shown to grow well on non-irrigated, or dryland, no-till farms. This farm scenario is common in the plains of northeastern Colorado and is assumed in this study. Fourth, after oil extraction, the remaining camelina seed can be sold as a high protein animal meal, offering a farmer additional revenue when choosing to grow camelina. These four factors make the implantation of camelina more attractive relative to other oilseed feedstocks in northeastern Colorado.

Specifically, the main objective of this research is to determine whether farmers in the plains of northeastern Colorado can profitably integrate camelina into their preexisting wheat-corn-fallow crop rotation and if so, what diesel price level is necessary to meet a 50% likelihood of profitability. The integration of camelina will provide significant energy independence for farmers and help maintain steady fuel costs, as well as provide a hedge against a disruption in the supply of diesel fuel. It must be stressed that camelina is only grown on lands that otherwise would have been in fallow, and the partial crop rotation budgets developed throughout this study are the opportunity cost of growing camelina compared to leaving the farmland resting in the fallow portion of the crop rotation. Any discussion of profitability only evaluates the addition of camelina and ignores the profits or losses a farmer would face if not choosing to integrate camelina. The profitable integration of camelina will result in the ability of farmers to use a biofuel that replaces nearly 90% of the petroleum-based diesel fuel consumed on-farm, eliminating the need to purchase large quantities of diesel fuel. This objective can be achieved by creating a simulation model that factors in changing input costs associated with an on-farm crop rotation budget and evaluating these costs against various diesel price scenarios. This study also accounts for the variability in both the price and quantity of all the variables in an inclusive simulated crop rotation budget. Much effort is dedicated to ensure proper distributions are modeled for each variable in the simulated crop rotation budget, based on sound economic logic, modeling, and examinations of previous trends.

Once the necessary variables are identified, their respective ranges and distributions are calculated. This is modeled using a series of 50,000 simulations using Simetar® simulation software. The repeated simulations are designed to take stochastic draws of the previously defined elements of the crop rotation budget, with careful emphasis placed on specific distributions of each element, and build an overall profitability calculator. Given the high number of stochastic simulations and the varying diesel fuel price levels, the results are then interpreted to find the likelihood of profit if camelina is integrated into on-farm operations.

It should be noted that this research does not intend to identify the actual amount of profit received by farmers due to the integration of camelina, compared with the same farm without camelina. Rather, this research instead focuses on the likelihood of profit. This distinction is important due to the nature of the research and the use of stochastic variables. Since the main motivating factor for the inclusion of camelina on-farm is to offset diesel fuel, the intention is to focus on the likelihood of success, measured in profitable camelina integration of achieving this focus, as opposed to the actual amount of additional profit.

The thesis is organized as follows: Chapter 2 summarizes past research and makes the case as to why *Camelina* Sativa was chosen as a focal point for research in this study. Chapter 3 is the methodology section, which explains all the elements that make up the simulated crop rotation budget used in the simulations. Chapter 4 demonstrates the outcomes from the simulations. Chapter 5, a final conclusion section, reviews the results and offers an interpretation of the outcomes found by the model.

CHAPTER 2. SUMMARY OF PAST RESEARCH AND REASONING FOR STUDYING CAMELINA

2.1. Eastern Colorado Crop Rotation

This study focuses on dryland no-till farmland located in the northeastern corner of the state of Colorado. This specific region of Colorado was chosen because of its unique agronomic conditions that lead to relatively favorable growing conditions for camelina. This area receives sufficient annual moisture to cultivate a dryland crop with modest yields, especially when compared with the more significant yields of irrigated farmlands.[4]

To be considered a potentially viable biofuel feedstock source in Colorado, both economically and agronomically, an oilseed must be able to be incorporated into the wheat-growing rotation of northeastern Colorado farmlands. Johnson et al. (2009) discusses the adaptability of *Camelina Sativa* into a wheat rotation. This study demonstrates the two basic needs for an oilseed to be successfully, and profitably, grown in northeastern Colorado. First, it must not interfere with the growth of, or entirely replace, wheat crops. Second, a viable oilseed must allow for a fallow period between late July and the middle of September to allow the land to recuperate at least some moisture before the next wheat planting. Camelina does adhere to these two necessary criteria. In the suggested crop rotation, corn or a similar crop is planted in April or May of year one, and is then harvested in October, followed by a

[4] Personal communication with Dr. Jerry Johnson, Associate Professor, Department of Soil and Crop Sciences, Colorado State University. In-person interview with the author, November 4, 2010.

planting of camelina. The camelina crop is harvested in July of year two, having already flowered before heat can harm the crop. In year two, the land is vacant during July, August, and the first half of September to collect the frequent rainfall that tends to accumulate in late summer. In September of year two, winter wheat is planted and will be ready to harvest in July of year three. This is followed by a fallow period until April or May of the fourth year, when the rotation restarts (Johnson et al., 2009).

While still experimental, camelina looks promising in the context of a value-added crop for the farmers of northeastern Colorado because it allows the farmer to complete the rotation and return to wheat again. While farmers have previously struggled to find a tertiary crop to add to the crop rotation in northeastern Colorado, camelina shows promise that it can fill the void. The most appealing aspect of the crop is that it allows farmers to grow three crops in three years, as opposed to two in three years under the current wheat-corn-fallow rotation. This allows the land to be ready to plant the next wheat rotation. The literature has expressed only minimal concerns about the amount of moisture that camelina uses, which should not cause detrimental harm to the wheat crop planted shortly after a camelina harvest. The low concern in the literature is attributed to the very short root system of camelina, which does not draw out excessive moisture from the soil (Robinson, 1987). Meteorological factors also play a significant role, as a large portion of the annual rainfall in northeastern Colorado falls after camelina is harvested in July and before wheat is subsequently planted in September. This helps to mitigate losses to the next wheat harvest.

2.2. Origin of Camelina

Camelina is an ancient crop that is believed to have evolved as a weed in fields planted with flaxseed (Frohlich and Rice, 2005). It belongs to the *Brassicaceae* family and has been cultivated in Europe as an oilseed since the 19th century (Frohlich and Rice, 2005). Known as “gold-of-pleasure” or “false flax”, camelina originated in a vast area expanding from the Mediterranean Sea through central Asia (Putnam et al., 1993). It held some significance in the area immediately surrounding Romania (Putnam et al., 1993). After losing any prominence in Europe during the 1940s, camelina breeding research started again in Germany in the 1980s (Vollmann et al., 2005).

2.3. Inherent Traits of Camelina

A member of the mustard family, camelina contains relatively high levels of Omega-3 fatty acids, at rates of 35-40% (Johnson et al., 2008; Stratton, Kleinschmit, and Keeney, 2007). Camelina has relatively small seeds, as about 450,000 seeds convert to a pound (Stratton, Kleinschmit, and Keeney, 2007). Compared to other oilseeds, the crop has a short growing season, which is between 85 and 100 days (Robinson, 1987; Stratton, Kleinschmit, and Keeney, 2007; Putnam et al., 1993). The short growing season could fit well within the proposed crop rotation.

Vollman et al. (2005) noted that both yield and oil content were influenced by effects caused by season and location. Vollman et al. (2005) also found a positive correlation between overall yield and oil content. These factors are taken into account in the creation of the camelina crop rotation budget.

One of the most notable traits of camelina is the cold tolerance of the seedling. Camelina seedlings can survive several freezes in the early spring. For example, in one trial, a May 12th frost of -2°C injured mustard, rape, and flax, but did not affect camelina (Robinson, 1987). This is critical to the viability of the crop in Colorado, which frequently presents high variability in spring temperatures, including freezes. Individual camelina seedlings are fairly small and non-competitive, but this early-emerging, cold-tolerant characteristic, especially when planted at high densities, provides excellent competition with many annual weeds (Robinson, 1987).

2.4. Camelina Meal as a Value-Added Byproduct

To be economically viable, camelina must also be utilized as a value-added byproduct that yields considerable revenue generation. The most promising value-added byproduct is the revenue generated from the sale of camelina meal. A study by Eidhin, Burke, and O'Berine (2003) demonstrates added value to camelina through the sale of meal after the crushing of the seed and extraction of oil. The market for camelina meal is emerging. Camelina recently was awarded FDA approval for use in cattle feed as well as poultry feed at rates of 10% and 3%, respectively.[5] Korsud, Keith, and Bell (1978) report that camelina meal is comparable to soybean meal in terms of nutritional content, containing 45% to 47% crude protein and 10% to 11% fiber. Johnson et al., (2008) suggest that due to a lack of toxic glucosinolate compounds, camelina meal should make a valuable co-product. These glucosinolate compounds are present in other oilseeds.

Literature sources, such as Frank and Garcia (2009); Frechette and Fackler (1999); Fore et al. (2009); Garcia and Leuthold (2004); and Pinzi et al. (2009) suggest that the best method to determine the value of the price of camelina meal is to compare it to the market price of other similar meal options. In the case of camelina, the closest alternative is meal created from soybeans. This study utilizes the price of soybean meal as a proxy for camelina meal.

[5] PRNewswire. "FDA Approves Camelina Meal for Cattle Feed." Accessed 10 December 2010. http://www.prnewswire.com/news-releases/fda-approves-camelina-meal-for-cattle-feed-69565017.html.

2.5. The Shelf Life of Camelina Oil

One of the concerns of any oil high in Omega-3 fatty acids is the oxidative stability of the oil, and therefore the shelf life. Eidhin, Burke and O'Beirne, (2003) address the concerns that oils rich in Omega-3 fatty acids have low shelf life, claiming that despite having low oxidative stability, camelina oil has a longer shelf life than similar oils. Room temperature stability of camelina oil has shown that it is higher than fish oil, under a range of experimental conditions (Eidhin, Burke, and O'Beirne, 2003) This suggests that camelina oil is sufficiently stable during storage and transportation, important both for camelina oil used for meal consumption as well as camelina oil that is meant to be turned into a biodiesel or used as SVO. The stability of camelina oil may lead to several diverse markets and thus more revenue generation.

2.6. Minimum Inputs to Grow Camelina

Camelina has few inputs relative to other oilseed crops and can be grown and harvested with the same equipment that would be used to farm a non-irrigated no-till wheat farm, common in the plains of northeastern Colorado.[6] The ability to plant camelina with the same equipment farmers already own and use to plant wheat helps to mitigate many of the fixed costs that are associated with incorporating camelina into northeastern Colorado farms (Enjalbert and Johnson, 2011). The relatively low cost of inputs is the safety net that allows farmers to grow camelina without fear of large economic losses in the event of an unexpectedly poor growing season. The input costs will be addressed in considerably more

[6] Personal communication with Dr. Nicolas Enjalbert, Colorado State University. In-person interview with the author. October 12, 2010.

detail when a partial crop rotation budget is created for the farms in northeastern Colorado later in this study.

Camelina is reported to have germination rates between 89% and 98% (Robinson, 1987), although anecdotally camelina is considered to have a relatively low germination rate. Colorado State University (CSU) researchers suggest applying a seeding rate of five to seven lbs./acre.[7] Robinson (1987) also suggests that the seeds do not show signs of dormancy, which implies that problems will not be caused for the next crops to be planted on the soil following a camelina harvest. This helps mitigate the potential damage to wheat crops following a camelina planting.

Robinson (1987) looks into whether camelina would perform better in a till or no-till planting scenario. The results show that plantings on frozen non-tilled soils compared with later plantings on tilled soil give equal stands, slightly taller plants, more lodging, equal test weight, equal protein, equal oil percentages, slighter higher yields, and earlier maturity.

Compared to other oilseeds, camelina requires fewer fertilizer, herbicide, and pesticide inputs required to successfully grow the crop (Putnum et al., 1993; Robinson, 1987). Unlike the oilseed crop canola, camelina has been reported to be highly resistant to blackleg (*Lepotosphaeria maculans*) (Putnum et al., 1993; Robinson, 1987). Camelina also demonstrates the lowest cost of production when compared with other oilseeds because no insecticide is required (Robinson, 1987). It is not susceptible to the fleabeetle and lygus bug, other common infestations found in similar oilseeds (Robinson, 1987). Camelina tends to emerge before other cruciferous crops and before any substantial weed germination in the spring (Robinson, 1987). The intrinsic cold tolerance of the seedlings, as previously discussed, also aids in the competition with weeds. Any elimination of competition helps

[7] Personal communication with Dr. Jerry Johnson, Associate Professor, Department of Soil and Crop Sciences, Colorado State University. In-person interview with the author, November 4, 2010.

reduce herbicide and input costs, making the economics behind the planting of camelina more favorable when compared with other oilseeds.

Regarding the use of fertilizer, Robinson (1987) and Putnam et al. (1993) both conclude that nitrogen is the only fertilizer with which camelina significantly responds. Yields were not significantly increased with the addition of potassium or phosphorous.

2.7. Camelina Oil Profile

Zubr and Matthäus (2002) claim that the specific composition of camelina oil makes it appear attractive for biofuel use. However, according to Pinzi et al. (2009), the oil profile of camelina is not yet optimized for engine performance, especially in the percentage of linolenic acid and total polyunsaturated fatty acids. Pinzi et al. (2009) suggest that the high value of total polyunsaturated fatty acids in camelina is advantageous and significantly helps cold weather engine performance, which has traditionally been a major concern for oilseed-based biofuels. This is important for the farmlands of northeastern Colorado, which can witness below freezing temperatures. Johnson et al. (2009) discuss the theory that the high levels of total polyunsaturated fatty acids originated as a survival mechanism in cold weather oilseeds because they are potentially beneficial for soil emergence. However, it has been found that the high levels of total polyunsaturated fatty acids can be degrading to engine cylinders over a long period of time (Nettles-Anderson and Olsen, 2009; Velasco, Fernanez-Martinez, and De Haro, 1999).

2.8. Emissions and Cumulative Energy of SVO Derived from Camelina

Shonnard, Williams, and Kalnes (2010) report that camelina combustion leads to a net greenhouse gas (GHG) emission reduction of 67% when compared to the combustion of petroleum-based diesel. This metric is an aggregate of all GHGs. While the reduction of emissions is not imputed as economic incentive to farmers in this study, potential GHG reduction is important to note for future camelina research, as GHG markets are likely to evolve and could provide farmers with substantial revenues in the future.

With respect to emissions and GHG markets, clarification must be provided as to the definition of profitability. Economists traditionally examine two types of profits, which include accounting profit and economic profit. Accounting profit, the type of profit examined in this study, looks at the total costs subtracted from the total revenues that are recorded by the economic entity. Only costs and revenues listed as a line item in an income statement are recorded. In addition to what is counted in an accounting profit, the economic profit looks at intangibles that are not able to have a cost or revenue directly attributed, such as the amount saved from the reduction in healthcare costs of a designated area due to reduced emissions. In the event that economic profit is included, and not strictly accounting profit, the argument can be made that camelina should have value-added economic incentives due to the emissions reduction it provides. As this study looks primarily at the accounting profit of growing camelina, emissions reduction incentives are ignored. The reductions could be considered when making an altruistic case for using SVO from camelina in place of petroleum-based diesel fuels. However, this study only evaluates financial profits to the farmer.

Similar to emissions, another advantage camelina has over diesel fuel is the energy input-output ratio. This ratio is often critiqued with regard to biofuels, as there is speculation that it is often less than one, indicating more energy is used to grow the crop and create the biofuel than is released upon combustion. It should be noted that Shonnard, Williams, and Kalnes (2010) report not only is the camelina crop-to-oil energy ratio greater than one, indicating that more energy is released than goes into creating a biofuel derived from camelina, but this ratio is greater than the ratio of petroleum-based diesel fuel. Therefore, camelina oil shows promise for energy production in general, as well as an energy alternative to diesel fuel.

2.9. Advantages of Using Straight Vegetable Oil in Place of Biodiesel

A more economically and mechanically efficient process for converting camelina oil into fuel involves the use of SVO, rather than the transestertification process. To process crude oil into biodiesel, the most common method is base-catalyzed transesterification. This method involves cleaving long-chained fatty acid hydrocarbons of triglyceride molecules from the glycerin backbone by a catalyst, usually sodium or potassium hydroxide at approximately 1%, and an alcohol, usually methanol at a 5:1 ratio (Fore et al., 2010; Patil et al., 2009). This process is not necessary, however and can be circumvented by the use of SVO.

SVO is processed directly from an oilseed crop and is not chemically altered, whereas biodiesel is a mix of monoalkyl esters which are produced in a chemical reaction between SVO and an alcohol in the presence of a catalyst (Van Gerpen, 2005). Once the fuels are processed, they have similar functions with varying efficiency. Camelina seeds must be cleaned and conditioned in order to avoid mechanical problems with the press. The seeds are then crushed using a mechanical press with multiple options available (Bernardo et al., 2002). The oil can be directly filtered using a canister or plate-style filtration system and used in diesel engines (McDonnell et al., 1999).

Biodiesel production, achieved through the transesterification process, also requires further steps including drying or heating, mixing, separating, washing, and another drying (Fore et al., 2010). These extra steps are not recommended in this study as biodiesel processing adds significant cost to the crushing process without adding benefits through efficiency. The final products of this process are biodiesel, excess alcohol, and glycerol. Despite the differences in processing, both SVO and biodiesel are fairly efficient in terms of conversion, at 99% and 95% respectively (Fore et al., 2010).

There is debate as to whether SVO or biodiesel would be more cost efficient for small-scale farmers. This discussion is the main emphasis of Fore et al. (2010), who conclude that SVO is slightly cheaper to produce than biodiesel due to reduced input costs. There is a drawback with SVO, however. It can be corrosive towards engine cylinders, causing increased machinery maintenance costs.

An alternative to the use of biodiesel or SVO is a method of duel fueling. Sidibe et al. (2010) outlines a synthesis of various studies that employ the process. In duel fueling, the engine is started with diesel oil. SVO is injected into the circuit once the engine is sufficiently heated, which enables the SVO to completely combust. Before turning the engine off, diesel is run through the engine again to ensure a clean start for the next cold start. This type of fueling system requires a second feed circuit to be installed for SVO, running parallel to the biodiesel feed circuit. The circuit consists of a fuel filter adapted to SVO, a heater to reduce viscosity, a pump, and a solenoid valve to switch between circuits. Although this process is initially semi-intensive in terms of inputs, estimates indicate that a total conversion process costs approximately $1,200, which over time may become more financially feasible than the alternative of continual inputs for biodiesel production (Sidibe et al., 2010). This method was not used in this study, but it should be considered for future camelina implementation studies, especially in very cold climates. The simplest and most economically advantageous method to create a biofuel is through the use of SVO. As a result, this study focuses only on SVO and ignores the other previously discussed alternatives, including biodiesel and a duel fueling system.

2.10 Summary of Personal Communications

As camelina is a relative new oilseed crop, the refereed literature has left some gaps when determining the applicability of growing camelina specifically in northeastern Colorado. This thesis utilizes a variety of personal interviews with local experts to synthesize information published about camelina tailored to other areas of the United States and Canada and make this information more applicable to northeastern Colorado. This helps make the refereed literature more relevant to this thesis. In order to accomplish this, personal communications were conducted with: Dr. Jerry Johnson in November of 2010. Dr. Johnson is an associate professor in the department of Soil and Crop Science at Colorado State University. Dr. Johnson offered considerable assistance by explaining the agronomic traits of farmlands in northeastern Colorado; Dr. Nicolas Enjalbert in October of 2010. Dr. Enjalbert is a graduate of Colorado State University, earning his Ph.D. in the department of Soil and Crop Science. Dr. Enjalbert assisted with an explanation of how the properties of camelina are suitable for Colorado; Dr. Neil Hansen in April of 2011. Dr. Hansen is an associate professor in the department of Soil and Crop Sciences, at Colorado State University. Dr. Hansen assisted by providing significant yield data for wheat both following and not following a fallow; Dr. Duane Johnson in October of 2010. Dr. Johnson is a former professor of the department of Soil and Crop Science at Colorado State University and a former professor at Montana State University. Dr. Johnson offered considerable assistance by explaining the intrinsic properties of camelina and their applicability to Colorado; Mr. John

Deering in July of 2011. Mr. Deering is an agriculture and business management economist with the Colorado State University Extension office. Mr. Deering assisted in the utilization of a budget generator that was used to determine farm equipment fuel demands; Mr. Rod Sharp in August of 2011. Mr. Sharp is an agriculture and business management economist with the Colorado State University Extension office. Mr. Sharp assisted by providing agricultural labor rates in the state of Colorado; Mr. Duane Griffith in January of 2011. Mr. Griffith is an economist at Montana State University. Mr. Griffith offered assistance (though not directly to the author) by developing an oilseed enterprise budget that was emailed to the author;[8] Joel Lundquist in July of 2011. Mr. Lundquist is the owner of Lundquist Farms Inc. and is currently growing camelina for SVO production. Mr. Lundquist helped to clarify any conflicting agronomic traits of camelina; Mr. Hal Holder in July of 2011. Mr. Holder is the owner of a crushing facility in Rocky Ford, Colorado. Mr. Holder assisted by providing financial information regarding the operating of the crushing facility; Mr. Andy Lenssen in May of 2011. Mr. Lenssen is a researcher for the USDA and is based in Montana. Mr. Lenssen assisted by offering information from his personal studies that correlate camelina and reduced wheat harvests; and Mr. Loran Suess in July of 2011. Mr. Suess is the owner of Suess Farms, Inc. Mr. Suess offered considerable data regarding diesel fuel use on his farm.

[8] The enterprise budget created by Mr. Griffith differs considerably from the crop rotation budget created in this thesis as this thesis utilizes dynamic variables while the budget created by Mr. Griffith uses static variable prices and quantities. In addition, the budget created by Mr. Griffith is specifically tailored for the state of Montana.

CHAPTER 3. METHODOLOGY OF THE SIMULATED CROP ROTATION BUDGETING MODEL

3.1. Reiteration of Research Goals

The intention of this research is to illustrate that farmers in northeastern Colorado can hedge against a disruption in the supply of diesel fuel by growing on farmland that would otherwise be in fallow. Furthermore, this study evaluates the likelihood of added profit to farmers who choose to grow the oilseed feedstock *Camelina Sativa* for the primary intention of converting oil found in camelina seeds to SVO. The incorporation of camelina will lead to a high degree of energy independence for farmers through the elimination of much of the on-farm petroleum-based diesel fuel requirements and the subsequent hedge against shocks in the supply and price of diesel fuel.

The study evaluates the likelihood that a farmer grows, but does not lose money by incorporating camelina, compared with a baseline farm that does not have camelina. This study does not take into account the total on-farm profit statement, but rather looks specifically at the gains or losses exclusively related to camelina.

3.2. The Price of Diesel Fuel

According to Yu, Wang, and Lai (2008), the fundamental mechanism governing the dynamics of the price of diesel fuel is complex. The price of diesel is affected by both changing demand and supply. It has been demonstrated that 80% of fluctuations in the long-run real price of gasoline are determined by refining shocks, and 54% of the short-term fluctuations come from demand shocks in the short-run. However, supply shocks still account for a substantial portion of both the short-term and long-term fluctuations in the price of crude oil. The ability for farmers to develop a hedge against severe fluctuations in the price of diesel fuel due to unpredicted supply shocks will help to ensure continued food production.

3.3. The Simulated Crop Rotation Budget Model

This research looks specifically at the simulated profitability of growing camelina on farms in northeastern Colorado on lands that otherwise are in fallow. Northeastern Colorado was specifically chosen because camelina appears to fit well on the fallow portion of the wheat-corn-fallow rotation, previously discussed, that is widely used by farmers in the region.[9]

A crop rotation budget is created to measure whether or not camelina can be profitably integrated on farmlands in northeastern Colorado. The simulated crop rotation budget is designed to include every input cost that a farmer will incur when growing camelina, as well as budgeting the expected savings from reduced off-farm diesel purchases and the revenue from the sale of camelina meal, an additional value-added byproduct. This simulated crop rotation budget exclusively evaluates the difference between a conventional

[9] See Appendix C and Appendix D for a map of the region of study.

farm without camelina and one with the crop, ignoring profits or losses a farmer faces when growing other crops in the rotation.

One of the drawbacks of many crop rotation budgets is the use of static, or fixed, input variables. To commit to adding camelina to the crop rotation, a farmer must consider the future price of diesel fuel, because the decision whether or not to grow camelina could come well before a potential supply shock occurs. However, future prices are not static. In order to address these issues, the simulated crop rotation budget used in this study is stochastic in regards to the appropriate variables.

The crop rotation budget developed in this study evaluates any added costs or revenues incurred exclusively from growing camelina. The costs include the production and processing costs associated with camelina as well as the opportunity cost of devoting land from fallow to camelina, resulting in mitigated wheat yields in the following wheat rotation. In this study, revenues and avoided costs of diesel fuel purchases are considered to have the same effect on the crop rotation budget model, as their effect on the bottom line of the farm is identical. Revenues and offset costs are counted the same way in an accounting budget. Acreage of camelina grown is computed by determining how much SVO is needed to cover all diesel fuel needs with the exception of about 10% supplementary diesel still required for blending. The aggregation of all these variables leads to the simulated crop rotation budget.

The variables used in the simulated crop rotation budget are summarized in Table 3.1. The variables on the left hand side are the added costs of growing camelina, while the variables on the right hand side are considered additional revenue to the farmer who chooses to grow camelina.

Table 3.1

VARIABLES CONSIDERED IN THE SIMULATED CROP ROTATION BUDGET

Variables considered added cost	**Variables considered added revenue**
Seeding Costs	Savings from Offset Diesel Purchases
Nitrogen Fertilizer Costs	Sale of Residual Camelina Meal
Herbicide Costs	
Supplemental Diesel Fuel Purchases[10]	
Labor Costs	
Loan Interest	
Seed Cleaning and Crushing Costs	
SVO Storage Costs	
Seed Hauling Costs	
Opportunity Cost of Forgone Wheat Harvest	

Given the need to account for uncertain future prices, fixed variables in the simulated crop rotation budget are instead replaced with ranges of variables that are modeled stochastically. The ranges of each stochastic variable are carefully selected based on literature recommendations and sound economic principles. In addition, specific distributions for each variable are applied in some cases. These distributions mimic real world conditions by emphasizing a specific range of the stochastic variable.

After setting the ranges and distributions of all the variables used in the simulated crop rotation budget, the variables are run through simulation software called Simetar®. This simulation program uses 50,000 iterations, or draws, of the variables listed in Table 3.1. While these variables are given set distributions, the 50,000 iterations actually incorporate outliers. These outliers are typically an observation on a tail end of the range that usually is eliminated from a static distribution. Running 50,000 simulations helps to account for the

[10] The supplementary diesel fuel purchases are used for blending SVO with diesel fuel to achieve the necessary 90:10 SVO to diesel fuel mixture ratio for optimal engine performance. A small portion of supplementary diesel fuel purchases are also used for winter farming operations which often require pure diesel fuel in vehicles as SVO does not have suitable cold start properties in freezing temperatures.

extremes which can occur in the real world of farming. An example is expected camelina yield. Careful collection of data has determined the range of expected yields, which run from zero to a yield of greater than 1,500 lbs./acre. A static model would simply calculate and use the average of all the yield observations. However, the stochastic model employed in this simulated crop rotation budget chooses a random value for each simulation. This model allows for a value of zero to be chosen, which is not an option when running a static model. This value could be indicative of a drought, for example, or other catastrophic event when no yield is produced. As there is a significant possibility that a farmer will have a crop failure, it is important to develop a model that accounts for this potential failure.

The simulated crop rotation budget is then used to calculate the expected profit, or loss, from each iteration. A set of values is randomly chosen from predetermined ranges, given a set distribution for each variable. The input price and quantity of each variable in the draw are summed to determine the total cost of operation and are compared with the total revenue for each iteration. As there are 50,000 simulations, the model will conduct 50,000 iterations and determine an expected profit, or loss, for each simulation. The program then aggregates all 50,000 simulations. The outcomes of each simulation are computed and placed in a Cumulative Density Function (CDF) which determines the overall likelihood, in terms of a percentage, of profitability when a farmer chooses to integrate camelina into the preexisting wheat-corn-fallow rotation.

3.4. Types of Distributions

As previously mentioned, the variables in the simulated crop rotation budget are assigned predetermined ranges to limit the high and low values of each variable. In addition, each non-fixed variable is also allocated a set distribution. A distribution is a probability density that describes where along the preset range of the variable in question the observations are likely to occur. The probability of profitability when incorporating camelina uses two types of distributions to define assumptions placed on the variables. These distributions are the uniform distribution and the triangular distribution. A list of the variables and their respective distributions can be found in Appendix F.

The most basic distribution used in econometrics is the normal distribution, which is a probability density function (PDF) that is bell shaped, with a mean of μ and a variance of σ^2 (Stock and Waston, 2007). The area under the normal PDF between μ-1.96σ and μ+1.96σ accounts for 95% of the observations. As explained by Kennedy (1998), the most compelling argument for the use of the normal distribution is its intrinsic ease of use. The shape of the bell curve allows for about 68% of the data points to lie between the mean and one standard deviation away from the mean. 95% of the data points are situated within two standard deviations from the mean.

Johnson (1997) claims that the triangular distribution is far simpler compared to the normal distribution, as only three distribution parameters are needed. These are the minimum, maximum, and mode, the latter of which is defined as the value of the most likely observation. Williams (1992) offers further support for the triangular distribution explaining that the triangular distribution is much simpler compared to the normal distribution. The normal distribution is more complicated because it requires knowledge of the mean and a standard deviation and thus involves more complicated calculations.

Keefer and Boddily (1983) did some of the earliest research relating to triangular distributions. They explain that in risk analysis simulations, such as Monte Carlo simulations, it is very popular to elicit three points per distribution and fit a triangular PDF to the points. The paper concludes that triangular distributions are widely applicable general purpose models and should be used when judged appropriate, typically when there are not enough observations to find a reliable standard deviation.

The continuous uniform distribution is a type of distribution in which all points within the bounded area are equally probable. Park and Bera (2009) explain that the distribution type has a "perfect smooth" density. It is most applicable when no prior information is known about the data other than the normalization constraint. Further detail, such as the mean and standard deviation, would transform the uniform distribution into a normal distribution. The continuous uniform distribution is defined by Equation 3.1:

$$\text{(3.1)} \qquad f(x) = \left[\frac{1}{\beta-\alpha} \text{ for } \alpha \le x \le \beta, 0 \text{ for } x < \alpha \text{ or } x > \beta\right],$$

where f(x) is the function in terms of x, and the α and β coefficients are the boundaries of the range of the variable. This suggests that once the constraint parameters α and β are set, the x-value must fall somewhere between the minimum and maximum parameter. This is a random draw of the x-value. In a continuous uniform distribution, any number can be selected inside the predetermined range, compared to a discreet uniform distribution, which restricts numbers to specific intervals, such as only whole numbers.

The dynamic variables used in this research are assigned either a triangular or uniform distribution. An explanation is given as to why a particular distribution is chosen in regards to each variable in the simulated crop rotation budget. The intention is to mimic the real world draws of observations on any given farm in northeastern Colorado, accounting for extremes but expecting normality.

3.5. Latin Hypercube Simulations

The Latin hypercube simulation is similar to the Monte Carlo simulations widely used in economics. Stein (1987) explains that Monte Carlo simulations have limitations when a large number of input variables are needed, suggesting that it is beneficial to pick a sampling scheme that keeps the number of simulations needed to a minimum. Stein (1987) expands on the work of McKay, Conover, and Beckman (1979), who suggest the Latin hypercube method of sampling as a means to create a seemingly random simulation parameter. Stein (1987) determines that Latin hypercube samples will give a very low variance as long as the number of simulations is large compared with the number of variables.

The main purpose of a Latin hypercube simulation is to preserve each marginal distribution as much as possible, but otherwise choose the x-values in a strict order that appears to be random. This allows for a stochastic simulation that can be re-created by other researchers. All the simulations employed in this research model use the Latin hypercube method of sampling.

3.6. Variables in the Simulated Crop Rotation Budget

3.6.1. Cost of Seeding

The first variable examined in the simulated crop rotation budget is the cost of seeding. While some studies, such as Robinson (1987), have called for seeding rates as high as 11 lbs./acre, the vast majority of work has suggested that less than 6 lbs./acre is necessary.[11] A survey of various university extension enterprise budgets shows a fairly

[11] Personal communication with Dr. Duane Johnson, formerly of Montana State University Extension. Interview via email with author. October 22, 2010.

consistent estimate of the expected price of camelina seed, averaging about $2.00/lb.[12] In the simulated crop rotation budget model, the price of camelina seed is fixed at $2.00/lb.[13]

The model, however, allows for a variable seeding rate. In the simulated crop rotation budget, the pounds per acre seeding rate is assigned a continuous uniform distribution between the range of 5 and 7 lbs./acre. This is consistent with the requirements of the camelina seeding rate in northeastern Colorado as established through personal communications with other camelina researchers.[14]

3.6.2. Nitrogen Fertilizer Cost

The amount of nitrogen fertilizer applied, per acre, is assigned a stochastic distribution in the simulated crop rotation budget. This is due primarily to the uncertainty of the residual nitrogen fertilizer levels in the ground following the harvest of corn in the previous portion of the crop rotation. The price of fertilizer incorporated in the simulated crop rotation budget is strongly correlated with the price of diesel fuel, explained in much greater detail in section 3.6.2.2. The per acre cost of nitrogen fertilizer is found by multiplying the application rate of nitrogen fertilizer per acre by its respective price, determined by its high correlation with the price of diesel fuel.

[12] See Appendix B for a complete list of enterprise budgets used to determine input variables.

[13] See Appendix F for a list of input variables and their assigned distributions.

[14] Personal email communication with Duane Griffith, Montana State University Extension economist. January 25, 2011.

3.6.2.1. Nitrogen Fertilizer Application Rate

The application rate of nitrogen fertilizer is assigned a triangular distribution, with a minimum-value and mode-value of zero lbs./acre. The value of zero was assigned to the distribution as the farmland will have a substantial likelihood of not requiring the addition of more fertilizer. This is due to significant nitrogen fertilizer levels remaining following the harvesting of corn. The maximum-value of the distribution is fixed at 40 lbs./acre.[15] Figure 3.1 is a graphical representation of the nitrogen fertilizer application rate PDF used by the simulated crop rotation budget.

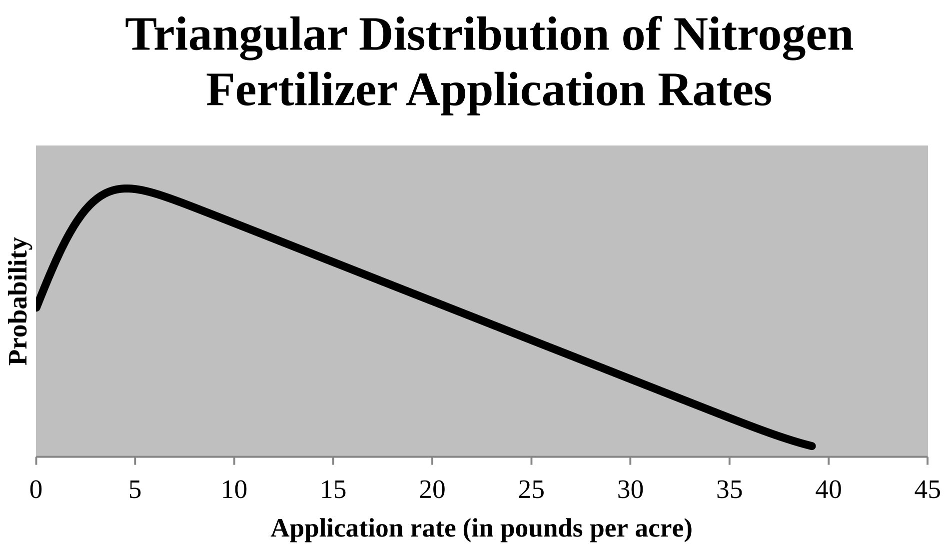

Figure 3.1. Graphical representation of the nitrogen fertilizer application triangular distribution.

3.6.2.2. Nitrogen Fertilizer Price

The next step to calculating the per acre cost of fertilizer is to determine the price of nitrogen fertilizer. The price of fertilizer is multiplied by the application rate to calculate a per acre price of fertilizer used in the simulated crop rotation budget. Determining the price of

[15] Personal communication with Dr. Jerry Johnson, Associate Professor, Department of Soil and Crop Sciences, Colorado State University. In-person interview with the author. November 4, 2010.

fertilizers used in the simulated crop rotation budget poses a challenge due to the volatility of the price of fertilizers in the past five years. In Figure 3.2 data was collected from the ERS.[16] The ERS publishes the annual average price of nitrogen fertilizer used in the United States for the past 50 years, from 1960 through 2010. Figure 3.2 demonstrates the average annual per ton price of nitrogen fertilizer annually from 1995 through 2010.

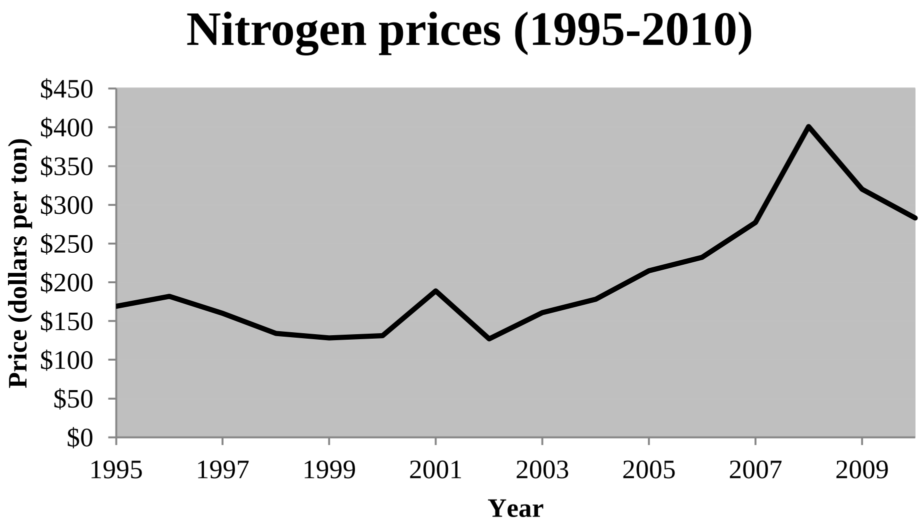

Figure 3.2. Nominal nitrogen prices from 1995 through 2010 in dollars per ton.

2008 presents a statistical challenge in regards to forecasting the price of nitrogen fertilizer, as it is difficult to determine if the spike in price is more than an anomaly. However, more clarity can be gained when comparing the average annual price of nitrogen fertilizer with the average corresponding annual price of diesel fuel, shown in Figure 3.3.

[16] See "Fertilizer Use and Price" in Appendix B.

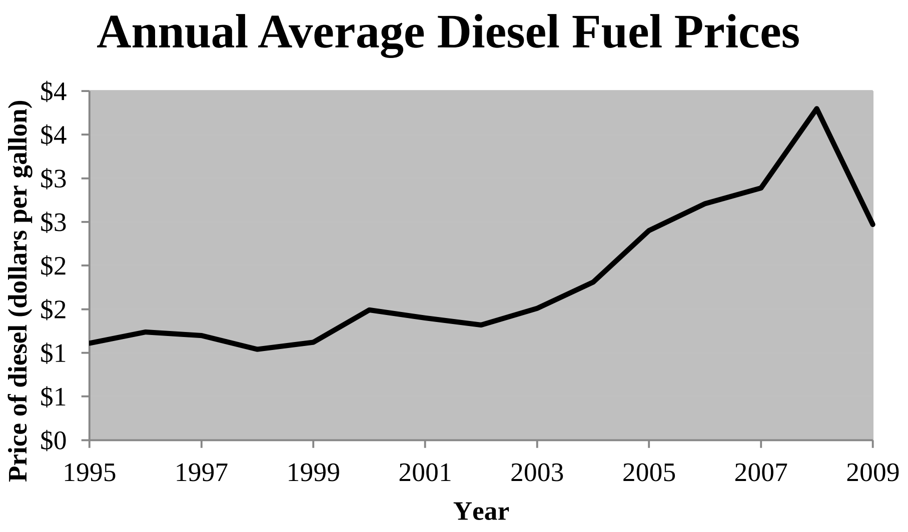

Figure 3.3. Average nominal aggregate U.S. diesel fuel prices from 1995 through 2010 measured in dollars per gallon.[17]

When the two graphs are examined, a clear correlation is evident between the price of diesel fuel and the price of nitrogen fertilizer.

This correlation can be explained upon further reflection of the relationship between the rising price of diesel fuel and the demand for ethanol. Du and Hayes (2008) note that ethanol has a significant substitution effect on gasoline prices, indicating that as gasoline prices increase, a shift in demand towards ethanol occurs. Johnson (2002) finds that retail diesel prices demonstrate fairly symmetrically responses to the price of crude oil, possibly because of the extensive price searching conducted by trucking firms prior to directing truckers to a specific fueling station. This allows for a correlation to be established between the price of diesel fuel and the demand for ethanol. Acheampong and Dicks (2012) note that the manufacturing of ethanol is now the second largest U.S. market for corn, while Tyner and Taheripour (2008) find that the corn share for ethanol is between 44 and 47%, due in large part to the mandates outlined in the RFS. The increased demand for ethanol is likely one of the contributing factors towards the recent increase in the total acreage of corn planted, as a

[17] Source of data in graph: U.S. Energy Information Agency. http://www.eia.gov/petroleum/gasdiesel/.

higher demand for ethanol may lead to a higher demand for corn to produce the ethanol and subsequently higher corn prices. As corn is nitrogen fertilizer intensive, the price of nitrogen fertilizer has risen along with the price of corn, as there has been a recent increase in demand for nitrogen fertilizer (Tyner and Taheripour, 2012). Thus it can be inferred that a correlation exists between the prices of gasoline (or diesel fuel, as demonstrated) and nitrogen fertilizer.

A Correlated Uniform Standard Deviate (CUSD) matrix was created in Simetar® in order to create a PDF of the price of nitrogen fertilizer for the simulated crop rotation budget. A CUSD allows for correlation between the price of diesel and the price of the fertilizer input. Through the use of a CUSD, correlation is maintained between nitrogen fertilizer prices and diesel fuel prices during the stochastic draws of observations.

The CUSD is calculated through a multistep process in Simetar®.[18] Step 1 is to organize fertilizer and diesel prices in arrays corresponding to an average price in a specific year. Figure 3.4 arranges the average annual per ton nitrogen fertilizer price used in the simulated crop rotation budget with the corresponding average annual per gallon diesel price.

N Fertilizer Prices Based on Diesel Prices

N Prices	Diesel
207.00	1.11
266.00	1.11
278.00	1.24
257.00	1.20
195.00	1.04
176.00	1.12
200.00	1.49
280.00	1.40
191.00	1.32
261.00	1.51
276.00	1.81
332.00	2.40
362.00	2.71
453.00	2.89
552.00	3.80
486.00	2.47
448.00	2.99
526.00	3.90

Figure 3.4. Arrays of the average nominal nitrogen fertilizer price per ton with the corresponding average nominal diesel price per gallon, annually from 1993 through 2010.

18 Directions for running CUSDs are adapted from a thesis by Aaron Sprague, Department of Agricultural and Resource Economics, Colorado State University.

Step 2 is to calculate summary statistics from the array, including the mean values of each variable. Step 3 is to calculate the unsorted deviations from the trend based off of the summary statistics, which had previously been calculated in step 2. The unsorted deviations, shown in Figure 3.5, are used in the calculation of the correlation matrix between the fertilizer in question and diesel fuel. This is done through Simetar® software.

Step 4 is to calculate the correlation matrix. The correlation matrix is calculated from the array featuring the unsorted deviations from the trend as well as the mean, calculated in the summary statistics in step 2. Figure 3.6 is the correlation matrix for nitrogen and diesel fuel prices.

Unsorted Deviations from Trend as a Percent of Predicted		
Obs.	N Prices	Diesel
1	0.314847	0.782421
2	0.507366	0.420256
3	0.421989	0.318658
4	0.19794	0.089932
5	-0.16513	-0.17008
6	-0.30325	-0.20875
7	-0.26372	-0.05367
8	-0.03671	-0.19221
9	-0.38328	-0.30328
10	-0.20606	-0.2646
11	-0.20638	-0.18128
12	-0.09489	0.013691
13	-0.06179	0.069864
14	0.118863	0.073624
15	0.302165	0.33628
16	0.097205	-0.17897
17	-0.03026	-0.05423
18	0.093529	0.173562

Figure 3.5. The unsorted deviations from trend as a percent of predicted nitrogen fertilizer and diesel fuel prices.

Correlation Matrix		
	N Prices	Diesel
N Prices	1	0.777497
Diesel		1

Figure 3.6. The correlation matrix between annual per ton nitrogen fertilizer prices and annual per gallon diesel fuel prices.

Step 5 is to calculate the CUSD using the correlation matrix already found in step 4. Figure 3.7 is an example of the CUSD calculated from the nitrogen and diesel correlation matrix.

Correlation Matrix				CUSDs
	N Prices	Diesel		
N Prices	1	0.777497		0.400216
Diesel		1		0.560974

Figure 3.7. The correlation matrix and Correlated Uniform Standard Deviates between per ton annual nitrogen fertilizer prices and per gallon annual diesel fuel prices.

The CUSD is stochastic and will change for each simulation. Figure 3.8 is a representation of one stochastic CUSD draw for nitrogen correlated with diesel.

Correlation Matrix				CUSDs
	N Prices	Diesel		
N Prices	1	0.777497		0.617823
Diesel		1		0.549255

Figure 3.8. The correlation matrix and Correlated Uniform Standard Deviates between annual per ton nitrogen fertilizer prices and annual per gallon diesel fuel prices.

Step 6 is to calculate the sorted percent deviations from the trend using the Simetar® software. This is demonstrated in Figure 3.9.

Sorted Deviations from Trend as a Percent of Predicted		
F(x)	N Prices	Diesel
0	-0.38332	-0.30331
0.027778	-0.38328	-0.30328
0.083333	-0.30325	-0.2646
0.138889	-0.26372	-0.20875
0.194444	-0.20638	-0.19221
0.25	-0.20606	-0.18128
0.305556	-0.16513	-0.17897
0.361111	-0.09489	-0.17008
0.416667	-0.06179	-0.05423
0.472222	-0.03671	-0.05367
0.527778	-0.03026	0.013691
0.583333	0.093529	0.069864
0.638889	0.097205	0.073624
0.694445	0.118863	0.089932
0.75	0.19794	0.173562
0.805556	0.302165	0.318658
0.861111	0.314847	0.33628
0.916667	0.421989	0.420256
0.972222	0.507366	0.782421
1	0.507416	0.782499

Figure 3.9. The unsorted deviations from trend as a percent of predicted nitrogen fertilizer and diesel fuel prices.

Step 7 is to place the function in an empirical formula run in Simetar®. The empirical formula found in Simetar® includes the sorted deviations from the trend and the CUSDs previously calculated in step 6. This empirical command gives a stochastic deviate as the output.

Step 8 is to run a simple regression. The fertilizer price is regressed against the corresponding diesel price for the respective year. The key output variables are the intercept and slope of the regression. The results for the example case of nitrogen fertilizer are shown in Figure 3.10.

Nitrogen Prices Regressed Againt Diesel Prices			
Intercept	80.89909		
Slope	120.8195		
R-Square	0.875868		

Figure 3.10. The slope, intercept, and goodness of fit of per ton annual nitrogen fertilizer prices regressed against per gallon annual diesel fuel prices.

In the case of nitrogen fertilizer, the intercept is $80.90 and the slope is $120.82. This can be interpreted that if the price of diesel fuel is kept constant, nitrogen fertilizer would cost $80.90/ton. For every dollar the price of diesel fuel increases, the price of nitrogen fertilizer increases by $120.82/ton.

Step 9 is to impute the expected diesel price per gallon values into the regression, once the slope and intercept of fertilizer regressed against diesel prices have been determined in step 8. Figure 3.11 shows three example per gallon diesel fuel price levels and their corresponding per ton nitrogen fertilizer price.

Diesel Price (per gallon)		Corresponding Expected Nitrogen Price (per ton)
Low Case:	$ 2.09	$ 333.41
Middle Case:	$ 3.10	$ 455.44
High Case	$ 4.78	$ 658.42

Figure 3.11. The expected per ton price of nitrogen fertilizer based on the per gallon price of diesel fuel.

Step 10 is to predict the fertilizer price based on the stochastic deviate already determined in the earlier application of the empirical formula. This is done using the formula:

$$\mathrm{Fp} = \mathrm{RFp} * (1 + \mathrm{SD}), \tag{3.2}$$

where Fp is the fertilizer price used in the simulated crop rotation budget, RFp is the regressed fertilizer price determined through the simple regression of fertilizer against diesel and multiplied by the expected diesel price level, and SD is the stochastic deviate determined through the steps listed above.

Using the CUSDs allows for fertilizer price levels to be compared with the predetermined expected diesel price levels. However, the nature of the stochastic draws imply that while the expected price of fertilizer is closely related to the price of diesel, anomalies can and will occur. This helps to mimic real world situations where fertilizer price is not completely responsive to the price of diesel fuel.

3.6.2.3. Per Acre Fertilizer Cost

The per acre application rate of nitrogen fertilizer is multiplied by the results of the CUSDs to determine the per acre cost of fertilizer. The application rate, drawn randomly, is multiplied by the price per ton of fertilizer determined through the CUSD. This is then divided by 2000 to convert the per ton price of fertilizer to the per pound price of fertilizer so that the subsequent cost per acre of fertilizer can be calculated.

3.6.3. Herbicide Cost

Herbicide practices are determined through personal communications with CSU Extension agronomists based in northeastern Colorado.[19] Herbicide costs incurred while growing camelina result in an overall reduction in input costs. This is because less herbicides are applied on farmland growing camelina compared with land that is otherwise in fallow. Using the recommendations from CSU Extension agronomists, this study assumes that an

[19] Personal communication with Mr. John Deering, Colorado State University Extension Agriculture and Business Management Economist. In-person interview with the author. July 21, 2011.

acre of camelina requires eight ounces of Clethodim Select® herbicide, at an average price of $120.00/gallon. This equates to a herbicide cost of $7.50/acre when growing camelina.

The herbicide cost of $7.50/acre displaces the herbicide costs of land in fallow. The herbicide requirements to maintain a fallow are comprised of one pint of Atrazine® herbicide, valued at $16.00/gallon, one quart of Dicamba® herbicide, valued at $60.00/gallon, one pint of 2,4D herbicide, valued at $16.00/gallon, and one half gallon of glyphosphate, more commonly known as Roundup®, valued at $15.00/gallon. The total fertilizer cost of land in fallow is valued at $19.00/acre. This implies that a farmer will save $11.50/acre in herbicide costs for every acre of camelina that is grown instead of fallow. Herbicide costs are fixed in the simulated crop rotation budget as there has not been significant volatility in the price of herbicides in recent years.

3.6.4. Acreage of Camelina Planted

It is important to calculate the optimal amount of acreage that should be dedicated to camelina. Acreage planted should be sufficient for SVO production, but surpluses should be minimized to decrease both risk and costs. While camelina is only grown on lands that are otherwise in fallow, there is still significant risk to farmers beyond the basic input costs of growing a new crop. The most significant risk is the losses to subsequent, already established, wheat yields grown on the same farmland just months after a camelina harvest. These potential losses, due to the lack of a fallow period preceding the planting of wheat, pose considerable risk and would potentially result in large costs. Therefore, in order to determine the economic viability of camelina, it is critical to determine how many acres of farmland need to be dedicated to camelina in order to have enough SVO to offset a significant portion of diesel purchases without producing excess camelina yields. It is worth noting that the model is designed to not allow the sale of SVO if surplus SVO is generated beyond what is used to offset diesel fuel. This is because it is currently illegal to sell homemade fuels and complex warranty issues would arise. Thus, excessive camelina would be considered costly.

It should be noted that for all acreage calculations, the farms are considered to be monoculture farmlands for all land annually. To give an example, if the farm is 1,000 acres, this study assumes that all 1,000 acres will be devoted to corn one year, to fallow the subsequent year, and to wheat the final year of the rotation. While many farms are not a monoculture farm annually, but rather grow multiple crops each year and rotate where the crops are grown, the calculation of how much fallow lands must be devoted to camelina is the same. It is simply a more straightforward calculation to assume the entire farm is devoted to one crop per year. In reality, if a farmer chose to split the farm and use a multiple cropping system, the SVO storage costs would be reduced because smaller storage tanks would be suitable for the farmer, which would involve a calculation that is beyond the scope of this paper.

To calculate the optimal acreage of camelina, the total on-farm diesel fuel use must be estimated. This involves a sequence of steps. First, calculations must be made to determine what portion of the fuel can be offset, as some diesel fuel is necessary to mix with SVO to properly run in farm machinery. It is then necessary to determine the expected yield of an acre of camelina, as well as determine the expected oil content percentage of the seed from that yield. Once the percentage of oil per seed and the yield per acre are determined, a conversion to calculate gallons of SVO per pound of seed is employed. This allows for the determination of how many pounds of seed are needed to sufficiently meet the SVO requirement of the farm. The final step is to determine how many acres of camelina need to be planted in order to give an average yield that is sufficient to meet the pounds of seed required to meet the maximum diesel fuel offset.

3.6.4.1. Average Yield

Based upon peer-reviewed literature, government reports, and anecdotal data, estimated camelina yields vary considerably. For this thesis, multiple sources were surveyed to determine average yield of camelina at harvest. Much of the literature that has yield information is from non-refereed sources, while only four peer-reviewed studies provided at-harvest yield information. The literature is still undecided as to where to expect average yields, but it is clear from many studies that it is not unreasonable to anticipate yields of camelina in no-till non-irrigated farmlands to reach 1,000 lbs./acre.

In a brief summary of the literature, Putnam et al. (1993) note that the reported yields showed a wide range at test trials in the state of Minnesota. Conducted at 45 degrees latitude, the trials reported yields of about 550 to 1,600 lbs./acre, with an average of about 1,000 to 1,100 lbs./acre over many of the trials. In the specific case of no-till early planting of camelina, with a seeding rate of about 10 lbs./acre, the average yield was 1,046 lbs./acre, a figure that was concluded over a three year study in Minnesota (Putnam et al., 1993). Other studies have concluded that average yields can be as high as 1,200 to 1,400 lbs./acre (Patil, Gude and Deng, 2009). The low end of the literature has found the mean to be between 570 and 874 lbs./acre (Vollmann et al., 1996). Robinson (1987) ran three studies, and found the yields to be 1,390 lbs./acre, 900 lbs./acre, and 930 lbs./acre, respectively.

However, it must be questioned how much the yield will change when moved from a carefully watched test plot to an actual farm with inexperienced farmers trying camelina for the first time. The National Agricultural Statistics Service (NASS), an agency within the USDA, has some published numbers on the expected yield at harvest for camelina. In its publications, the NASS is reporting average yields as low as 569 lbs./acre and 615 lbs./acre, respectively, conducted in independent studies. However, the NASS also noted that the upper

20% of test yields exceeded 1,581 lbs./acre, while the lower 20% of yields were reported below 550 lbs./acre and 238 lbs./acre, respectively, in the two studies.

The non-peer reviewed literature includes numbers that may be too optimistic. While some have average yields below 600 lbs./acre, others are showing yields that are exceeding 2,000 lbs./acre. It is difficult to completely disregard the non-peer reviewed literature because few examples of camelina yield information are available through the peer-reviewed works. Discarding the literature that is neither from the USDA, personal communication with CSU researchers, nor other peer-reviewed literature sources, the summary statistics show a mean yield of 822 lbs./acre, with a standard deviation of 346 lbs./acre. Several studies demonstrated a total crop failure, while the highest of any study reported a yield of 1,585 lbs./acre. If the non-peer reviewed literature is used in the calculation of the expected yields, the mean increases to 1,136 lbs./acre, with a standard deviation of 481 lbs./acre.

Figure 3.12 demonstrates a histogram of the expected yields based upon the peer-reviewed literature, CSU Extension recommendations, and figures published by the USDA.

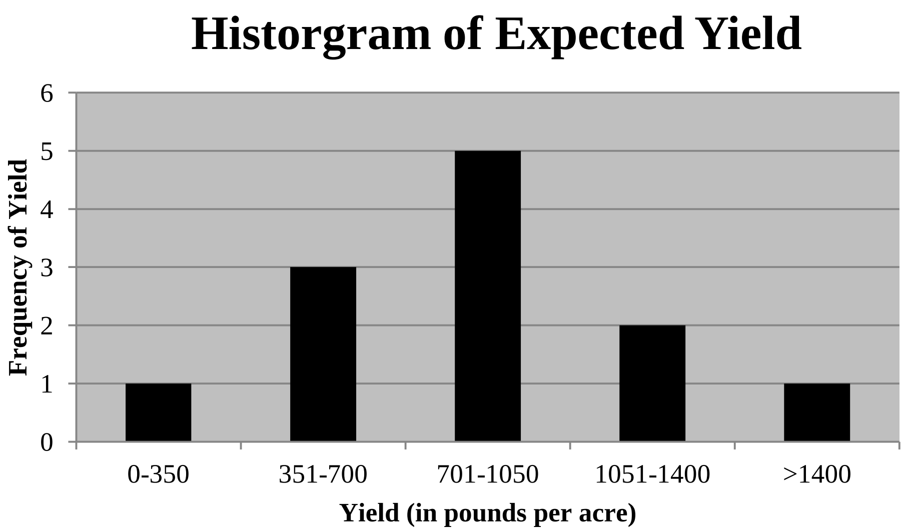

Figure 3.12. Histogram of per acre camelina yields as reported in the peer-reviewed literature.

Although there are limited observations, it is still possible to conclude that yields follow a normal distribution. This distribution has a mean of 822 lbs./acre and a standard deviation of 346 lbs./acre.

This distribution is not appropriate for northeastern Colorado, however. Due to the relative uncertainty of camelina growing practices, there is a much higher likelihood of zero yields for farmers. The average yield of 822 lbs. is also considerably too high, as it is developed for a national average and not specific to northeastern Colorado. The yield variable in the simulated crop rotation budget is instead assigned a triangular distribution, with a minimum-value and mode-value fixed at zero, in order to force the model to draw more zero yields for farmers. The maximum-value is set at 1,200 lbs./acre, which is expected to be an accurate estimation of the maximum yields in northeastern Colorado. Figure 3.13 demonstrates the PDF drawn by the simulated crop rotation budget for camelina yields specific to northeastern Colorado.

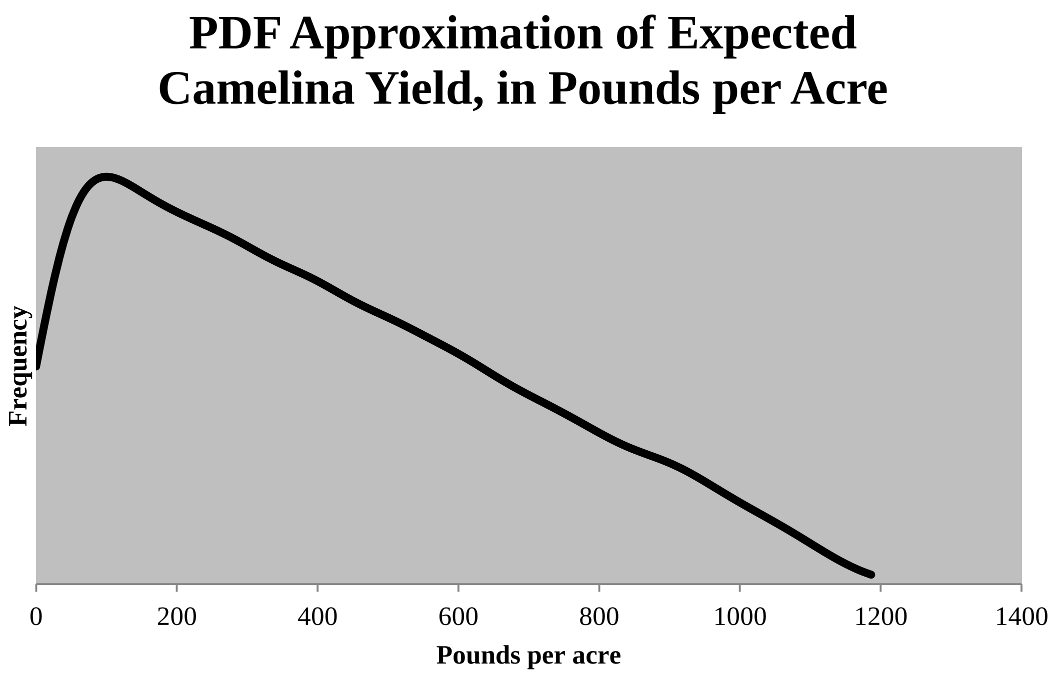

Figure 3.13. PDF of per acre camelina yields drawn in the simulated crop rotation budget.

Note that the mean yield in Figure 3.13 is 400 lbs./acre, a significantly lower per acre camelina yield than the national average of 822 lbs./acre.

3.6.4.1.1. The Effect of Rainfall on the Yield Distribution

Although camelina is considered relatively drought-resistant, rainfall does factor into profitability calculations. Forecasting the effects of rainfall on yield proves difficult due to the uncertainty of predicting climatic conditions. Senay and Verdin (2001) write about the Water Requirement Satisfaction Index (WRSI). The WRSI is based on the water supply and demand a crop experiences during a growing season.[20] Other models have been published with similar results as the WRSI (Martin and Gilley 1993; Allen et al., 1998). These models, however, have not been adapted to camelina (Hunsaker et al., 2011). Another commonly used drought index is the Palmer Drought Severity Index (PDSI), which was developed by Palmer (1965). This approach combines various hydroclimatological variables (Araghinejad, 2011). Salvati, Liberta, and Brunetti (2005) research the evaluation of drought severity, using the PDSI. One of the major flaws with the PDSI exposed in the literature is that the index has values that lag for several months for emerging droughts, rendering the algorithm unhelpful for prediction of a camelina harvest during a growing season. Other models are available. Vangelis, Spiliotis, and Tsakiris, (2011) publish a work on the rainfall anomaly index, while Guttman (1998) writes extensively about the Standardized Precipitation Index (SPI), developed by Mckee, Doesken, and Kleist, (1993) and Mckee, Doesken, and Kleist (1995). This SPI is a standardizing transformation of the probability of observed precipitation. It is a way of measuring drought that differs from the PDSI in that it only measures precipitation, as opposed to evapotranspiration and runoff.

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[20] "Water Requirement Satisfaction Index." 2007. USGS. http://earlywarning.usgs.gov/fews/readme/wsreadme.php.

The most significant problem with trying to associate a drought or rainfall prediction index with expected crop yield is the lack of understanding of the correlation between rainfall and camelina yield (Pilgeram et al., 2007; Eskridge, Byrne, and Crossa, 1991). It is therefore important to note that the yield distribution assigned to camelina is all encompassing. The emphasis on lower yields accounts for a season with unusually low rainfall instead of attempting to use one of the many drought indices. The low yield also accounts for the learning curve farmers will face when implementing camelina for the first time. While higher yields are possible, they are not likely in the first few camelina rotations. This requires a distribution that emphasizes the lower yield possibilities, and mitigates much, but not all, of the possibility of drawing a high yield. That is captured in the triangular distribution assigned to camelina yields.

3.6.4.2. Percentage of Oil Content in the Seed

Vollman et al. (2005) note a link between the percentage of oil content in the camelina seed and the overall yield. That correlation is incorporated into the simulated crop rotation model using the same CUSD procedure documented for determining the price of nitrogen fertilizer based on the correlated price of diesel fuel. In this scenario, the percentage of oil content in the seed is predicted based off of the corresponding correlation of the overall yield. Using data published in Vollman et al. (1996), Vollman et al. (2005) and Vollman et al. (2007), the correlation between oil content percentage and yield was determined to be 0.96.

Once the oil content percentage is determined using the CUSD, the percentage is multiplied by 0.8. This is due to the inefficiencies of extraction, as only about 80% of the oil in the seed will actually be extracted. Figure 3.14 is a PDF of 50,000 iterations of seed oil content percentage.

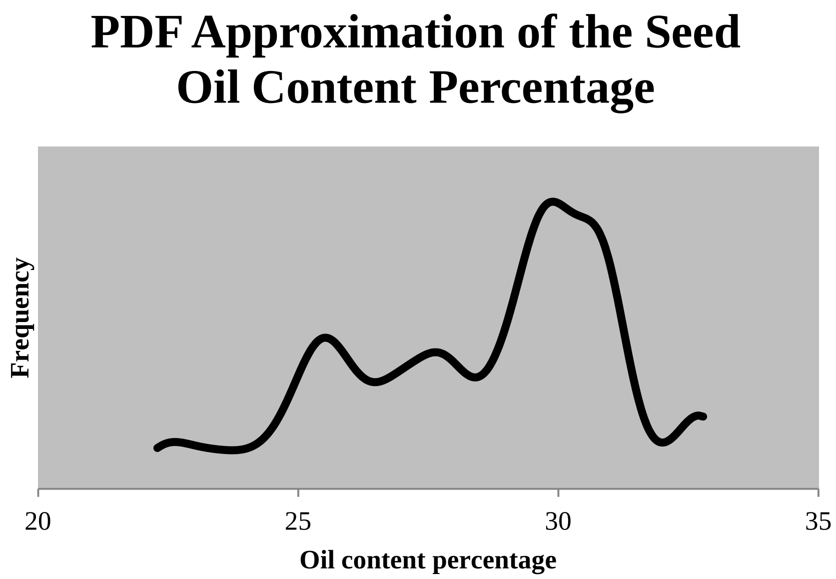


Figure 3.14. The seed oil content percentage for camelina.

The minimum oil content is 22.2%, and the maximum is 32.7% after accounting for the inefficiencies in extraction. The mean value is determined to be 28.4%.

3.6.4.3. On-Farm Fuel Needs

The on-farm fuel needs are determined by the formula shown below in Equation 3.3. Following the formula is a thorough explanation of how the numbers are derived. The formula is populated with either the average or median of each variable as it is used in the simulated crop rotation budget:

$$(3.3)\quad CamelinaAcres = \left[\frac{FS*MDO}{(CY*OC)*\left(\frac{0.1022625}{1-OC}\right)}\right] + \left[\frac{FS*MDO*DC}{\left((CY*OC)\left(\frac{0.1022625}{1-OC}\right)\right)^2}\right],$$

where CamelinaAcres is the acres of farmland that should grow camelina in order to supply the target amount of SVO for maximum diesel offset; FS is the farm size, in acres; MDO is the maximum diesel offset, the per acre amount of diesel fuel that can potentially be offset with the use of SVO not including the additional offset of diesel fuel used in the camelina rotation; CY is the expected yield of camelina, in lbs./acre; OC is the percent of oil content converted to a decimal, the percent of the camelina seed that is oil; 0.1022625 is a constant used to convert pounds of SVO into gallons of SVO; and DC is the diesel fuel measured in gallons per acre that can be offset when growing the next camelina rotation.

The amount of on-farm diesel fuel required is determined from the enterprise budgets published by CSU Extension with northeastern Colorado as the target area. In these budgets, it has been determined, using CSU Extension data input in the Mississippi State Budget Generator, that it takes 3.198 gallons of diesel fuel to grow one acre of corn. It has also been determined through the CSU Extension enterprise budgets that 4.726 gallons of diesel fuel are needed to grow one acre of wheat. It should be noted that an acre of camelina uses the same fuel requirements as an acre of wheat, as the two crops are planted and harvested using the same machinery. Therefore, 4.726 gallons of diesel fuel are also used per acre of camelina. There is also the consideration of diesel fuel that is used to maintain the fallow. According to the Mississippi State Budget Generator, an additional 1.2 gallons of diesel fuel are needed per acre of land in fallow. The fuel that otherwise would have been devoted to fallow must also be considered when growing camelina. Since 1.2 gallons of diesel fuel are devoted to a fallow and camelina uses 4.726 gallons of diesel fuel, growing an acre of camelina uses an additional 3.526 gallons of diesel fuel than is needed to maintain a fallow.

A farmer will use 9.124 gallons/acre of diesel fuel to grow a complete rotation of wheat-corn-fallow. However, as previously stated, SVO is not suitable to completely replace diesel fuel. The most ambitious offsets occur in a 90:10 ratio of SVO to diesel fuel. This is to help maintain the proper specific gravity of the fuel, as well as help the cold start properties. This means that for every gallon of biofuel produced, 90% is from SVO derived from camelina, and 10% remains the same diesel fuel previously used. This implies that a farmer needs 8.212 gallons/acre of SVO to offset a complete rotation of wheat-corn-fallow. However, one caveat of SVO is its less than ideal cold start properties, suggesting that it does not work well in the winter. This is especially true in the high altitude farms of Colorado. Through personal communication, it is determined reasonable to expect farmers to use about 1.5% of their total fuel consumption during the winter months.[21] This results in 98.5% of the fuel consumption occurring in the spring, summer, and fall months when an SVO offset is an option. In all, 8.088 gallons/acre of SVO are needed to offset the maximum amount of diesel fuel without risking engine damage or the inability to start in the winter. This value is the MDO, maximum diesel offset, variable shown in the equation at the beginning of this section. Referring again to Equation 3.3, the MDO variable has now been replaced with the assumption that 8.088 gallons of SVO are required for the maximum diesel offset:

$$(3.3.1) \qquad CamelinaAcres = \left[\frac{FS*8.088}{(CY*OC)*\left(\frac{0.1022625}{1-OC}\right)}\right] + \left[\frac{FS*8.088*DC}{\left((CY*OC)\left(\frac{0.1022625}{1-OC}\right)\right)^2}\right].$$

The next step towards determining the amount of camelina that needs to be planted is to convert extracted oil from the camelina seed to gallons of SVO. The per acre average yield and median oil content have previously been determined. These values are about 400 lbs./acre and 29.21% oil content in the seed, respectively. As previously discussed, the 29.21% oil content in the seed figure accounts for the 80% oil extraction rate from the seed. Using these two values, the expected oil from an acre of camelina is 116.84 lbs. The conversion rate published by CSU Extension indicates that 7.945 lbs. of seed extracted at a rate of 35% oil is equivalent to a gallon of SVO. However, the extraction rate is not always 35% and can vary significantly. Equation 3.3 compensates for the variance in the extraction rate by using a constant of 0.1022625. This figure is derived from the 7.945 lbs. of seed per

[21] Personal Communication with Mr. Loran Suess, Suess Farms Inc., Hanska, MN. In-person interview with author, July 27, 2011.

gallon conversion rate found by CSU Extension. This constant of 0.1022625 is divided by the extraction rate, in decimal form, subtracted from one.

Equation 3.3 is now updated with CY, the camelina yield variable, and OC, the oil content percentage variable in decimal form, replaced with the assumptions of 400 lbs./acre of camelina yield and an oil content percentage of 29.21% after accounting for an 80% seed oil extraction rate:

$$(3.3.2) \qquad CamelinaAcres = \left[\frac{FS*8.088}{(400*0.2921)*\left(\frac{0.1022625}{1-0.2921}\right)}\right] + \left[\frac{FS*8.088*DC}{\left((400*0.2921)\left(\frac{0.1022625}{1-0.2921}\right)\right)^2}\right].$$

An example farm of 1,000 acres will be used to simplify calculations when determining the acreage of camelina that must be planted to achieve the maximum diesel offset. The actual size of the farm is not significant, as the acreage of camelina needed is determined as a percentage of total farm size. Equation 3.3 is updated below to replace the FS variable with the 1,000 acre example farm:

$$(3.3.3) \qquad CamelinaAcres = \left[\frac{1{,}000*8.088}{(400*0.2921)*\left(\frac{0.1022625}{1-0.2921}\right)}\right] + \left[\frac{1{,}000*8.088*DC}{\left((400*0.2921)\left(\frac{0.1022625}{1-0.2921}\right)\right)^2}\right].$$

The final variable needed to determine how much camelina should be planted to maximize diesel offset is the DC variable. The DC variable is the diesel fuel needed to grow the camelina that can also be offset. As previously determined, 4.726 gallons/acre of diesel fuel are needed to grow camelina. However, 1.2 gallons of diesel fuel are used to maintain the fallow if camelina is not grown. Therefore, each acre of camelina uses 3.526 gallons/acre of diesel fuel in addition to the diesel fuel that would otherwise have been used to maintain the fallow. Using the 90:10 SVO to diesel fuel substitution ratio, an additional 3.173 gallons of SVO are needed to offset the maximum amount of diesel fuel used to grow camelina. Equation 3.3 is updated below to also include 3.173 gallons/acre of camelina as the DC variable:

(3.3.4) $$CamelinaAcres = \left[\frac{1{,}000*8.088}{(400*0.2921)*\left(\frac{0.1022625}{1-0.2921}\right)}\right] + \left[\frac{1{,}000*8.088*3.173}{\left((400*0.2921)\left(\frac{0.1022625}{1-0.2921}\right)\right)^2}\right].$$

Equation 3.3.4 is solved below:

$$CamelinaAcres = \left[\frac{1{,}000*8.088}{(400*0.2921)*\left(\frac{0.1022625}{1-0.2921}\right)}\right] + \left[\frac{1{,}000*8.088*3.173}{\left((400*0.2921)\left(\frac{0.1022625}{1-0.2921}\right)\right)^2}\right],$$

= $$CamelinaAcres = \left[\frac{8{,}088}{(400*0.2921)*\left(\frac{0.1022625}{1-0.2921}\right)}\right] + \left[\frac{25{,}663.22}{\left((400*0.2921)\left(\frac{0.1022625}{1-0.2921}\right)\right)^2}\right],$$

= $$CamelinaAcres = \left[\frac{8{,}088}{(116.84)*\left(\frac{0.1022625}{1-0.2921}\right)}\right] + \left[\frac{25{,}663.22}{\left((116.84)\left(\frac{0.1022625}{1-0.2921}\right)\right)^2}\right],$$

= $$CamelinaAcres = \left[\frac{8{,}088}{(116.84)*\left(\frac{0.1022625}{0.7079}\right)}\right] + \left[\frac{25{,}663.22}{\left((116.84)\left(\frac{0.1022625}{0.7079}\right)\right)^2}\right],$$

=` $$CamelinaAcres = \left[\frac{8{,}088}{(116.84)*(0.144459)}\right] + \left[\frac{25{,}663.22}{\left((116.84)(0.144459)\right)^2}\right],$$

= $$CamelinaAcres = \left[\frac{8{,}088}{16.8786}\right] + \left[\frac{25{,}663.22}{(16.8786)^2}\right],$$

= $$CamelinaAcres = \left[\frac{8{,}088}{16.8786}\right] + \left[\frac{25{,}663.22}{284.8866}\right],$$

= $$CamelinaAcres = [479.186] + [90.082],$$

= $$CamelinaAcres = 569.268.$$

Thus, Equation 3.3 yields an answer of 569.268. This is the acreage of camelina that must be grown to supply enough SVO to allow for the maximum diesel fuel offset. To convert this to a percentage, the solution to Equation 3.3 is divided by the FS variable. In Equation 3.3.4, the FS variable is 1,000. 569.268 divided by 1,000 yields a result of about 57%, the percentage of the fallow that must be converted to camelina. Using the variable averages specific to northeastern Colorado, a farmer should commit 57% of the fallow to camelina, regardless of the size of the farm, to generate enough SVO to allow for the maximum diesel offset.

To demonstrate that the size of the farm is irrelevant when determining the percentage of fallow to instead devote to camelina, Equation 3.3 is shown again, labeled 3.3.5, but the 1,000 acre farm size variable is instead replaced with a farm size of 500 acres:

(3.3.5) $$CamelinaAcres = \left[\frac{500*8.088}{(400*0.2921)*\left(\frac{0.1022625}{1-0.2921}\right)}\right] + \left[\frac{500*8.088*3.173}{\left((400*0.2921)\left(\frac{0.1022625}{1-0.2921}\right)\right)^2}\right],$$

and solving through,

$$= \quad CamelinaAcres = \left[\frac{4,0444}{16.8786}\right] + \left[\frac{12,831.61}{284.8866}\right],$$

$$= \quad CamelinaAcres = [239.59] + 45.04,$$

$$= \quad CamelinaAcres = 284.63.$$

As this farm is 500 acres, dividing 284.63 acres of camelina by the 500 acre sized farm yields the same result of about 57% of the fallow that must be devoted to camelina to produce sufficient SVO.

3.6.5. Additional Diesel Fuel Purchases

The additional diesel fuel purchases variable captures the initial diesel fuel used to grow camelina before any SVO is available, as well as diesel fuel that must be purchased to maintain the 90:10 SVO diesel ratio in subsequent camelina rotations. Diesel fuel used to maintain the 90:10 SVO diesel ratio in the corn and wheat rotations is not considered in this variable, as corn and wheat are not considered revenue in the simulated crop rotation budget. A farmer must purchase some diesel fuel regardless of whether camelina is grown. The SVO to diesel ratio would either be allocated as part of the 90:10 ratio if camelina is grown, or allocated as part of the total diesel fuel purchases if camelina is not grown.

It was previously determined that an acre of camelina uses an additional 3.526 gallons of diesel fuel (see page 55 for reference regarding how this value was derived). This value is multiplied by the acres of camelina planted and the price of diesel fuel. Equation 3.4 demonstrates the cost of additional diesel fuel purchases to the farmer:

(3.4) $$AdditionalDiesel = 3.5256 * FS * Camelina\% * PD,$$

where AdditionalDiesel is the price the farmer must pay to procure enough diesel fuel to grow camelina instead of maintaining a fallow, FS is the farm size in acres, Camelina% is the percentage of fallow instead growing camelina, and PD is the per gallon price of diesel fuel.

The crop rotation model does not assume that the farmer will pay for the entire additional diesel purchases upfront, however. The model is designed to allow the farmer to pay off the additional diesel fuel needed to grow camelina over a 10 year period, with interest. The 10 year amortization period is chosen as the time horizon in this study as camelina appears to be an economically viable option for the next decade, after which a new economic evaluation should be considered. Thus, the model does not assume a farmer would continue to make payments on past camelina purchases should camelina no longer become a suitable option for the farm. In addition, the farmer is charged a 4% interest rate on the fuel purchases.[22]

Equation 3.5 demonstrates the annual cost paid by the farmer due to the need to purchase additional diesel fuel:

(3.5) $$AnnualPayment = AdditionalDiesel * \left(\frac{r(1+r)^n}{((1+r)^n)-1}\right),$$

where AdditionalDiesel is the result from Equation 3.4, r is the interest rate, assumed to be 4% in this thesis, and n is the number of years to repay the interest, assumed to be 10 in this thesis. As the crop rotation model assumes camelina is grown every three years (see page 48),

[22] The 4% interest rate is fixed for ease of calculation, based on past operating interest rates published by the USDA Farm Service Agency. Although current interest rates are considerably lower than 4%, historically they have been at or around 4%. The interest rate has only a small effect on the overall results of the model and in this case causes the model to become slightly less optimistic regarding camelina integration. See http://www.fsa.usda.gov/FSA/webapp?area=home&subject=fmlp&topic=dfl-ir for current interest rates.

the AnnualPayment value is multiplied by three before it is added as a cost in the crop rotation model.

In addition to the amortized and discounted diesel fuel costs used in the initial planting of camelina, more diesel fuel is also needed to maintain the 90:10 SVO to diesel ratio for future camelina plantings. This is shown in Equation 3.6:

(3.6) $$3.526 * 0.1 * \mathrm{FS} * \mathrm{Camelina\%} * \mathrm{PD},$$

where 3.526 is the additional gallons of diesel fuel needed to grow an acre of camelina instead of maintaining an acre of fallow, FS is the farm size, Camelina% is the percentage of fallow that is instead devoted to camelina (the result of Equation 3.3), and PD is the per gallon price of diesel fuel. The result of Equation 3.6 is also to the crop rotation model when determining the cost of the additional diesel fuel purchases needed.

3.6.6. Additional Labor Cost

Additional labor costs account for the additional labor time used to grow camelina beyond the normal labor allocation needed to maintain a fallow. The Mississippi State Budget Generator estimates that an additional 0.9 hours/acre of labor are needed to grow camelina after accounting for the labor time used to maintain a fallow. The labor rate is estimated to be $10.22, the average farm labor rate in Colorado.[23] The additional cost of labor is shown in Equation 3.7:

(3.7) $$\$10.22 * 0.9 * \mathrm{FS} * \mathrm{Camelina\%},$$

where $10.22 is the hourly labor rate, 0.9 is the additional time, per acre, needed to grow camelina after accounting for time spent maintaining a fallow, FS is the per acre farm size, and Camelina% is the percentage of the fallow that is dedicated to growing camelina.

[23] Personal communication with Mr. Rod Sharp, Colorado State University Agriculture and Business Management Extension Economist. Interview via email correspondence with author, August 9, 2011.

3.6.7. Interest on a Six-Month Operating Loan

The six-month operating loan to grow camelina is the summation of variables used in the planting stage before income is earned from camelina. Like additional labor costs, this loan applies specifically to the extra acreage of camelina and overlooks any operating costs to grow wheat and corn, as those are not additional costs incurred as the simulation assumes wheat and corn are grown regardless of whether a farmer chooses to add camelina to the crop rotation. The loan is given a continuous uniform distribution and bounded between 5% and 10%. A uniform distribution is employed as there is no ability to set a mean and standard deviation based on observations. The loan repayment period is set to six months to allow for sufficient time from planting to harvesting. The formula for the six-month loan is:

$$LoanPayment = \frac{\frac{P*\left(\frac{r}{12}\right)}{1-\left(1+\left(\frac{r}{12}\right)\right)^{-6}}}{2}, \tag{3.8}$$

where P is the principal amount and r is the interest rate determined by the simulation software. The interest rate is divided by 12 to convert to months, and the entire equation is divided in half as the loan is repaid in half a year. The exponent on the denominator represents the number of months needed to repay the loan, in this case six. The result for LoanPayment is added to the simulated crop rotation budget as an additional incurred cost.

3.6.8. Hauling Cost

Hauling, crushing, and storage costs are all post-harvest variables that also need to be considered in the simulated crop rotation budget. The cost of hauling the seed from the farm to the crushing facility was determined using the same rate given to hauling wheat in the CSU

Extension enterprise budgets.[24] In the CSU Extension enterprise budgets, the cost for hauling a bushel of wheat is estimated to be $0.20/bushel. As there are 56 pounds in a bushel, this equates to hauling costs of $0.00357/lb. Given 2,000 pounds in a ton, the per ton hauling cost is $7.14. This $7.14/ton hauling cost amount is used for camelina in the simulated crop rotation budget. In the simulated model, the stochastic yield per ton is multiplied by $7.14 to determine the hauling costs.

3.6.9. Crushing, Cleaning, and Filtering Cost

The model used for crushing the camelina seed is based off of the model currently used by a crushing facility in Rocky Ford, Colorado. Personal communications with crushing facility management in Rocky Ford as well as CSU Extension agents helped establish a price for the crushing services.[25] [26] The Rocky Ford crushing facility is in a community cooperative that allows farmers to bring seed to the facility to be crushed at a rate of $60/ton. There is also an additional cost for cleaning the seed and filtering the oil.

The relatively low-cost model used by the crushing facility in Rocky Ford may not be replicated elsewhere as this crushing facility is not-for-profit and used as an experimental cooperative. Crushing, cleaning, and filtering costs would likely be significantly higher, especially if the crushing facility is for-profit. This results in a large range of the crushing, cleaning, and filtering costs. These costs are assigned a uniform distribution between $75 and $150 in the simulated crop rotation budget model.

[24] See "Crop Enterprise Budgets" in Appendix B.

[25] Personal communication with Mr. Hal Holder, Rocky Ford, CO. In-person interview with author, July 14, 2011.

[26] Personal communication with Mr. John Deering, Colorado State University Extension. Interview by phone with author, October 7, 2011.

3.6.10. Onsite SVO Storage Cost

The cost of storing SVO on-farm was determined to be about $5,000 after speaking with local farmers in the Rocky Ford area.[27] This cost includes a 9,000 gallon used storage tank, as well as some of the mixing and pumping equipment necessary to utilize the SVO. The $5,000 principal investment is amortized over 10 years and assigned the 4% interest rate, as previously demonstrated in Equation 3.5.

3.6.11. Savings from Offset Diesel Fuel

The maximum potential diesel offset was determined in section 3.6.4.3 to be 8.088 gallons per acre. The savings from offset diesel fuel are demonstrated in Equation 3.9:

(3.9) $$OffsetDieselSavings = \mathrm{MDO} * \mathrm{FS} * \mathrm{PD},$$

where MDO is the maximum diesel offset variable used in Equation 3.3, valued at 8.088 gallons per acre; FS is the farm size, in acres; and PD is the per gallon price of diesel fuel. The savings from offset diesel are considered a subtracted cost, which is the equivalent to revenue in the accounting process used in the simulated crop rotation model.

3.6.12. Sale of the Residual Camelina Seed as Meal

Selling the meal from the residual camelina seed after crushing is expected to earn more revenue for the farmer than the cost savings of offset diesel purchases, making meal sales an important value-added byproduct. The residual meal available for sale is the inverse

[27] Personal Communication with Mr. Joel Lundquist, Lundquist Farms, In-person interview with author, July 14, 2011.

of the seed oil content percentage multiplied by the yield determined in the simulated crop rotation budget, shown in Equation 3.10:

(3.10) $$Meal = (1/\mathrm{OC}) * \mathrm{CY},$$

where Meal is the available meal in lbs./acre, OC is the oil content percentage, and CY is the crop yield. Following the Rocky Ford crushing cooperative approach, this study assumes the meal is sold directly to nearby dairies at the market rate. As previously discussed, there is no direct camelina meal market, but soybean meal prices offer a good benchmark for the price of camelina meal and can therefore be used as a proxy. The last five years of soybean meal prices are gathered and assigned a triangular distribution.[28] The distribution has a minimum-price of $0.088/lb., a mean-price of $0.19/lb., and a maximum-price of $0.226/lb. These correspond to the lowest soybean meal price in the past five years, the average of all monthly soybean meal prices over the past five years, and the maximum soybean meal price over the past five years. Figure 3.15 is a graphical representation of the per pound soybean meal cost PDF used by the simulated crop rotation budget.

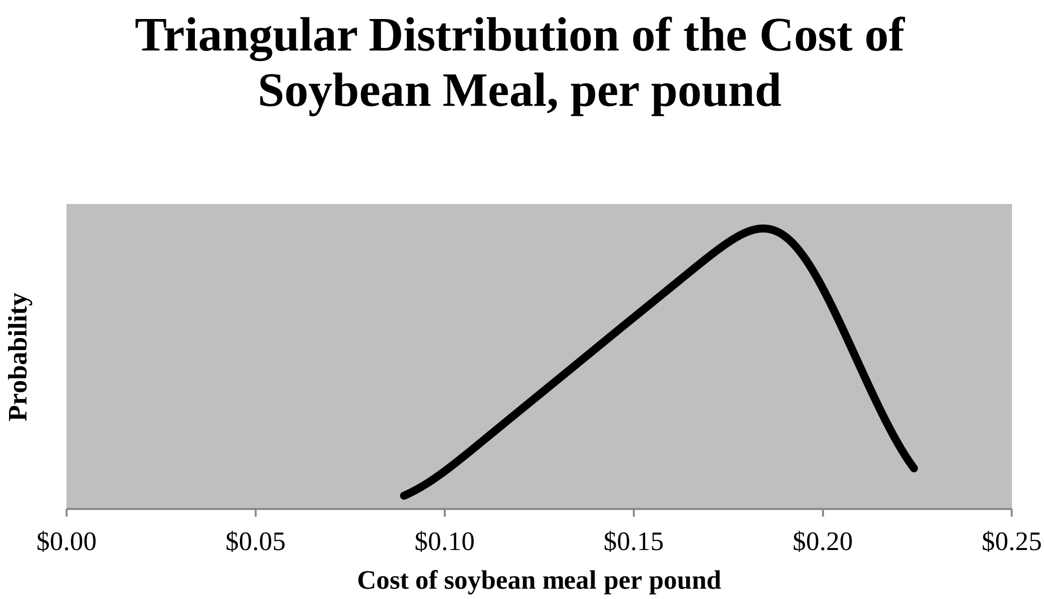


Figure 3.15. Graphical representation of the per pound cost of soybean meal triangular distribution.

[28] Index Mundi. "Soybean Meal and Prices."Accessed 19 August 2011. http://www.indexmundi.com/commodities/?commodity=soybean.

The expected value of the price of soybean meal is $0.168/lb. As soybean meal is a proxy for camelina meal, the simulated crop rotation budget uses the distribution demonstrated in Figure 3.15 to determine the price of camelina meal.

3.6.13. The Loss of Revenue from Reduced Wheat Yields

The final variable that is considered in the simulated crop rotation budget is the reduction in revenue of the subsequent wheat harvest following the camelina portion of the crop rotation. This significant reduction in revenue is caused by the nearly 57% of farmland that is dedicated to camelina in lieu of a fallow. This fallow generally allows for the accumulation of water in the soil, which is especially important on non-irrigated farmlands. The lack of water accumulation can lead to lower wheat yields per acre, and therefore reduced revenue.

The goal of this variable is to accurately represent the expected reduction in revenue so that this reduction can be added to the simulated crop rotation budget as an additional expense. It represents the opportunity cost of growing camelina instead of keeping the land in fallow. This variable is designed to not be sensitive to the region where camelina is grown, as the month with the most average rainfall varies considerably in the western United States. This implies that some areas will see a greater disturbance in the subsequent wheat crop than others with regards to the skipped fallow. Farmlands of northeastern Colorado will likely demonstrate a relatively small disturbance in the following wheat crop, as much of the annual rainfall occurs in the months following the harvesting of camelina and preceding the planting of wheat. It is, however, important to anticipate some losses to accurately generate a simulated model for camelina.

As expressed throughout this section, the variable representing the loss of wheat revenue is designed to compensate for any other costs that have been overlooked in the simulated crop rotation budget model. The loss from wheat revenue variable is designed to add a cost to the model greater than the actual expected amount in order to create a conservative model. It also allows the model to be applied to all regions of the western United States and not specifically northeastern Colorado.

In order to determine the opportunity cost of growing camelina on a portion of farmland instead of allowing the land to rest in fallow, an alternative method of forecasting wheat prices is presented. It is designed to evaluate the economic loss to farmers of the wheat harvest following a limited fallow. The model developed and presented in the following sections is designed to generate a higher than expected price per bushel for wheat than is currently forecasted by many of the leading wheat price forecasting models, so that the opportunity cost of growing wheat is slightly exaggerated.

It is necessary to create a model to predict the price of wheat that leads to a higher wheat price than the consensus of other models so that the farmers can update the necessary input variables annually and regenerate a new crop rotation budget. A static prediction of the price of wheat would quickly render the simulated crop rotation budget obsolete, as would a prediction of the price of wheat that proves to be below the actual market price. It is imperative for farmers to have a reasonably accurate forecasted value of wheat per bushel before the planting of an oilseed crop in order to better understand the true risks of the loss of income from a reduced wheat harvest. However, the price should err on the high side as this would help hedge against other costs that have been overlooked or underestimated. In the context of this study, using the average yield and median seed oil content percentage, 57% of the farmland would be subjected to the opportunity cost of growing camelina. The other 43%

is still allowed to remain in fallow. As shown in this section, these losses are substantial relative to other expenses in the simulated crop rotation budget.

While many models currently exist to find the forecasted price of wheat, most are overly simplified for the needs of this study as they fail to evaluate both exchange rates and the significance of the rising price of crude oil on input costs in wheat production, which motivate the need for energy security. Thus, when considering camelina as a crop for the purposes of energy security, other variables should be considered in the forecasted price of wheat. This section will present new approaches to model non-conventional independent variables in the wheat price regression to reflect energy security. The models presented in this section offer an alternative approach to forecasting the price of wheat, which will serve to aid farmers in the decision process as to whether to grow an oilseed feedstock or allow the land to rest before a wheat rotation.

3.6.13.1. Past Wheat Modeling

The modeling of wheat prices has long been a difficult task for many agricultural economists. Working (1927) contains a quote suggesting that many grain elevator owners have tried to forecast wheat prices and failed. "Yes, a good many elevator owners have tried it, but most of them have lost their elevators" (Working, 1927, p 274). Working (1927) explains that until the early 1920s, wheat forecasts were principally made with a measurement of the quantitative relationships between supply and price. However, this often yielded inconclusive results due to low correlations.

Bessler et al. (2010) review the previous contributions of the past 100 years in the field of agricultural economics. In the forecasting section, much credit is given to Holbrook Working, who is said to be the first to tackle the issue of wheat forecasting. Bessler et al.

(2010) also cite Just and Rausser, and specifically their 1981 paper, as early pioneers of commodity forecasting.

Just and Rausser (1981) contribute some of the first comprehensive work towards econometric modeling of wheat prices. The paper explores the notion that an accurate forecast must be made out of expectations of exogenous influences, including yields and consumption. It also states that this information must be passed on to the general market in order to affect futures prices. There are other influences that must be considered, such as random noise, and errors in the forecasts of exogenous variables. Other errors also exist and are numerous. These include uninformed market participants, numerous omitted variables that can cause bias, inappropriate functional forms, simple measurement errors, and other problems with aggregation. The paper uses futures markets as a basis for comparison and concludes that often the futures markets offer a better forecast than econometric models. The conclusion of the authors also suggests that econometric forecasting is often valid for long-term models, but futures markets are often the better option for short-term price predictions.

Kellard et al. (1999) find evidence that suggests that futures and spot prices are co-integrated with a long-run slope coefficient of unity; that is, the long-run equilibrium condition holds. However, in the short-run there is evidence of inefficiencies in most of the markets studied. This also suggests that futures prices are more indicative of wheat markets in the short-run than spot prices.

Allen (1994) evaluates econometric and univariate models compared with naïve models and concluded that naïve models are the best option. Naïve models predict the value of the next year in the forecast based on the value of the observation in the previous year plus a random error term. One of the reasons given as to why naïve models perform better is due to the characteristics of agricultural production. Since farmers have minimal ability to alter the rate or amount of growth of wheat, it is difficult to increase or reduce supply to meet demand. Allen (1994) finds that the best estimator of harvest amount is the acreage planted, which has a lagged period until it can reach the market. This lag leaves wheat susceptible to random shocks, such as drought or pests, making an accurate price prediction difficult. In terms of questioning the validity of work being done, Allen (1994) explains that two questions must be asked. These questions are how well does the model perform out-of-sample and how well does the model perform compared to the one it replaces.

Armstrong (1985) writes that forecasting is concerned with what the future will look like, as opposed to what it should look like. His work advocates looking at objectives, developing indicators of success, generating alternative strategies, and finally selecting a program to implement. In the context of wheat forecasting, Armstrong writes that multiple methods may be the best approach, including exponential smoothing, bootstrapping, and segmentation.

Tomek (1997) notes that structural breaks such as the oil price increases in the 1970s can influence the results of stationarity tests as well as the presence of time-varying risk premiums. Prior to the presence of structural breaks, the main influences on agricultural prices were simply supply and demand and not government programs as is the case today. This research also implies that past wheat prices are not reliable due to the significant structural breaks, severely limiting the usable data set.

Schnepf (2008) evaluates the effects of exportation on international commodity markets. Along with Trostle (2008) and von Braun (2008), the research presents a case for including international trade and preferences as one of the factors in determining the forecasted price of wheat. One of the significant conclusions developed in Schnepf (2008) is the notion that prices will be permanently elevated, due in large part to the newfound global demand for meat products, as the meat production industry uses considerable quantities of grain for animal feed.

Chen, Rogoff, and Rossi (2010) evaluate whether exchange rates could be used to help predict wheat prices. The paper concludes that exchange rates provide an accurate forecast for future commodity prices as they are forward thinking and embody future movements in the commodity markets that cannot be captured by a simple time series model. The study uses quarterly data from five countries, including Australia, Canada, Chile, New Zealand, and South Africa, in order to create country specific export earnings and weighted commodity price indices. Chen, Rogoff, and Rossi (2010) determine that when market participants recognize future commodity price shocks, this expectation will be priced into the current exchange rate through its anticipated impact on future export income and exchange values.

Collins (2008) finds that higher crude oil prices managed to increase farm production costs as well as food processing and distribution costs. This has been viewed as one of the factors leading to the higher commodity prices seen in the past few years. To accommodate this finding, the wheat model presented in this section takes into account crude oil prices.

3.6.13.2. Building the Wheat Forecasting Model

As a point of clarification, it should be noted that any discussion of U.S. wheat in this paper applies to the aggregate average of all varieties of wheat grown in the United States. It is important to include as many relevant variables as possible into the forecasted price of wheat model. However, some of the basic variables that are expected to be significant in determining the price of wheat (including acres of production, past year yields, and export quantities) prove to have little importance in the final models. This is in direct conflict with many of the suggestions made in the literature.

The literature suggests that quarterly forecasts are more appropriate, but they do not apply in this case as annual forecasts are needed to determine the amount lost to farmers through the lack of fallow. Farmers need to decide nearly a year in advance whether or not to have a fallow, which renders quarterly forecasts moot.

Most of the data used for the forecast is gathered from the ERS.[29] The ERS maintains data sets that have wheat outputs and past price information, as well as export information. The ERS also supplies considerable data on the other commodities used in the regression, which includes the price of corn and soybeans. The Energy Information Administration provides the data sets used for crude oil prices, including past and current prices, as well as the United States ethanol production numbers. [30] All exchange rate information is gathered from Oanda.com, a website that specializes in foreign exchange services.[31] It maintains a database with all past and present exchange rates, averaged annually, from 1991.

Running straight Ordinary Least Squares (OLS) regressions delivered varied results, as many variables, such as the ones previously mentioned, are insignificant when calculating the price of wheat per bushel. One of the largest difficulties with the model is the unreliability of data. Due to the significant correlation between crude oil and commodity prices (see Schnepf, 2008) it is difficult to reliably use many years of data. Another factor in the limited data set is the desire to use the exchange rate between the U.S. dollar (USD) and the Euro, which only dates back to the Euro's origin in 1998. All modeling includes a panel data set with no gaps from 1996, with the exception of the exchange rate from the USD to Euro,

[29] US Department of Agriculture Economic Research Service. 2011. Farm Income and Costs: 2011 Farm Sector Income Forecast. Accessed 08 October 2011.
http://www.ers.usda.gov/Briefing/FarmIncome/.

[30] U.S. Energy Information Agency, Independent Statistics and Analysis. Accessed 09 December 2011.
htttp://www.eia.gov/petroleum/gasdiesel/.

[31] "Oanda Historical Exchange Rates." Last modified April 15, 2011, Accessed 25 June 2011.
http://oanda.com/currency/historical-rates.

which dates to 1998. Any lagged variable included in the models developed in this section have no data inputs from 1996.

The models tested regress the real wheat price (all prices have been adjusted using a consumer price index deflator to 2010 values) against a combination of variables, including: the amount of wheat planted in the previous year of planting, per acre; the real corn price (again deflated to 2010 dollars), per bushel; the exchange rate between the Euro and the USD; the exchange rate between the Great British Pound (GBP) and the USD; the exchange rate between the Japanese Yen and the USD; the real price of crude oil in annual averages with the exception of 2011, for which the average crude price as of April 15th, 2011 was used; a linear trend variable which was updated to exclude 2008, a potential outlier in wheat price (more discussion of this will follow); a quadratic trend variable which also excludes 2008 (with more discussion to follow); the real price of soybeans, per bushel (deflated to 2010 dollars); the real prices of nitrogen fertilizer as well as of diammonium phosphates fertilizer (DAP), per ton (deflated to 2010 dollars); the amount of U.S. ethanol production, per billion gallons; and a lagged wheat export variable. It should be noted that no government interaction variables, such as subsidies and tariffs, were included. It was determined that it would simply be too difficult to try to capture inconsistent changes in government policy, especially towards subsidies and biofuels, into the regression. The models are run through diagnostic tests outlined in the following section to determine the best model to forecast wheat prices.

The results of six models are presented in Appendix A. All six models are OLS regressions. The first four models are standard linear regressions, with the predicted 2012 price deduced from a one period out-of-sample forecast. None of the linear models showed signs of autocorrelation. All of the models were run in STATA®, Version 10, with robust regressions to correct for the low possibility of heteroskedastic error terms. All of the coefficients can be interpreted as unit changes, meaning a one unit change in one of the regressors will result in an increase or decrease in the real price of wheat, measured in 2010 dollars. For example, in model 1, the coefficient of the regressor "corn price" is 2.17. This suggests that if the price of corn per bushel increased by one cent, the price of wheat would increase by 2.17 cents, *ceteris paribus*. Models 5 and 6 are log-log models, suggesting that all of the coefficients should be interpreted as percent changes. For example, in model 5, the coefficient of the regressor "corn price" is 0.84. This suggests that if the price of corn increases by one percent, the price of wheat would increase by 0.84 percent, *ceteris paribus*.

3.6.15.3. Forecasting Model Selection

Appendix A features the outputs of the six models tested as well as key model selection factors. Three key goodness-of-fit factors were considered when selecting a model: the Akaike's Information Criterion (AIC); the R-squared value; and the Root Mean Square Error (RMSE). Gujarati and Porter (2009) suggest that the AIC is a good diagnostic tool as it penalizes a model for adding more regressors. This penalty is not present in the R-squared values, which are simply determined by dividing the explained sum of squares by the total sum of squares. Gujarati and Porter (2009) explain that maximizing the R-squared value only measures in-sample goodness-of-fit, and has no guarantee of the accuracy of the forecast for out-of-sample predictions. The R-squared value also cannot fall when more regressors are added, which leads to what Gujarati and Porter (2009) call "the game of maximizing the R-squared." Minimizing the AIC, however, is a better evaluator because it is also useful for out-of-sample regressions. The RMSE is the final criterion used to judge the models. The RMSE test gives information on the short-term performance of the correlations by allowing a term-by-term comparison of the actual deviation between the estimated and measured values. This implies that the lower the RMSE, the more accurate the estimate (Evans and Nalampang, 2009). However, the RMSE is limited because it does not distinguish between under and over predictions (Tomek and Robinson 2003).

Based on the three criteria listed above, model 5 appears to be the best model for forecasting the price of wheat. It has the lowest AIC at -39.05 and the lowest RMSE at 0.0523. The model also has a high R-squared at 0.96, but this value is less important, as previously discussed. It should be stressed that model 5 is a log-log model, suggesting that measuring percentages is more appropriate for forecasting the price of wheat than measuring unit changes.

Model 5 also finds every regressor to be statistically significant at the 99% level with the exception of the constant term, which bears limited importance in a log-log model. All of the coefficients of the regressors are of the anticipated sign with the exception of the Japanese Yen to USD exchange rate variable.

Model 6 is evaluated by substituting the GBP to USD exchange rate for the Japanese Yen to USD. This model does not find every regressor significant, as both fertilizer and the exchange rates have high P-values. This is the only model, however, that finds the anticipated sign in front of every coefficient.

Model 2 has the lowest AIC of the non-log-log models at -24.68. It also has the highest R-squared value of any model with a goodness of fit measurement of 0.9989. However, many of the coefficients of the independent variables do not follow *a-priori* expectations. Nonetheless, all results will be reported for models 2 and 5, in the event that a comparison between a log-log model and a non-log-log model is deemed desirable.

3.6.13.4. Forecasted Price of Wheat

The forecasted per bushel price of wheat is multiplied by the expected reduction, in bushels per acre, of wheat production on lands without a fallow preceding the wheat planting compared with lands that remained in fallow. This is then multiplied by the number of acres that were not allowed to lie in fallow and the resulting amount is the expected opportunity cost of growing camelina instead of allowing land to lie in fallow. The out-of-sample 2012 forecasted price of wheat is listed in Appendix A for all models. For the non-log-log models, the forecasted prices range from \$8.16/bushel to \$8.91/bushel, a significant increase over the 2011 price of \$5.12/bushel. It should be noted that the all-time high recorded price for wheat is \$8.12/bushel in 2010 dollars, suggesting that the forecasted prices are likely not accurate.

The forecasted price for model 5, the best model in terms of the criteria described in the model selection discussion, has a much more reasonable out-of-sample prediction. The model anticipates an increase of 29.97% of the 2011 price in 2012, as it is a log-log model. This increase equates to a forecasted price of \$6.65/bushel. As a point of comparison, the other log-log model anticipates a 31.96% increase in the 2011 price, with a forecasted value of \$6.76/bushel. These estimates can be viewed as a more accurate prediction based on the high crude oil prices and higher prices seen in all the commodity futures markets. All models can easily be updated to include 2012 end-of-year values, and futures prices can be used to estimate a 2012 wheat price once that information is available.

3.6.13.5. Inclusion of the Forecasted Price

Data from three planting sites in eastern Colorado were supplied to measure the reduction of wheat yields without a fallow compared to wheat yields following a fallow.[32] The data evaluates harvests from Stratton, Sterling, and Walsh, Colorado. All the plantings were from dryland no-till farmlands. The planting rotation included wheat, corn, and fallow or wheat, corn, and soybean. Averaging the seven years of data and omitting outliers caused by drought, it can be estimated that wheat harvests that fail to follow a fallow are 81.5% as productive as the with-fallow counterpart. This is demonstrated on Figure 3.16.

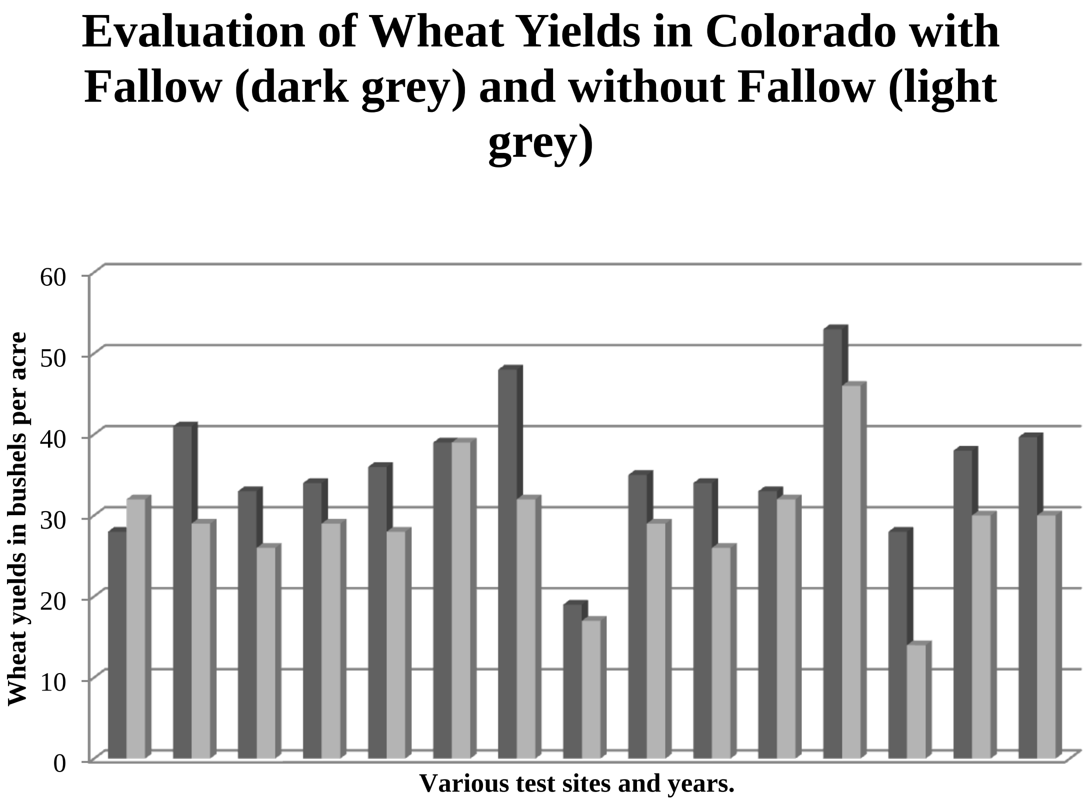


Figure 3.16. Wheat yields in Colorado with and without a fallow, as provided by Dr. Neil Hansen, Associate Professor, Department of Soil and Crop Science, Colorado State University.

As can be seen in Figure 3.16, the non-fallow yields are consistently less than yields following a fallow. This estimate is in line with anecdotal data found by the USDA as well,

[32] Personal communication with Dr. Neil Hansen, Associate Professor, Department of Soil and Crop Sciences, Colorado State University. In-person interview with author. April 25, 2011.

and will be used henceforth as the predictive measurement of wheat reduction. Using the total average yield information from the same study, it can be concluded that the total average yield per acre for dryland wheat is about 35 bushels/acre. This results in an expected loss of about 7 bushels/acre.

Personal communications with researchers from the USDA in Montana have estimated larger reductions in wheat harvests following camelina as opposed to a fallow. In an unpublished study, this discrepancy averaged 31%.[33] The caveat of the study from Montana is the lack of data, as it only covers three years of harvests. A simple average is used to predict the total wheat reduction, using the study from Montana as well as the results from CSU.

In the simulated crop rotation budget, the expected wheat losses are assigned a triangular distribution, with a minimum of 0% reduction in the subsequent wheat yield, a maximum reduction of 24.75%, and a mode reduction of 12.38% (the average of the 0% and 24.75% reductions). The triangular distribution allows the model to compensate for varying weather patterns in different locations. In the simulated crop rotation budget, the price of wheat is fixed at $6.65/bushel as that value is the price forecasted by model 5 shown in Appendix A. Model 5, however, can be readily updated as the input values change.

[33] Personal communication with Mr. A.W. Lenssen, USDA, ARS, Sidney, MT. Email correspondence with author, May 25, 2011.

CHAPTER 4. RESULTS

4.1. Results from the Simulated Crop Rotation Budget

The simulated crop rotation budget is subjected to 50,000 iterations using various diesel fuel price levels. Table 4.1 demonstrates the overall likelihood of profitability given the various diesel fuel price levels. Once the price of diesel fuel surpasses \$4.30/gallon, the likelihood of profitability is greater than 50%. This suggests that given all other risk factors built into the simulated crop rotation model, once the price of diesel fuel is greater than \$4.30/gallon, a farmer has a greater chance of profits than losses when integrating camelina.

Following Table 4.1 is Figure 4.1, which is the CDF of the likelihood of profitability at the \$4.30/gallon diesel fuel price level. This is the breakeven per gallon diesel fuel price level determined by Table 4.1. Notice that the CDF crosses the \$0 profit axis, or breakeven point, almost exactly at 50%.

Table 4.1
OVERALL LIKELIHOOD OF PROFITABILITY

Diesel fuel price level (per gallon)	Percent likelihood of profitability
$2.00	24.4%
$2.10	25.6%
$2.20	26.9%
$2.30	27.6%
$2.40	29.0%
$2.50	30.2%
$2.60	30.9%
$2.70	32.4%
$2.80	33.8%
$2.90	35.5%
$3.00	36.4%
$3.10	37.6%
$3.20	38.9%
$3.30	40.0%
$3.40	40.3%
$3.50	41.7%
$3.60	42.6%
$3.70	44.0%
$3.80	45.4%
$3.90	46.4%
$4.00	47.3%
$4.10	48.1%
$4.20	49.8%
$4.30	**51.0%**
$4.50	52.6%
$5.00	57.1%
$6.00	62.9%
$7.00	65.8%
$8.00	68.4%
$10.00	72.0%

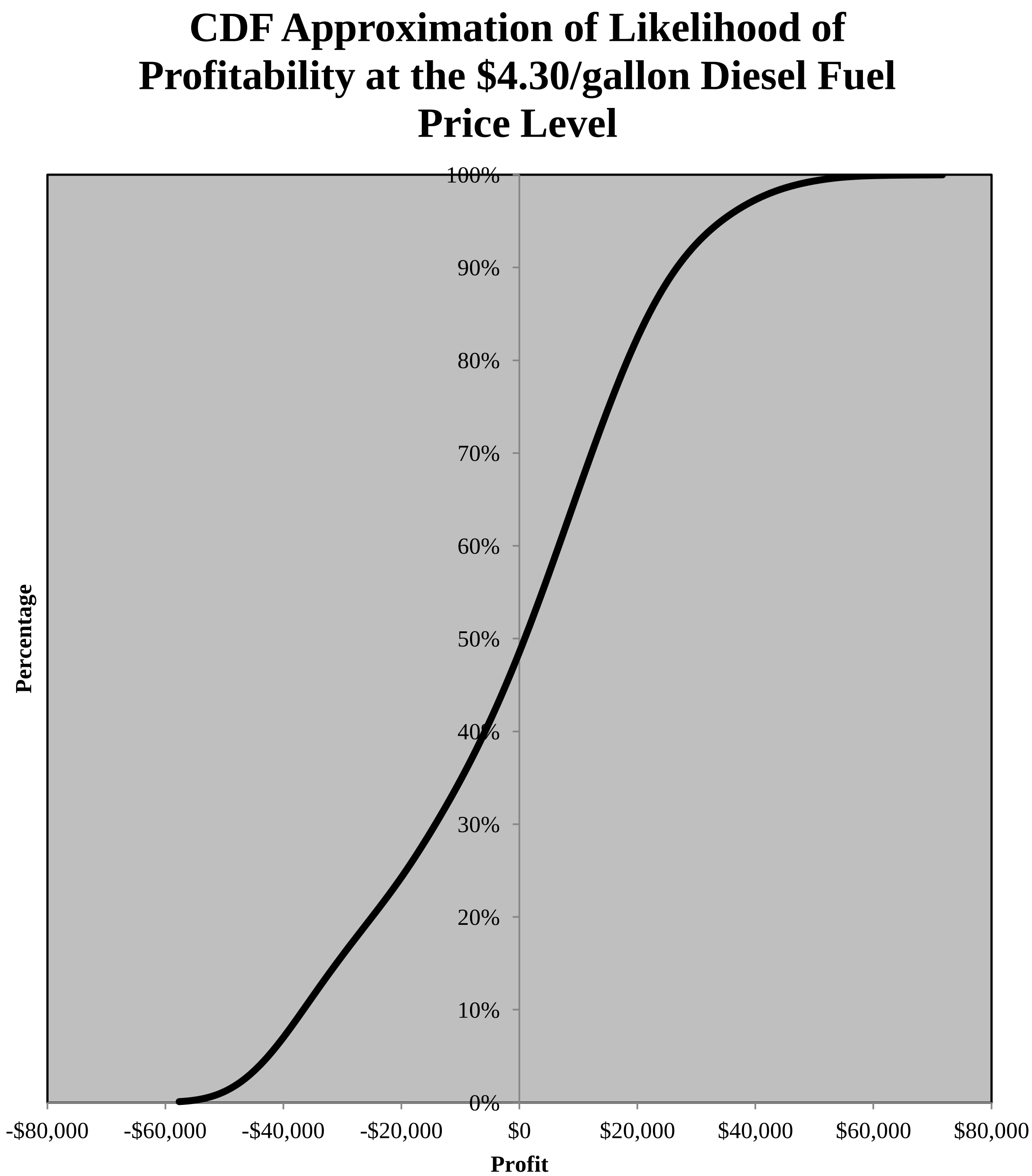


Figure 4.1. CDF of the likelihood of profitability at the $4.30/gallon diesel fuel price level.

Table 4.2 lists the expected costs, expected revenues, and expected profits based on various diesel fuel price levels. Note that Table 4.2 assumes a 1,000 acre farm devoting 57% of the fallow to camelina.

Table 4.2
OVERALL EXPECTED PROFIT (1,000 ACRE FARM, 57% CAMELINA)
Listed in Expected Values

Diesel price (per gallon)	Expected Cost	Expected Revenue	Expected Profit
$2.00	$50,704	$43,293	$(7,411)
$2.10	$50,840	$44,102	$(6,738)
$2.20	$50,976	$44,911	$(6,065)
$2.30	$51,111	$45,720	$(5,392)
$2.40	$51,247	$46,528	$(4,719)
$2.50	$51,384	$47,337	$(4,046)
$2.60	$51,519	$48,146	$(3,373)
$2.70	$51,654	$48,955	$(2,700)
$2.80	$51,790	$49,763	$(2,026)
$2.90	$51,926	$50,573	$(1,353)
$3.00	$52,062	$51,381	$(680)
$3.10	**$52,197**	**$52,190**	**$(7)**
$3.20	$52,333	$52,999	$665
$3.30	$52,469	$53,808	$1,339
$3.40	$52,605	$54,617	$2,012
$3.50	$52,741	$55,426	$2,685
$3.60	$52,876	$56,234	$3,358
$3.70	$53,012	$57,043	$4,031
$3.80	$53,148	$57,852	$4,704
$3.90	$53,283	$58,661	$5,377
$4.00	$53,419	$59,470	$6,051
$4.10	$53,555	$60,279	$6,724
$4.20	$53,691	$61,088	$7,397
$4.30	$53,827	$61,896	$8,070
$4.50	$54,098	$63,514	$9,416
$5.00	$54,777	$67,588	$12,781
$6.00	$56,134	$75,647	$19,512
$7.00	$57,492	$83,735	$26,243
$8.00	$58,850	$91,824	$32,974
$10.00	$61,565	$108,000	$46,436

As shown in Table 4.2, the list of the expected values of overall farm profits, the break-even diesel fuel price level is $3.10/gallon. However, use of expected values does not allow for an accurate simulation as many of the risk factors are mitigated. Figure 4.2 demonstrates the CDF of the likelihood of profitability when the price of diesel fuel is $3.10/gallon.

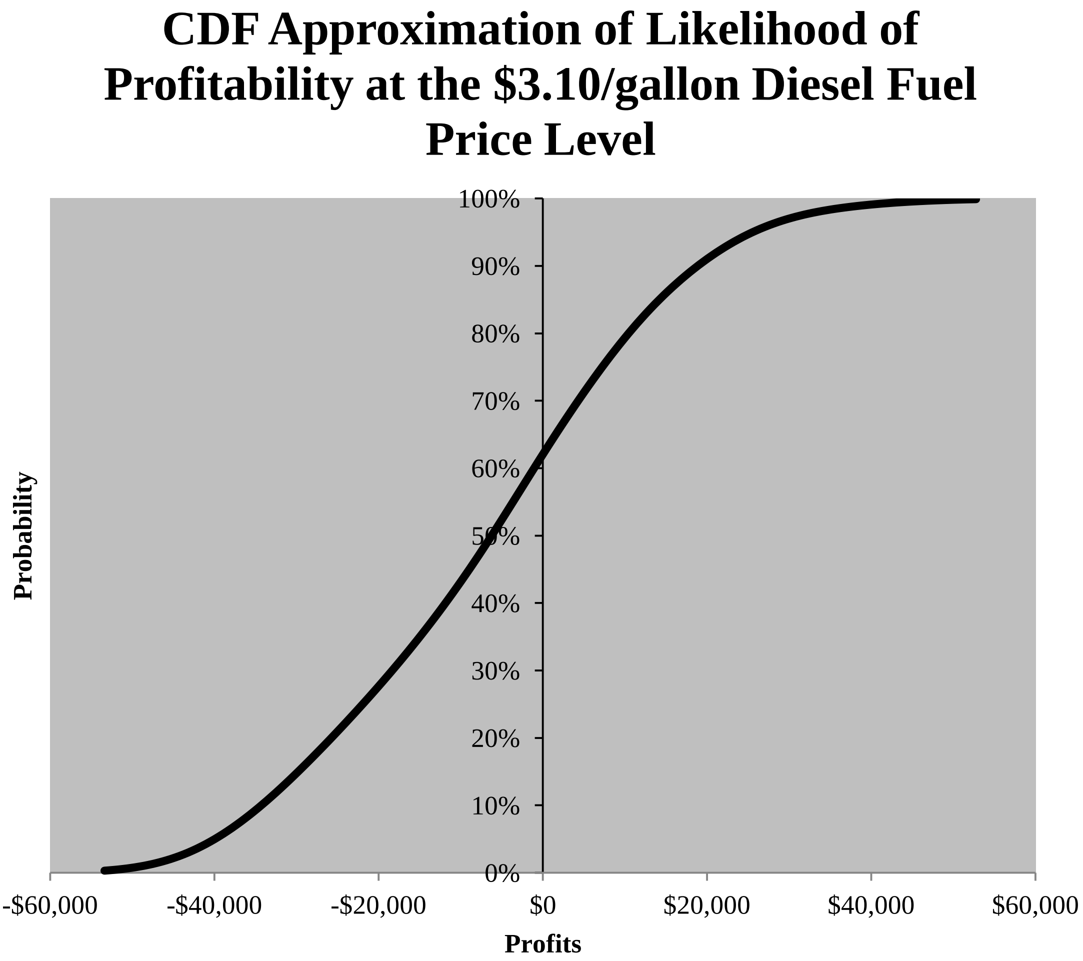


Figure 4.2. CDF of the likelihood of profitability at the $3.10/gallon diesel fuel price level.

Note that despite having an expected value of just below $0 profit, the CDF does not cross the $0 profit axis until well above the 50% mark of the probability axis. As probability is the inverse of where the CDF crosses the vertical axis, this suggests that there is a far less than 50% probability of breaking-even.

4.2. Evaluating the Risk Associated with the Simulated Model

Despite the observation that there is a 50% likelihood that diesel could reach the 50% break-even of $3.10/gallon, there is considerable risk that a farmer could lose large amounts of money. Thus, it is prudent to quantify the risk associated with each diesel fuel price level. This quantification may help a farmer decide if growing camelina is a favorable decision. Risk preference is certainly an important decision factor, as some farmers are more willing to take on additional risk than others. However, there are economic tests that have been developed to help quantify the added risk.

Figure 4.3 demonstrates the PDFs of the aggregate profits after 50,000 iterations of the simulated crop rotation budget, using three diesel price scenarios. The $3.10 and $4.30/gallon price scenarios are used as a means of comparison as the $3.10/gallon diesel price level represents the break-even value of expected profits from camelina, as shown in Table 4.2 and the $4.30/gallon diesel price level represents the diesel fuel price that must be exceeded for camelina to have greater than a 50% chance of becoming profitable, as shown in Table 4.1.

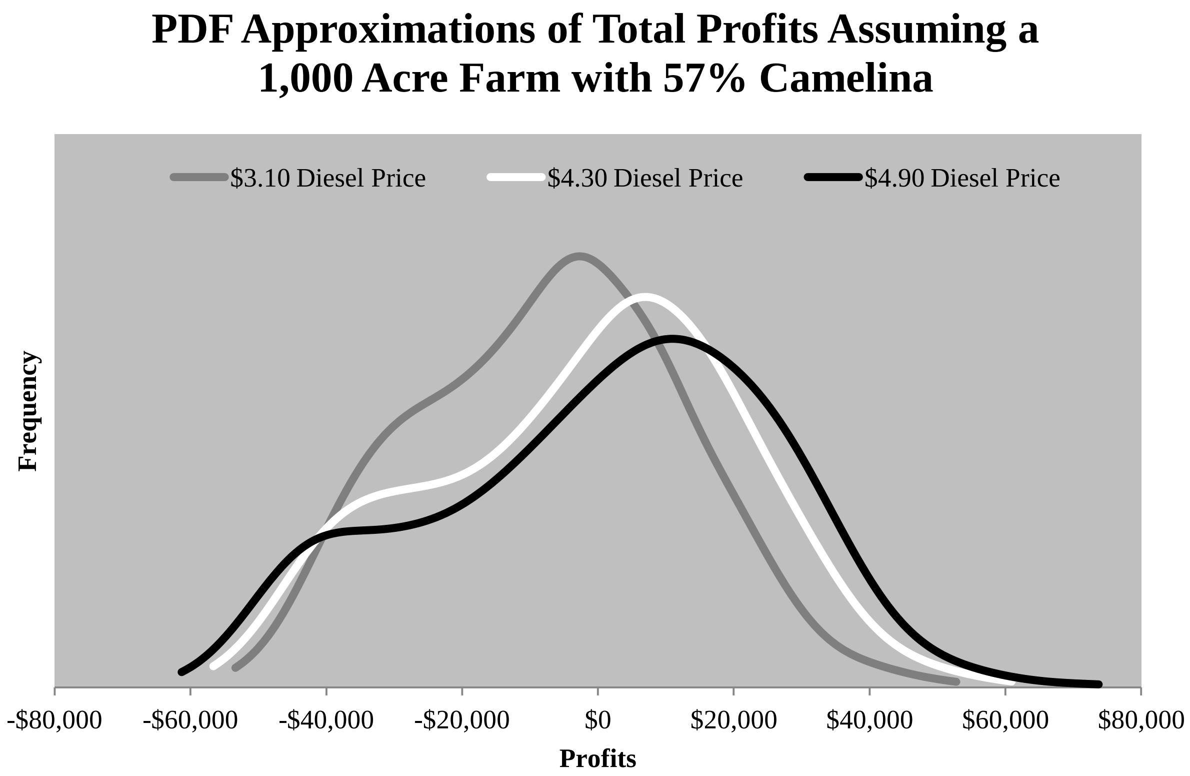


Figure 4.3. PDF approximations of total profits given three per gallon diesel fuel price scenarios.

Figure 4.3 presents the $3.10 and $4.30/gallon diesel fuel price scenarios as they have been previously discussed in section 4.1. The $4.90/gallon diesel fuel price scenario is significant as it is the minimum per gallon diesel fuel price that allows for the incorporation of camelina to be second-degree stochastically dominant compared to a farm without camelina. This is explained in greater detail in section 4.2.1.

Notice the possibility of significant losses presented in all three PDFs shown in Figure 4.3. In all three scenarios, maximum losses approach $60,000 on a farm that chooses to integrate camelina. These potential losses pose a significant risk to a farmer when choosing whether or not to incorporate camelina. This study evaluates the potential risk to the farmer by employing a stochastic dominance test, the evaluation of safety-first criteria, and a stoplight analysis. All of these risk indicators aid the farmer in making an informed decision as to whether or not camelina is a viable option for the specific farm.

4.2.1. Stochastic Dominance

Figure 4.4 represents the CDF of the results from the simulated crop rotation model when the per gallon price of diesel fuel is fixed at $4.90/gallon. The solid black line represents the probability of various levels of profits on a farm that incorporates camelina into its rotation. This is the CDF of profits when growing camelina. The dashed vertical line represents the change in profits in a farm that does not incorporate camelina. This is the CDF of profits for a farm that does not grow camelina. As this study does not take into account total farm profits and losses, but rather only the profits and losses from the addition of camelina, this vertical dashed line is centered at zero. This indicates there will be zero additional profit or loss for a farm that chooses not to grow camelina.

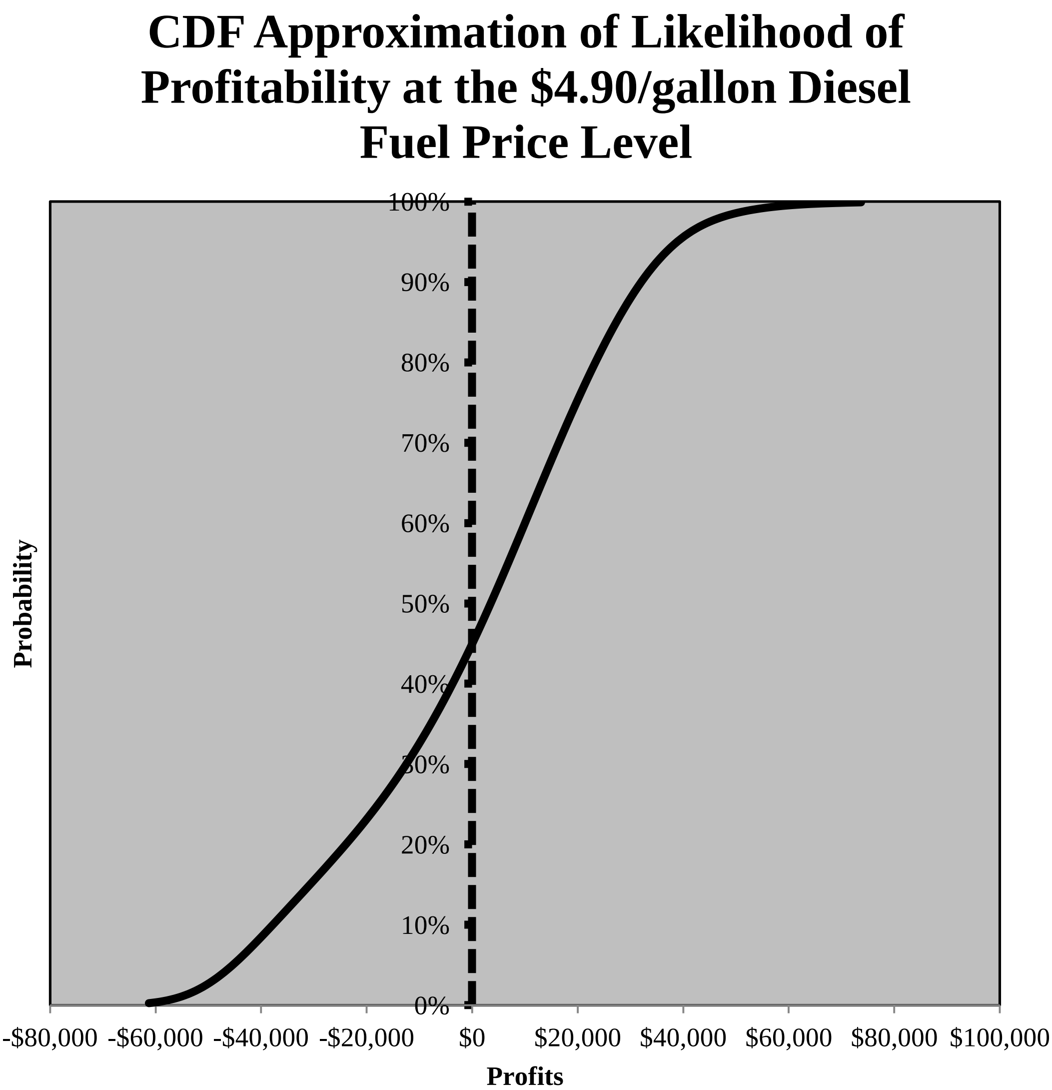


Figure 4.4. CDF of the likelihood of profitability at the $4.90/gallon diesel fuel price level.

Stochastic dominance is found by comparing two CDFs and determining which has the higher likelihood of delivering more utility to the producer. Refer to Figure 4.4. In this figure, assume that the vertical dashed line representing the baseline farm without camelina is a vertical CDF. First-degree stochastic dominance occurs when one CDF is always to the left of another, when profit is increasing on the horizontal axis (Hoag, 2010). Assuming a positive utility function, a producer will always prefer a higher profit given the same amount of risk. This requires the CDFs to never cross, which is not the case in Figure 4.4. In this case, there is no first-degree stochastic dominance. This implies that no CDF is preferred under all price levels, but rather more testing is needed to determine which CDF is preferable.

However, there is also a second-degree stochastic dominance test that may be helpful. Hoag (2010) explains that second-degree stochastic dominance can be evaluated by determining where the CDFs cross and evaluating whether the area under the left CDF is larger than the area above the right CDF at the point they cross. Second-degree stochastic dominance assumes that all decision makers are risk averse or their utility function is concave (Richardson, Schumann, and Feldman, 2006). This means that if a CDF is considered second-degree stochastically dominant, it will apply to all levels of risk aversion. This includes those that are risk loving as well as those that are more risk averse.

Figure 4.5 and 4.6, demonstrate second-degree stochastic dominance.

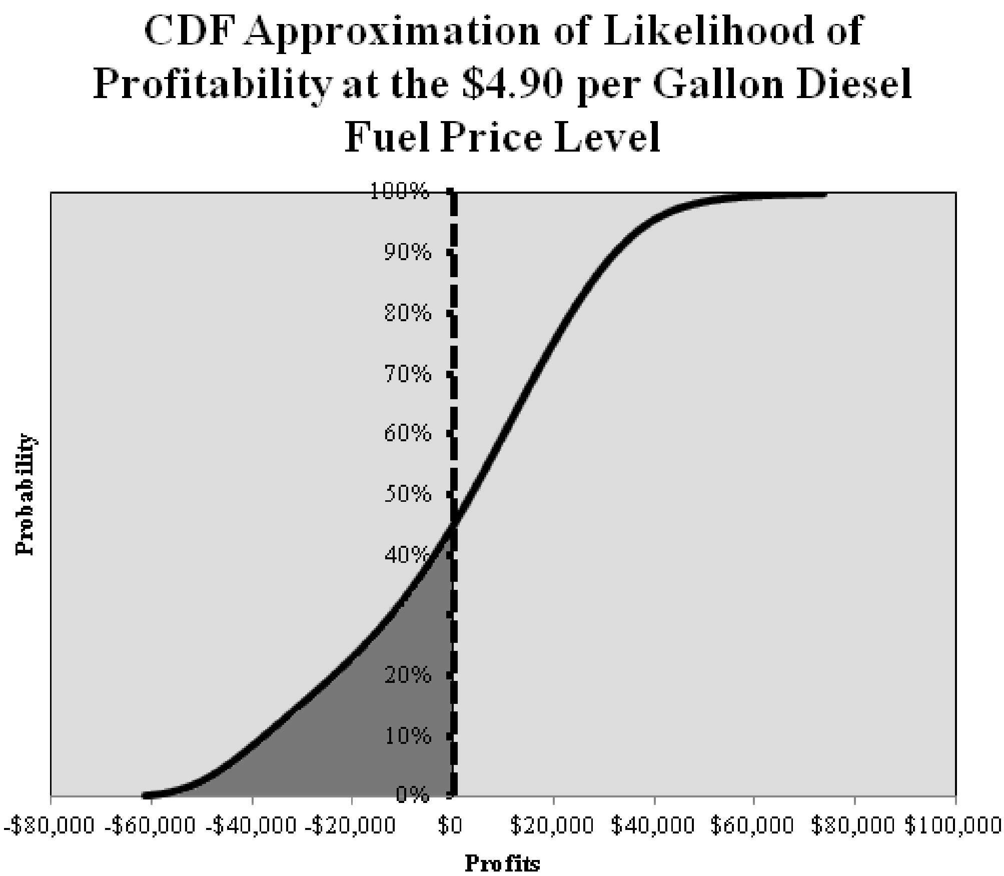


Figure 4.5. An update of Figure 4.4 with the darker shaded area under the CDF representing potential losses.

In Figure 4.5 the area under the curve that represents the potential losses when incorporating camelina is shaded in dark grey. This area includes all probabilities below the CDF and left of the intersection of the CDF of the baseline farm without camelina. This area represents all the possible losses that a producer will face.

Figure 4.6 represents the opposite scenario.

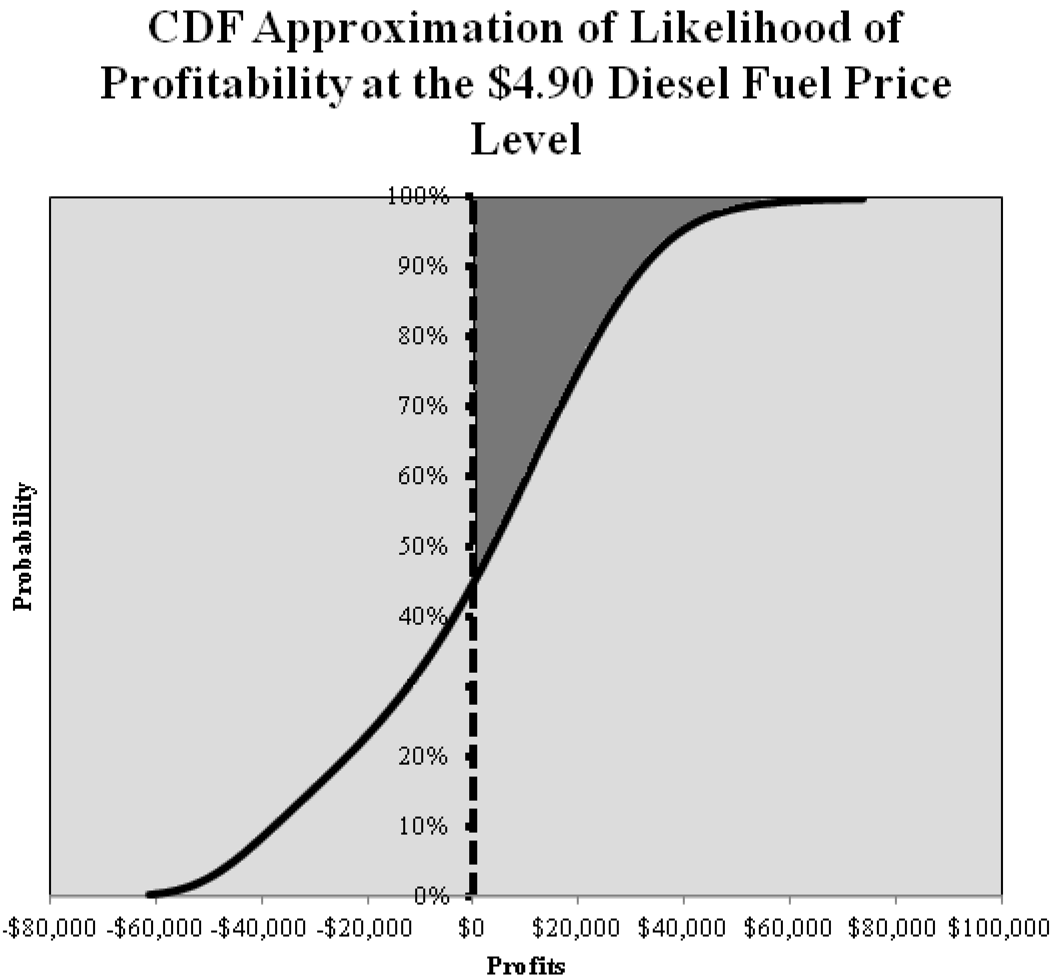


Figure 4.6. An update of Figure 4.4 with a darker shaded area above the CDF representing potential profits.

In Figure 4.6, the area shaded in dark grey represents all the potential profits the producer will face. This area includes all probabilities above the CDF and to the right of the intersection of the CDF representing the baseline farm without camelina. The second-degree stochastic dominance evaluates the areas pointed out by the darker shaded areas of Figures 4.5 and 4.6 and determines which one is larger.

The results determine that the shaded area in Figure 4.6 is about 1.5% larger than the shaded area in Figure 4.5. This is calculated using the Simetar® software. This indicates that once the price of diesel fuel reaches $4.90/gallon the option of growing camelina becomes second-degree stochastically dominant to the option of excluding it from the same farm in northeastern Colorado. This implies that risk loving, risk neutral, and risk averse farmers will be comfortable growing camelina once the price of diesel fuel reaches the $4.90/gallon threshold.

4.2.2. Safety-First Criteria

As explained by Bigman (1996), the safety-first criteria are a cardinal measure of risk. It is concerned with the risk for failing to achieve the minimum target or predetermined safety margin. It measures the risk of reaching the disaster level, a loss greater than the producer is comfortably willing to risk. The safety-first criteria are relevant for modeling camelina because they are most applicable to farmers that are risk averse. This tool helps set loss thresholds and objectively quantifies the maximum amount a farmer can lose before the loss threshold is reached. In this manner, a farmer has a clearer understanding of how much money is at risk, in addition to the percentage of likelihood of profitability previously established in Table 4.1.

Table 4.3 calculates the safety-first criteria for the $3.10, $4.30, and $4.90/gallon diesel fuel price scenarios. The figures in the table assume the farm is 1,000 acres and growing 57% camelina. The values listed in the chart are the approximate amount the farmer is willing to lose to reach the given safety threshold. These thresholds, shown as 90%, 95%, and 99%, are the certainty thresholds. For example, in the $3.10/gallon diesel price scenario, the farmer can say with 95% certainty that no more than $39,000 is at risk when choosing to incorporate camelina. The farmer also knows with 99% certainty that no more than $47,000 is at risk. These safety thresholds allow a farmer to understand with more certainty the actual dollar amounts at risk while minimizing the probability of losing more. Referring again to the $3.10/gallon example, if the farmer wants to be at the 99% safety threshold, the farmer must be willing to lose about $47,000. This indicates that in 99 out of 100 growing cycles, the farmer can expect to lose no more than $47,000. There is still a 1% risk of losing more than $47,000, but the safety-first thresholds are designed to choose a small enough risk percentage that a farmer would be comfortable ignoring this possibility.

Table 4.3
SAFETY-FIRST CRITERIA (VALUES ARE THE AMOUNT THE FARMER WOULD BE WILLING TO RISK IN ORDER TO REACH THE CERTAINTY THRESHOLD)

Diesel price (per gallon)	90% Threshold	95% Threshold	99% Threshold
$3.10	~$34,000	~$39,000	~$47,000
$4.30	~$35,000	~$41,000	~$49,000
$4.90	~$38,000	~$44,000	~$52,000

Note ~ signifies an approximate estimate

4.2.3. Stoplight Analysis

Another means to analyze the risk to farmers when incorporating camelina is through a stoplight analysis (Richardson, Schumann, and Feldman, 2006). A stoplight analysis is similar to the safety-first criteria, in that a threshold or cutoff value is assigned. However, in a stoplight analysis, lower and upper cutoff values are assigned, compared to just the lower threshold of the safety-first criteria. The green area of the stoplight analysis is representative of a green traffic light, indicating to continue. The yellow zone indicates that a farmer should proceed with caution, as returns are neither highly profitable nor indicate a substantial loss. The red zone indicates to stop, as returns are considerably negative. Once the cutoff values are assigned, the simulations are aggregated and presented in a chart that is similar in appearance to a traffic light. The green area of the chart is the probability that actual profits will exceed the upper cutoff value. The yellow area is the probability that profits will fall between the upper and lower cutoff values. The red area is the probability the profits will fall below the lower cutoff area. Figure 4.7 is the stoplight chart for the $3.10/gallon diesel price scenario, the $4.30/gallon diesel price scenario, and the $4.90/gallon diesel price scenario. Each scenario assumes a 1,000 acre farm growing 57% camelina. The upper and lower cutoff values are assigned a $10,000 profit and a $10,000 loss, respectively.

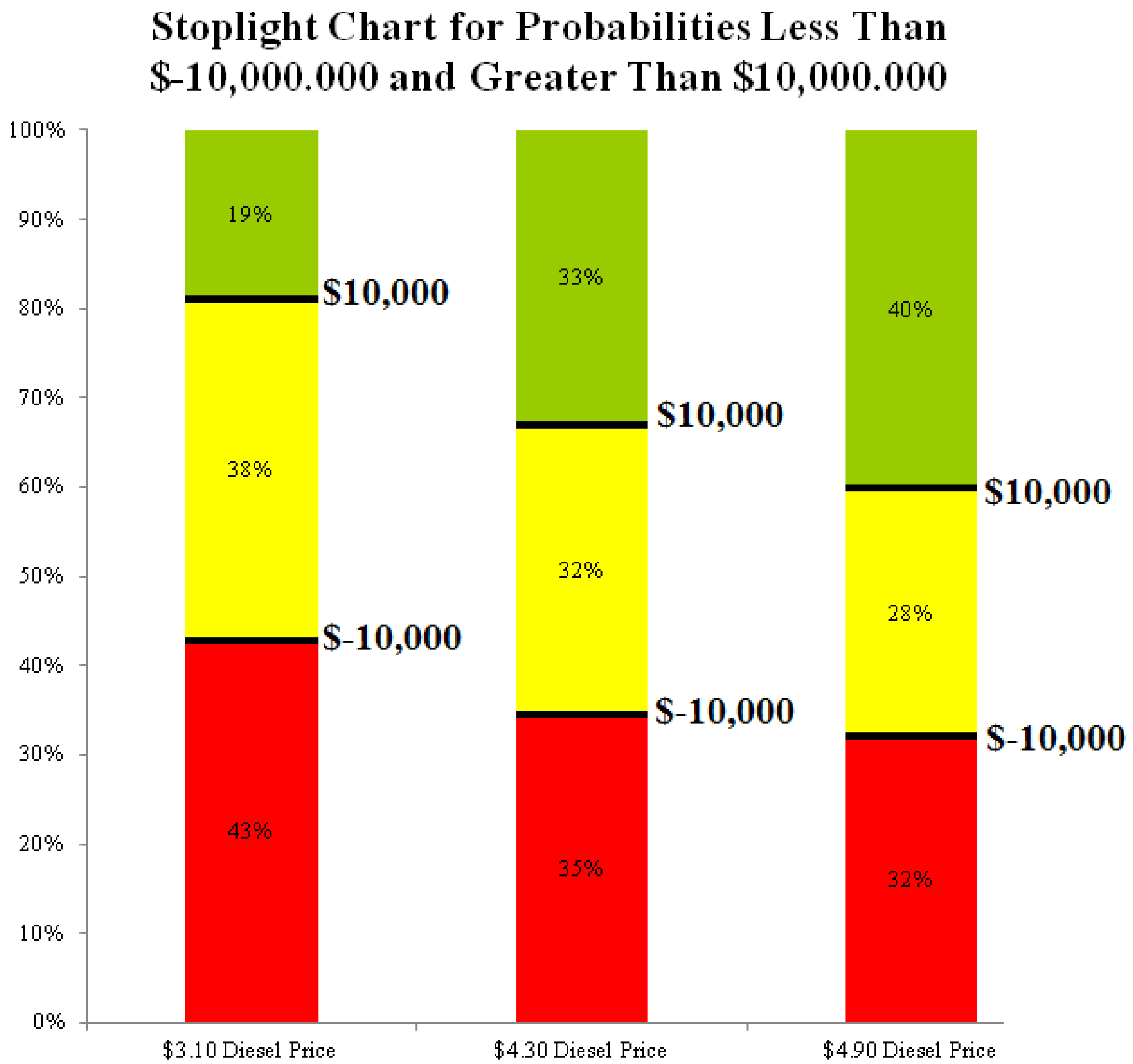


Figure 4.7. Stoplight analysis of three diesel fuel price scenarios using cutoff values of a $10,000 profit and a $10,000 loss.

The green area of Figure 4.7 is the percent likelihood that adding camelina to the crop rotation will earn at least $10,000 in profits. $10,000 was chosen as an arbitrary example to demonstrate a set of results possible from utilizing the stoplight analysis charts. The yellow area represents the percent likelihood of returns between -$10,000 and $10,000 if camelina is added. The red area is the percent likelihood of losing more than $10,000.

As previously demonstrated, the $4.30/gallon diesel fuel price scenario has just over a 50% likelihood of profitable integration of camelina (the exact value is 51.0% as demonstrated in Table 4.1). However, if a farmer is willing to consider the yellow area as an acceptable return, or in other words risk as much as $10,000, there is a 65% likelihood that the farmer will be satisfied with the returns generated from incorporating camelina.

The cutoff values for the stoplight analysis are entirely arbitrary. The farmer is able to determine which cutoff values would be appropriate for the specific farm and run another stoplight analysis according to the specific farm needs. The stoplight analysis allows for a quick and basic understanding of the overall risk percentages of incorporating camelina. Choosing lower cutoffs values will increase the size of the green area and reduce the size of the red area, creating a scenario where camelina is more favorable. The cutoff values are best utilized when chosen by an individual farmer, as they can be better tailored to match specific risk aversion levels. Unlike the second-degree stochastic dominance test, a stoplight analysis does not demonstrate potential camelina favorability for all risk aversion levels, but rather for a unique farmer.

4.3. The Opportunity Cost of Growing SVO

The opportunity cost of each gallon of SVO derived from camelina represents the per gallon cost of energy security the farmer pays. This opportunity cost is calculated by determining the expected value of the costs of each per gallon diesel fuel price level and subtracting the expected revenue from the sale of camelina meal. The remaining figure is divided by the gallons of diesel replaced by SVO. This represents the per gallon cost of energy security. The opportunity cost of growing SVO assumes a 1,000 acre farm growing 57% camelina. Table 4.4 lists the per gallon opportunity cost of growing SVO.

Table 4.4
PER GALLON OPPORTUNITY COST OF ENERGY SECURITY

Diesel price (per gallon)	Opportunity Cost	Energy Security Premium
$2.00	$2.92	$0.92
$2.10	$2.93	$0.83
$2.20	$2.95	$0.75
$2.30	$2.97	$0.67
$2.40	$2.98	$0.58
$2.50	$3.00	$0.50
$2.60	$3.02	$0.42
$2.70	$3.03	$0.33
$2.80	$3.05	$0.25
$2.90	$3.07	$0.17
$3.00	$3.08	$0.08
$3.10	**$3.10**	**$0.00**
$3.20	$3.12	$(0.08)
$3.30	$3.13	$(0.17)
$3.40	$3.15	$(0.25)
$3.50	$3.17	$(0.33)
$3.60	$3.18	$(0.42)
$3.70	$3.20	$(0.50)
$3.80	$3.22	$(0.58)
$3.90	$3.24	$(0.66)
$4.00	$3.25	$(0.75)
$4.10	$3.27	$(0.83)
$4.20	$3.29	$(0.91)
$4.30	$3.30	$(1.00)
$4.50	$3.34	$(1.16)
$5.00	$3.42	$(1.58)
$6.00	$3.59	$(2.41)
$7.00	$3.76	$(3.24)
$8.00	$3.92	$(4.08)
$10.00	$4.26	$(5.74)

In Table 4.4, the third column, representing the energy security premium, is the difference between the per gallon opportunity cost of growing SVO and the per gallon diesel fuel price. The fuel price level of $3.10/gallon represents the shift between the farmer paying for energy security and the farmer receiving a premium for energy security. When the price of diesel fuel is below $3.10/gallon, the farmer pays a premium for energy security. Once the per gallon price of diesel fuel rises above $3.10/gallon, the farmer is paid a premium to become energy secure, as the opportunity cost of growing SVO is less than the current per gallon price of diesel fuel.

4.4. The Best-Case Scenario

The best-case scenario evaluates the simulated crop rotation budget with each stochastic variable fixed at the most economically favorable level that the range of the variable allows. This allows the farmer to determine the maximum profits available. Although an unlikely scenario, the best-case scenario allows for a farmer to understand the maximum profit possible given the input parameters. Table 4.5 lists the stochastic variables that have been fixed to allow for maximum profit.

Table 4.5
THE VARIABLES AND FIXED VALUES IN THE BEST-CASE SCENARIO SIMULATION

Variable	Best-case value	Range used in full simulation
Pounds of seed (per acre)	12	12-14
Nitrogen application (pounds/acre)	0	0-40
Nitrogen price (per pound)	$0.40	$.40-$0.97
Operating loan rate	5%	5%-10%
Cost of foregone wheat	$0.00	$0.00-$32,775.00
Camelina yield (pounds/acre)	1200	0-1200
Oil content percentage	32.78%	22.30%-32.78%
Camelina meal price (per pound)	$0.226	$0.880-$0.226

Table 4.6 demonstrates the results of the best-case scenario, using the best case values shown in Table 4.5. The results in Table 4.6 demonstrate the expected profit for various diesel fuel price levels of integrating camelina. The profits assume a 1,000 acre farm growing 57% camelina.

Table 4.6
EXPECTED PROFITS FROM THE BEST-CASE SCENARIO

Diesel price (per gallon)	Expected Profits
$2.00	$42,126
$3.00	$49,339
$4.00	$56,552
$5.00	$63,765
$6.00	$70,978
$7.00	$78,191
$8.00	$85,403
$9.00	$92,616
$10.00	$99,829

As expected, the best-case scenario is highly profitable given any diesel fuel price level. These profit levels represent the maximum profit a farmer can expect when incorporating camelina at various diesel fuel price levels.

4.5. Sensitivity Analysis of the Variables in the Crop Rotation Budget

Figure 4.8 represents a sensitivity analysis of the overall elasticities of each of the input variables in the simulated crop rotation budget. The sensitivity tree, also known as a tornado diagram because of its shape, shows the magnitude of the influence each variable has on the overall likelihood of profitability. The larger the line associated with each variable is, the larger the influence that variable has on total profit. Figure 4.8, the sensitivity tree, determines that the variable associated with the revenue generated from the sale of camelina meal is the most influential variable with respect to total profits. A 1% increase in the revenues generated from the sale of camelina meal is associated with a 3.3% increase in the total expected profits when a farmer incorporates camelina. In contrast, a variable considerably lower in the sensitivity tree, such as the price of nitrogen fertilizer, has considerably less influence on the total profits. A 1% decrease in the price of nitrogen fertilizer only increases total profits by 0.28%.

Figure 4.8 demonstrates the relative insignificance the application rate and price of nitrogen fertilizer, as well as the loan rate paid by farmers, have on total profits from a camelina rotation. Other variables such as meal price, oil content percentage, total camelina yield, the cost of foregone wheat production, and the seeding rate have comparatively more influence on the total profits in the simulated crop rotation budget.

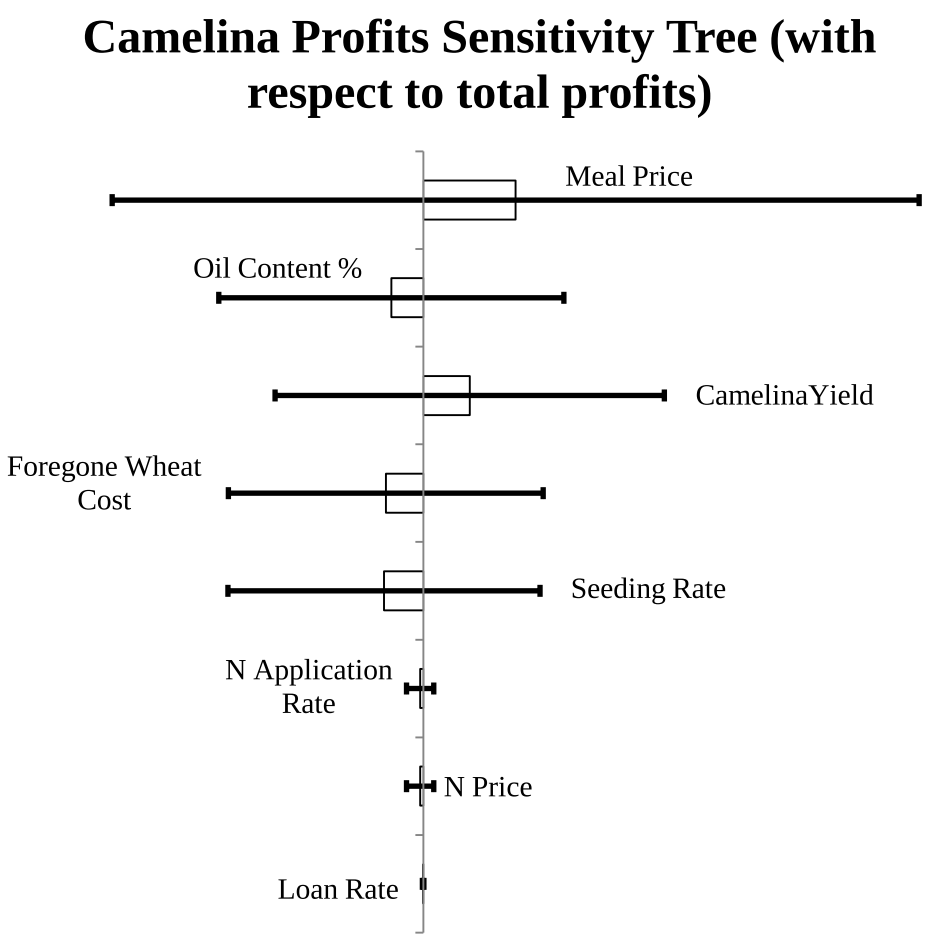


Figure 4.8. Camelina profits sensitivity tree.

Figure 4.8 has varying signs on the variables. Meal price and camelina yield are positive, indicating that as the price of meal increases and as the total yield from an acre of camelina increases, profits will increase. The percentage of oil content, the cost of forgone wheat, the seeding rate, the nitrogen application rate and price, and the loan rate are all indicative of negative variables. This implies that as any of these variables increase, either in price of quantity, total profits when growing camelina will decrease.

Oil content percentage and total profits have an inverse relationship as camelina meal often has more economic value to the farmer than the SVO created from camelina. Lower seed oil content percentages equate to less SVO and more camelina meal available to the farmer. Figure 4.8 indicates that it is important for a farmer to find a market to sell the camelina meal for a fair market price before committing to grow camelina, as the meal variable is the most influential variable regarding total camelina profits. Table 4.7 demonstrates the ratio between revenues generated from the sale of camelina meal compared with the savings of offset diesel fuel purchases. Table 4.7 lists these ratios against various per gallon diesel fuel prices.

Table 4.7
THE RATIO BETWEEN THE REVENUE FROM THE SALE OF MEAL AND DIESEL FUEL COST SAVINGS

Diesel price (per gallon)	**Camelina meal: offset diesel (expected values)**
$2.00	1.67:1
$3.00	1.11:1
$3.40	**1:1**
$4.00	0.83:1
$5.00	0.67:1
$6.00	0.56:1
$7.00	0.48:1
$8.00	0.42:1
$9.00	0.37:1
$10.00	0.34:1

Notice that until the price of diesel fuel surpasses $3.40/gallon the farmer can expect to generate more income from the sale of camelina meal than savings from offsetting diesel fuel purchases. This ratio is formulated by dividing the expected value of the sale of camelina meal by the expected value of the diesel fuel offsets generated by producing camelina. The results from Table 4.7 help establish the relative importance the revenues from the sale of camelina meal have on the overall profitability derived from growing camelina.

CHAPTER 5. CONCLUSIONS

5.1. Discussion of the Results

The simulated crop rotation budget places a strong emphasis on camelina grown in northeastern Colorado due to the specific agronomic conditions found in the region. The specificity of location does not translate to other regions and states, especially due to the crop yields used by the model. However, the model does offer a template for other crops and other regions by employing simulations to help recreate scenarios found in the real world, compared with static projections commonly used when creating farm budgets.

Finding a biofuel that can grow in northeastern Colorado presents a unique challenge. This is due in part to the large percentage of farmland that is not irrigated, despite being relatively arid compared with other regions. An economically viable biofuel must be able to grow on these lands with minimal inputs. As there are considerable uncertainties regarding revenues and costs when growing camelina, the viability of camelina becomes contingent on the ability of the crop to offer energy sovereignty to farmers. The simulated crop rotation budget and other models support decision making by simplifying information to help farmers have a better understanding of the likelihood of profits from camelina.

The model employed by the simulated crop rotation budget does not attempt to anticipate the amount of profit a farmer will see when incorporating camelina, but rather works as a guide to help determine the likelihood of profits. This thesis presents three diesel fuel price levels that represent price benchmarks when choosing to incorporate camelina. The model predicts that a farmer who wishes to only grow camelina if there is a better chance of profits than losses will be comfortable growing camelina once the price of diesel exceeds \$4.30/gallon. If a farmer would prefer to avoid any simulation and instead only utilize the expected values of input prices and quantities when growing camelina, the farmer will be comfortable growing camelina once the price of diesel fuel passes \$3.10/gallon. If a farmer is risk averse, the farmer will wait until the per gallon price of diesel fuel allows for a farm growing camelina to become second-degree stochastically dominant to the same farm without camelina. Thus, the farmer will not be comfortable growing camelina until the price of diesel fuel is greater than \$4.90/gallon.

5.1.1. The Overall Likelihood of Profitability

Table 4.1 lists the overall likelihood of profitably integrating camelina after aggregating the results of the 50,000 simulations. As shown in the table, the model determines that once the price of diesel fuel surpasses \$4.30/gallon, a farmer in northeastern Colorado is more likely to see a profit than a loss when integrating camelina into the rotation. A diesel fuel price of \$4.30/gallon is a low enough threshold that camelina may appear attractive in the near future, as current diesel fuel price levels are around \$4.00/gallon in the western United States.[34]

Achieving a 50% overall likelihood of profitability when incorporating camelina does not guarantee profits to a farmer. This metric is an explanation of the likelihood of success of the gamble, in this case incorporating camelina. It states that once the price of diesel fuel is more expensive than \$4.30/gallon, the farmer will more likely than not see profitable returns to the farm when choosing to grow camelina.

[34] U.S. Energy Information Agency, Independent Statistics and Analysis. Accessed 09 December 2011. htttp://www.eia.gov/petroleum/gasdiesel/.

This metric does not reflect the amount of profits, or losses, however. Even if the price of diesel fuel exceeds, for example, $5.00/gallon, a farmer could still lose close to $60,000, especially if the camelina crop failed to have a harvestable yield. This is despite the estimate shown in Table 4.1 that the farmer will have about a 57% likelihood of profitable camelina integration. Likewise, if the price of diesel fuel is only $2.00/gallon, a farmer could still make earn more than $20,000 in profits despite the more than 75% likelihood of a loss given the particular diesel fuel price. This can be best understood by evaluating the tails of the CDF drawn in Figure 4.1. While raising or lowering the per gallon price of diesel fuel shifts the CDF (to the left when diesel fuel is lower than $4.30/gallon and the right when diesel fuel is higher than $4.30/gallon), it does not eliminate the tails. These tails of the CDF can represent significant profits or losses.

Table 4.1 should be interpreted as a guide to understand how various diesel fuel price levels change the chances of profitability. The overall likelihood of profitability does not address some of the risk concerns as it is not an attempt to quantify overall profits and losses. The main purpose of the overall likelihood of profitability table is to identify that the $4.30/gallon diesel fuel price level represents the diesel fuel price that allows for the partial crop rotation budget simulations to draw more positive iterations than negative iterations.

5.1.2. The Expected Values of Profits and Losses

Table 4.2 lists the expected values of profits and losses in the partial crop rotation budget. The expected values and losses are not stochastic, however. As the expected values are fixed based on the input parameters of the model, determining the expected values of profits and losses does not maintain the same actual world realism that is found in stochastic simulations. Using the expected values of all input variables exclusively, the model determines that once the diesel fuel price exceeds $3.10/gallon, farmers in northeastern Colorado can expect profits.

The main reason why using expected values exclusively fails to translate to real world situations is the limitations of the model to account for a crop failure. In this scenario, yield is always fixed at 400 lbs./acre, and does not have the variance to account for a particularly bad year. This consistency in the yield allows for the model to lower the price of diesel fuel in order to create a profitable situation for the farmer.

However, one of the challenges of the integration of camelina is the relative uncertainty of the growing practices of this oilseed. As previously mentioned, camelina appears attractive to the farmlands of northeastern Colorado, but a learning curve must be in place to allow farmers to better understand what agronomical practices are necessary to increase crop yields. Any non-stochastic evaluation of the partial crop rotation model ignores this learning curve, and separates the model from more realistic situations.

Table 4.2 helps to predict the future per gallon diesel fuel price levels that will allow for the profitable integration of camelina. Yields will likely become more consistent once the crop is established in northeastern Colorado. However, the establishment of camelina will also likely lead to more certainty regarding many of the inputs needed to grow the crop. Once many of the stochastic levels or prices of input factors become more consistent, determining the expected values will hold more importance in the partial crop rotation budget. This establishment, however, is likely to be a lengthy process and a simulated stochastic model is more relevant in the near future when determining whether or not camelina can be profitably integrated in northeastern Colorado.

5.1.3. Discussion of Second-Degree Stochastic Dominance

Figures 4.5 and 4.6 discuss the second-degree stochastic dominance risk criteria. This integrates the areas under and above the CDF of a farm growing camelina and CDF of a farm without camelina and determines whether the potential profits to a farmer outweigh the potential losses, given a specific diesel price. The simulated partial crop rotation budget determines that once the price of diesel fuel is greater than $4.90/gallon, incorporating camelina becomes second-degree dominant compared to the same farm without camelina. Likewise, any diesel fuel price less than $4.90/gallon results in a farm without camelina showing second-degree dominance over the same farm with camelina.

The second-degree dominance metric is perhaps as influential to farmers in northeastern Colorado as the evaluation of the likelihood of profitability. This refers back to the evaluation of risk presented in section 4.2. While the likelihood of profitability is applicable in a risk-neutral scenario, the second-degree stochastic dominance results are most useful for a risk-averse farmer.

The second-degree stochastic dominance metric allows for the incorporation of total losses and total gains. This is compared with the likelihood of profitability metric, which allows for the understanding of where losses or gains are more likely, but does not allow the farmer to evaluate the severity of these losses or gains. The second-degree stochastic dominance evaluation determines the per gallon diesel fuel price that allows for the integration of all possible profits to exceed the integration of all possible losses.

The model determined that the diesel fuel price that corresponds to a 50% likelihood of profits when incorporating camelina is $4.30/gallon. Likewise, the model determines that the diesel fuel price of $4.90/gallon allows the incorporation of camelina to be second-degree dominant over the same farm without camelina. This implies that the risk-averse farmer needs the price of diesel fuel to rise by about $0.60/gallon in order to become comfortable with growing camelina once the $4.30/gallon threshold is reached. This additional rise in the price of diesel fuel allows for the potential profits to become greater than the potential losses.

The higher diesel price allows the integration of potential profits to exceed potential losses because of the influence the cost of procuring diesel fuel has on the farm budget. As diesel fuel becomes more expensive, the procurement costs rise. Since the model determines a portion of profits to be the savings from offset diesel purchases, the profits to the farmer will rise as diesel costs rise. Once the price of diesel fuel exceeds $4.90/gallon, more risk-averse farmers will be willing to incorporate camelina.

5.2. The Impacts of Growing Camelina in Northeastern Colorado

One of the benefits of growing camelina is the ability of the crop to grow on lands that are otherwise in fallow. While this benefit has been previously stressed, the true impact of this characteristic of camelina should be further explored. Dryland farming in northeastern Colorado requires the use of a fallow to allow for recuperation of moisture in farmland. This implies that no other food commodity would be growing on the land should a farmer not incorporate camelina, implying that no food is displaced in order to create a biofuel.

The main counter-argument to the lack of food displacement is that camelina can cause a reduced wheat harvest in the subsequent wheat portion of the northeastern Colorado crop rotation. However, this is currently hypothetical, as no consensus has yet been reached on the true impact. Rainfall patterns in northeastern Colorado can help to lessen the severity of the impact to the subsequent wheat harvest or entirely eliminate any impact on wheat yields. This is because a significant portion of the region’s annual rainfall is expected to occur after camelina is harvested in July.

This unique rainfall pattern suggests that camelina is likely to be a good fit for northeastern Colorado, but may not be the best biofuel option in other regions and states. This is important for two reasons. The first reason is that other locations may see a greater benefit from different biofuel options. While camelina appears to be a good option for northeastern Colorado, there are many other biofuel feedstocks that are better tailored for other areas than camelina. Second, if camelina production is limited, no market dependencies will develop. There is no danger of replacing the current petroleum dependency with a camelina dependency. This suggests that a total crop failure would have limited negative impacts on the national fuel markets.

Camelina offers an opportunity to grow a biofuel feedstock with minimal impacts, specifically in northeastern Colorado. As no other crop is displaced in order to grow camelina, many of the negative connotations associated with biofuels, especially the displacement of food crops, is negligible. Camelina offers the opportunity to grow a biofuel while avoiding the controversy of displacing food crops.

5.3. Camelina as an Insurance against Diesel Supply Shocks

Much emphasis has been placed on the profitability of incorporating camelina on farmlands in northeastern Colorado. However, camelina also offers insurance against an expected shock in the diesel fuel supply system. Table 4.4 lists the per gallon opportunity costs of growing camelina using the expected values from the simulated crop rotation budget. While the expected values do not mimic real world scenarios, they do allow for a better understanding of the price paid to hedge against diesel supply shocks.

The per gallon price paid to hedge against a diesel fuel supply shock is the difference between the total cost of producing camelina and the revenues generated from selling camelina meal. This is then divided by the gallons of diesel fuel that are offset from SVO generated by camelina. It is important to determine the per gallon premium a farmer would be willing to pay to have more certainty regarding future fuel costs. Even if growing camelina is not profitable, it still may be advisable if the premium of growing camelina is below the per gallon threshold that a farmer is willing to pay for this increased energy supply and price certainty. If a farmer is willing to pay a $1.00/gallon premium for a more certain energy supply, for example, then camelina would be a good option despite the lack of profitability.

This is why thinking of camelina as an insurance policy helps to greatly increase its usefulness. A farmer would expect to pay a premium for this policy, but if the price of diesel fuel significantly increases, the farmer is paid rather than paying for this insurance. In addition to the price of diesel, other factors that contribute to a farmer not paying a hypothetical insurance premium include a particularly high yield or high camelina meal price, among others.

In order to be an applicable hedge against high diesel fuel prices or a complete lack of available diesel fuel, camelina yields must become more consistent in northeastern Colorado. The simulated crop rotation budget is programmed to favor lower yields to accommodate for the difficulties farmers face when incorporating an unproven crop. However, if camelina is the key to energy security in northeastern Colorado, there must be stable yields to allow for the displacement of diesel fuel. The simulated crop rotation budget is designed to maintain a relatively high probability of a complete crop failure and demonstrate an overall likelihood of profitability that reflects the high failure rate. If farmers are able to learn how to grow the crop with more certain yields, the need for profitable integration of camelina becomes less important as the benefits of a hedge against diesel supply shocks becomes more pronounced. Certainty in yields leads to a stronger insurance against diesel supply shocks and offers a hedge for which farmers are likely willing to pay more. The future of camelina is not contingent on profitability, but rather is better considered as insurance to combat an unpredicted shock to the diesel fuel supply system.

5.4. The Value of Energy Security

The model demonstrates that once the price of diesel fuel exceeds $4.30/gallon, a farmer in northeastern Colorado is more likely than not to generate a profit when choosing to integrate camelina. However, the true price of energy security is difficult to measure. In addition to extra income to farmers, growing camelina allows for a hedge against unpredictable diesel prices, or a complete shutdown of the diesel fuel supply system. Growing camelina provides an insurance policy that can help ensure the continued supply of food from farms in northeastern Colorado, regardless of the national diesel fuel situation. However, if a farmer is able to generate additional profits from growing camelina, this insurance policy has a negative premium. A farmer is paid to hedge against diesel fuel shocks, as opposed to paying for this energy security.

The true value of energy security is difficult to measure. The ability for a farmer to become energy secure has many positive impacts. Energy security leads to food security, as a farmer is able to continue food production despite external pressures on the price of diesel fuel. By ensuring that commodity production is not disrupted, food prices may be stabilized. Stable food prices are particularly important for lower income families who spend proportionately more of their income on food. Energy security also offers a significant reduction of risk to the farmer and leads to continued production of all crops regardless of the price or availability of diesel fuel. The introduction of camelina will not immediately lead to energy security, but may become a viable option as camelina yields become more stable.

5.5. Influence of the Sale of Camelina Meal on Profits

As determined in Table 4.7, camelina meal is more valuable to the farmer than the savings from the offset diesel fuel when the price of diesel fuel is below $3.40/gallon. Once the price of diesel fuel exceeds $3.40/gallon, the savings from offsetting diesel fuel exceeds the revenues from the sale of camelina meal. This indicates that for relatively low diesel fuel price levels, the price received by farmers upon the sale of camelina meal is the more influential variable in regards to total profits than the offset diesel fuel.

The *a-priori* expectations of the simulated crop rotation model anticipated that the revenue generated from the sale of camelina meal would be the most influential variable with regards to total profits. The reasoning for the high significance towards total profits of the revenue generated from the sale of meal becomes evident when examining the expected ratio of revenue generated from the sale of camelina meal to cost savings of offset diesel fuel. When the price of diesel fuel is relatively low, below $3.40/gallon, the role of revenue from camelina meal is particularly evident, as it makes up greater than half of the gains seen by a farmer when incorporating camelina.

The meal variable has a high degree of influence because it is based on three input factors. These include the total yield, the inverse of the percent of the oil content of the camelina seed, and the price of soybean meal, which serves as a proxy for camelina meal. If these three input factors are favorable, the farmer is likely to see higher profits when growing camelina. This is especially evident with the yield, as a higher yield will not only supply more camelina meal for the farmer to sell, but will also replace more diesel fuel with SVO. This results in additional profits for the farmer.

Another factor that adds to the influence of the camelina meal variable is independence from the price of diesel fuel. This allows for additional revenues, should the expected price of diesel fuel not materialize. If the price of diesel happens to be significantly lower than expected, the farmer is hedged with the sale of camelina meal. As long as yields are relatively consistent and there is no significant drop in the price of camelina meal, farmers have some income that can be expected, regardless of oil price.

Much of the motivation for growing camelina is to hedge against unexpectedly high diesel prices. In the event of unexpectedly low diesel prices, albeit a rare occurrence, the intrinsic nature of the camelina meal variable supplies added protection to the farmer who is able to sell meal for revenues. The ability to mitigate losses if diesel prices are too low to profitably offset with SVO allows the farmer to reduce the risk of incorporating camelina.

5.6. Biofuel Subsidies

This study intentionally did not include any biofuel subsidies or tax credits offered by the federal or state governments. Many subsidies are promised and phased out, which leads to high levels of uncertainty for biofuel producers. Eliminating uncertainty is one of the motivating factors for incorporating camelina on farmlands in northeastern Colorado. If a farmer is counting on a subsidy for camelina production, energy sovereignty is replaced with a reliance on a government program. This eliminates the independence that the incorporation of camelina helps to establish.

A subsidy is often necessary as the result of a market failure, which is not the case for SVO created from camelina. Rather, all values determined in this thesis exclude subsidies and government credits. If subsidies or tax credits are available to the farmer when camelina is grown, the likelihood of profitability will increase and results will be more favorable to the farmer. The lack of subsidies from the simulated crop rotation budget helps determine the cost and profits of independently growing camelina. All related outcomes from the model will improve if subsidies remain or become available.

5.7. Concluding Remarks

This simulated crop rotation budget model should be used as a tool to determine the likelihood of profitability of integrating camelina with respect to the price of diesel fuel. As diesel fuel prices trend higher, the usefulness of the model will greatly increase. The model is applicable to farmers in northeastern Colorado who want to take steps towards energy sovereignty.

The addition of camelina will provide a hedge against the disruption of the food distribution system should there be a shock in the supply of diesel fuel. This stability should aid in the alleviation of spikes in the price of food commodities directly caused by the price of diesel fuel. As previously discussed, higher food prices tend to have the greatest impact on those most income sensitive, specifically lower class families and those in poverty. Any aid to help stabilize food prices should not be overlooked. Camelina is an oilseed that has not yet had significant genetic research, which implies that yields are not yet optimized. As this increases and the genome is perfected, growing camelina will become more opportune for farmers in northeastern Colorado. As the simulated crop rotation budget is fine tuned to match the agronomic factors of northeastern Colorado, yields are adjusted to accommodate for difficulties of incorporating a new crop. These yields are likely to increase significantly as camelina becomes more prevalent, helping to increase the profitability of the crop, and help farmers take the necessary steps towards energy sovereignty.

The simulated crop rotation budget demonstrates that the price of diesel does not need to rise significantly in order to make the likelihood of profitably of growing camelina greater than 50%, as $4.30/gallon represents the diesel fuel price that allows for a 50% likelihood of profitable integration under the conditions assumed in the model. Camelina should find a comfortable home in the arid plains of northeastern Colorado as diesel prices trend upwards. This oilseed offers farmers an opportunity to move towards energy self-sufficiency and provides a small step towards national energy security.

References

Acheampong, K., and M.R. Dicks. 2012. “Fertilizer Demand for Biofuel and Cereal Crop Production in the United States.” *Selected Paper Prepared for Presentation at the Southern Agricultural Economics Association Annual Meeting, Birmingham, Alabama, February 4-7,2012.*

Allen, P. Geoffrey. 1994. "Economic Forecasting in Agriculture." *International Journal of Forecasting* 10 (1):81-135.

Allen R.G., et al. 1998. “Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements.” *FAO Irrigation and Drainage Paper* No. 56. FAO, Rome.

Araghinejad, Shahab. 2011. "An Approach for Probabilistic Hydrological Drought Forecasting." *Water Resources Management* 25.1: 191-200.

Armstrong, J.S. 1985." Long-range Forecasting: from Crystal Ball to Computer", 2nd ed. Wiley, New York.

Bernardo, A., Howard-Hildige, R., O’Connell, A., Nichol, R., Ryan, J., Rice, B., Roche, E., Leahy, J. 2002. "Camelina Oil as Fuel for Diesel Transport Engines. " *Industrial Crops and Products* 17: 191-197.

Bessler, David A., J. Dorfman, M.T. Holt, and J.T. LaFrance. 2010. "Econometric Developments in Agricultural and Resource Economics: The First 100 Years." *American Journal of Agricultural Economics* 92 (2):571-589.

Bigman, David. 1996. "Safety-First Criteria and Their Measures of Risk." *American Journal of Agricultural Economics* 78 (1):225-235.

Bourgeon, J.-M. and D. Tréguer. 2010. "Killing Two Birds with One Stone: US and EU Biofuel Programmes." *European Review of Agricultural Economics* 37(3): 369- 394.

Capareda, S, et al. 2010. "Energy Usage Survey of Dairies in the Southwestern United States." *Applied Engineering in Agriculture* 26.4:667-675.

Chen, Yu-Chin, K.S. Rogoff, and B. Rossi. 2010. "Can Exchange Rates Forecast Commodity Prices?" *The Quarterly Journal of Economics* 125 (3):1145-1194.

Collins, K. 2008. “The Role of Biofuels and Other Factors in Increasing Farm and Food Prices: A Review of Recent Development with a Focus on Feed Grain Markets and Market Prospects.” Prepared for Kraft Foods Global, Inc., Glenview Illinois.

Demirbas, A. 2010. "Biodiesel for Future Transportation Energy Needs." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 32(16): 1490-1508.

Du, X., and D.J. Hayes. 2008. "The Impact of Ethanol Production on U.S. and Regional Gasoline Prices and on the Profitability of the U.S. Oil Refinery Industry." Working Paper, Center for Agricultural and Resource Development, Iowa State University.

Eidhin, D. Ní, J. Burke, and D. O'Beirne. 2003. "Oxidative Stability of ω3-rich Camelina Oil and Camelina Oil-based Spread Compared with Plant and Fish Oils and Sunflower Spread." *Journal of Food Science* 68 (1):345-353.

Enjalbert, N, and J. Johnson. 2011. "Guide for Producing Dryland Camelina in Eastern Colorado". *Farm and Ranch Series*. Colorado State University.

Eskridge, K. M., P. F. Byrne, and J. Crossa. 1991. "Selection of Stable Varieties by Minimizing the Probability of Disaster." *Field Crops Research* 27.1-2: 169-81.

Evans, E., and S. Nalampang. 2009. "Forecasting Price Trends in the U.S. Avocado (Persea Americana Mill.) Market." *Journal of Food Distribution Research* 40(2).

Fargione, J., J. Hill, D. Tilman, S. Polasky, P. Hawthorne. 2008. "Land Clearing and the Biofuel Carbon Debt."*Science* 319: 1235-1238.

Fore, S., Porter, P., Lazarus, W., Jordan, N. 2009. "Net Energy Balance of Small-Scale On-Farm Biofuel Production: Canola and Soybean Based Biodiesel and Straight Vegetable Oil Biofuels." Master's Thesis, University of Minnesota, St. Paul, MN.

___2010. "Economics of Small-Scale On-Farm Use of Canola and Soybean for Biodiesel and Straight Vegetable Oil Biofuels." *Biomass and Energy* 1-10.

Frank, J., and P. Garcia. 2009. "Time-Varying Risk Premium: Further Evidence in Agricultural Futures Markets." *Applied Economics* 41.6: 715-25.

Frechette, Darren L., and P.L. Fackler. 1999. "What Causes Commodity Price Backwardation?" *American Journal of Agricultural Economics* 81.4: 761.

Frohlich, A., Rice, B. 2005. "Evaluation of *Camelina Sativa* Oil as a Feedstock for Biodiesel Production." *Industrial Crops and Products* 21: 25-31.

Garcia, Philip, and R.M. Leuthold. 2004. "A Selected Review of Agricultural Commodity Futures and Options Markets." *European Review of Agricultural Economics* 31.3: 235-72.

Gujarati, D., and Porter, D. *Basic Econometrics*, 5th. ed. New York: McGraw Hill Book Co. 2009.

Guttman, Nathaniel B. 1998. "Comparing the Palmer Drought Index and the Standardized Precipitation Index." *Journal of the American Water Resources Association* 34.1: 113-21.

Heaton EA, F.G. Dohleman, and S.G. Long. 2008. "Meeting US Biofuel Goals With Less Land: the Potential of Miscanthus." *Global Change Biology* 14: 2000-2014.

Hoag, D.L. *Applied Risk Management in Agriculture*. Boca Raton: CRC Press, 2010.

Hunsaker, D., et al. 2011. "Water Use, Crop Coefficients, and Irrigation Management Criteria for Camelina Production in Arid Regions." *Irrigation Science* 29.1: 27-43.

Index Mundi. "Soybean Meal and Prices."Accessed 19 August 2011. http://www.indexmundi.com/commodities/?commodity=soybean.

Johnson, David. 1997. "The Triangular Distribution as a Proxy for the Beta Distribution in Risk Analysis." *Journal of the Royal Statistical Society. Series D (The Statistician)* 46 (3):387-398.

Johnson, J., Enjalbert, N., Schneekloth, J., Helm, A., Malhotra, R., Coonrod, D. 2009. "Development of Oilseed Crops for Biodiesel Production Under Colorado Limited Irrigation Conditions." Completion report no. 211. *Colorado Water Institute*.

Johnson, J., Enjalbert, N., Shay, R., Heng, S., Coonrod, D. 2008. "Investigating Straight Vegetable Oil as a Diesel Fuel Substitute." *Final Report to Colorado Agricultural Value-Added Development Board.*

Johnson, R. 2002. " Search Costs, Lags, and Prices at the Pump." *Review of Industrial Organization* 20:33-50.

Just, Richard E., and Gordon C. Rausser. 1981. "Commodity Price Forecasting with Large-Scale Econometric Models and the Futures Market." *American Journal of Agricultural Economics* 63 (2):197.

Keefer, Donald L., and Samuel E. Bodily. 1983. "Three Point Approximations for Continuous Random Variables. "*Management Science* 29 (5):595-609.

Kennedy, Peter. *A Guide to Econometrics.* Malden, MA: Blackwell Publishing, 2008.

Kellard, Neil, et al. 1999. "The Relative Efficiency of Commodity Futures Markets." *Journal of Futures Markets* 19.4: 413-32.

Korsrud, G., M. Keith, and J. Bell. 1978. "Comparison of Nutrional-Value of Crambe and Camelina Seed Meals with Egg and Casein." *Canadian Journal of Animal Science* 58.3: 493-499.

Martin D.L., and J.R. Gilley 1993. "Irrigation Water Requirements." Part 623, National Engineering Handbook, chap 2. USDA-SCS, Washington.

McDonnell, K., Ward, S., Leahy, J., McNulty, P. 1999. "Properties of Rapeseed for Use as a Diesel Fuel Extender." *JOACS* 76: 539-543.

McKay, M. D., J.W. Conover., and R. J. Beckman. 1979. "A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output From a Computer Code." *Technometrics*, 21, 239-245.

McKee, T.B., N.J. Doesken, and J. Kleist. 1993. "The Relationship of Drought Frequency and Duration of Time Scales." Eighth Conference on Applied Climatology, American Meteorological Society, Jan 17-23, 1993. Anaheim CA, pp. 179-186.

___1995. "Drought Monitoring with Multiple Time Scales." Ninth Conference on Applied Climatology, American Meteorological Society, Jan 15-20, 1995, Dallas TX, pp. 233-236.

Nettles-Anderson, S.L. Olsen, D.B. 2009. "Survey of Straight Vegetable Oil Composition Impact on Combustion Properties." *SAE International*.

Oanda. "Oanda Historical Exchange Rates," last modified April 15, 2011, Accessed 25 June 2011. http://oanda.com/currency/historical-rates.

Palmer, W.C. 1965. "Meteorological Drought." Research paper no 45. US Department of Commerce Weather Bureau, Washington.

Park, Sung Y., and Anil K. Bera. 2009. "Maximum Entropy Autoregressive Conditional Heteroskedasticity Model." *Journal of Econometrics* 150 (2):219-230.

Patil, Prafulla D., et al. 2009. "Microwave-Assisted Catalytic Transesterification of Camelina Sativa Oil." *Energy & Fuels* 24.2: 1298-304.

Patil, Prafulla D., V.G.Gude, and S. Deng. 2009. "Biodiesel Production from Jatropha Curcas, Waste Cooking, and Camelina Sativa Oils." *Industrial & Engineering Chemistry Research* 48.24 10850-56.

Pilgeram AL, Sands DC, Boss D, Dale N, Wichman D, Lamb P, Lu C, Barrows R, Kirkpatrick M, Thompson B, Johnson DL. 2007. "*Camelina Sativa*, a Montana Omega-3 Fatty Acid and Fuel Crop." In: Janick J, Whipkey A (eds) Issues in New crops and New Uses. ASHS Press, Alexandria, pp 129–131

Pinzi, S., Garcia, I.L., Lopez-Gimenez, F.J., Luque de Castro, M.D., Dorado, G., Dorado, M.P. 2009. "The Ideal Vegetable Oil-Based Biodiesl Composition: a Review of Social, Economical and Technical Implications." *Energy and Fuels* 23: 2325-2341.

PRNewswire. "FDA Approves Camelina Meal for Cattle Feed."Accessed 10 December 2010. http://www.prnewswire.com/news-releases/fda-approves-camelina-meal-for-cattle-feed-69565017.html

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.

Richardson, J.W., Schumann, K., Feldman, P., 2006. Simulation and Econometric Models for Probabilistic Forecasting and Risk Analysis. SIMETAR Inc., College Station, TX, pp 1-109.

Robinson, R. G. 1987. "Camelina: A Useful Research Crop and a Potential Oilseed Crop." *Minnesota Agricultural Research Station,* Station Bulletin 579-1987.

Salvati, L., A. Liberta, and A. Brunetti. 2005 "Bio-climatic Evaluation of Drought Severity: a Computational Approach using Dry Spells." *Applied Ecology and Environmental Research* 6(1): 129-138.

Schnepf, R. 2008. “High Agricultural Commodity Prices: What Are the Issues?” Congressional Research Service, CRS Report for Congress. May 8.

Searchinger et al., 2008. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land Use Change."*Science* 319: 1157-1268.

Senay, G.B. and J. Verdin. 2001. "Using a GIS-Based Water Balance Model to Assess Regional Crop Performance." Proceedings of the Fifth International Workshop on Application of Remote Sensing in Hydrology, October 2-5, 2001, 5 Montpellier, France.

Shonnard, David R., L Williams, and T.N. Kalnes. 2010. "Camelina-Derived Jet Fuel and Diesel: Sustainable Advanced Biofuels." *Environmental Progress & Sustainable Energy* 29.3: 382-92.

Sidibe, S., Blin, J., Vaitilingom, G., Azoumah, Y. 2010. "Use of Crude Filtered Vegetable Oil as a Fuel in Diesel Engines State of the Art": Literature review. *Renewable and Sustainable Energy Reviews* 14: 2748 2759.

Somerville C, H. Youngs, C. Taylor,S.C. Davis, S. Long. 2010. "Feedstocks for Lignocellulosic Biofuels." *Science* 329: 790-792.

Stein, Michael. 1987. "Large Sample Properties of Simulations Using Latin Hypercube Sampling." *Technometrics* 29 (2):143-151.

Stock, J.H. and M.W. Watson. *Introduction to Econometrics.* Boston: Pearson Education, 2007.

Stratton, A., J. Kleinschmit, and D. Keeney. 2007. "Camelina Sativa." Institute for Agriculture and Trade Policy Rural Communities Program.

Tomek, W. 1997. “Commodity Futures Prices as Forecasts.” *Review of Agricultural Economics* 19:23–44.

Tomek, W.G. and K.L. Robinson. 2003. "Agricultural Product Prices." Ithaca, NY: Cornell University Press.

Trostle, R. 2008. “Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices,” U.S. Department of Agriculture, Economic Research Service, WRS-0801, May.

Tyner, E.W., and F. Taheripour. 2008. "Policy Options for Integrated Energy and Agricultural Markets." *Review of Agricultural Economics* 30:387-396.

US Congress. 2005. *Energy Policy Act of 2005*. 109th Congress

US Department of Agriculture 2009. "Recent Volatility in U.S. Fertilizer Prices."*Amber Waves*. Accessed10 December 2011. http://www.ers.usda.gov/AmberWaves/March09/Features/FertilizerPrices.htm.

US Department of Agriculture. 2010. "A USDA Regional Roadmap to Meeting the Biofuels Goals of the Renewable Fuels Standard by 2022." USDA Biofuels Strategic Report.

US Department of Agriculture Economic Research Service. 2011. Farm Income and Costs: 2011 Farm Sector Income Forecast. Accessed 08 October 2011. http://www.ers.usda.gov/Briefing/FarmIncome/.

US Department of Agriculture Farm Service Agency. 2012. Farm Loan Programs. Accessed 05 February 2012. http://www.fsa.usda.gov/FSA/webapp?area=home&subject=fmlp&topic=dfl-ir.

U.S. Energy Information Agency, Independent Statistics and Analysis. Accessed 09 December 2011. htttp://www.eia.gov/petroleum/gasdiesel/.

Vangelis, Harris, Mike Spiliotis, and George Tsakiris. 2011. "Drought Severity Assessment Based on Bivariate Probability Analysis." *Water Resources Management* 25.1: 357-71.

Van Gerpen, J. 2005. "Biodiesel Processing and Production." *Fuel Process Technology* 86: 1097-1107.

Velasco, L. Fernanez-Martinez, J.M., De Haro, A. 1999. "Intraspecific Breeding for Reduced Glucosinolate Content in Ethopian Brown Mustard (*Brassica carinata* A. Braun)." *Euphytica* 106: 125-130.

Vollmann, J., A. Damboeck, A. Eckl, H. Schrems, and P. Ruckenbauer. 1996. "Improvement of Camelina Sativa, an Underexploited Oilseed." p. 357-362. In: J. Janick (ed.), Progress in New Crops. ASHS Press, Alexandria, VA.

Vollmann, Johann, et al. 2007. "Agronomic Evaluation of Camelina Genotypes Selected for Seed Quality Characteristics." *Industrial Crops and Products* 26.3: 270-77.

Vollmann, J., H. Grausgruber, et al. 2005. "Genetic Diversity in Camelina Germplasm as Revealed by Seed Quality Characteristics and RAPD Polymorphism." *Plant Breeding* 124(5): 446-453.

von Braun, J. 2008. “Rising Food Prices: What Should Be Done?” Policy Brief 1, International Food Policy Research Institute, Washington DC.

Williams, T. M. 1992. "Practical Use of Distributions in Network Analysis." *The Journal of the Operational Research Society* 43 (3):265-270.

Working, Holbrook. 1927. "Forecasting the Price of Wheat." *Journal of Farm Economics* 9 (3):273-287.

Yu, Lean, Shouyang Wang, and Kin Keung Lai. 2008. "Forecasting Crude Oil Price with an EMD-Based Neural Network Ensemble Learning Paradigm. *Energy Economics* 30 (5):2623-2635.

Zubr, J. and B. Matthaus. 2002. “Effects of Growth Conditions on Fatty Acids and Ttocopherols in *Camelina Sativa* Oil.” *Industrial Crops and Products* 15,155-16.

Appendix A. Wheat Models Regression Results

Coefficients and P-Values Shown. Variable	Model 1	Model 2	Model 3	Model 4	*Model 5 (log-log)*	*Model 6 (log-log)*
Intercept	-21.4910	1.0815	-3.0668	0.5036	***-0.0069***	***-0.0192***
	0.0450	0.5370	0.0130	0.6400	***0.6540***	***0.4980***
Crude Oil	0.0211	0.0249	0.0148	0.0066	***0.3485***	***0.2313***
	0.0060	0.0050	0.0070	0.3830	***0.0001***	***0.0500***
US Dollar/Yen	0.0066	0.0131	0.0232		***0.8410***	
	0.2050	0.1140	0.0110		***0.0001***	
Corn Price	2.1735	2.1257	1.3096	1.1709	***0.8409***	***0.8101***
	0.0020	0.0060	0.0001	0.0001	***0.0001***	***0.0001***
Soybean Price	-0.1514	-0.1948				
	0.1010	0.1120				
Nitrogen Fertilizer			0.0009	0.0013		
			0.0760	0.1850		
DAP Fertilizer	0.0002	0.0005			***0.1088***	***0.0639***
	0.5330	0.2380			***0.0030***	***0.3980***
Lagged Wheat Exports	0.0001	0.0001				
	0.0390	0.1820				
Lagged Wheat Planting	0.0001	0.0001	0.0001	0.0001		
	0.4410	0.3950	0.0370	0.0050		
US Dollar/Euro		-0.8234	-0.2944			
		0.2120	0.7380			
U.S. Ethanol	-0.3007					
	0.0090					
Quadratic Trend		-0.7916				
		0.0370				
Linear Trend	4.4595					
	0.0540					
USD/GBP						***-0.2863***
						0.4780
AIC	-17.4730	-24.6880	-5.5820	4.6300	***-39.0550***	***-22.9560***
R-squared	0.9975	0.9989	0.9985	0.9803	***0.9621***	***0.8803***
RMSE	0.1187	0.0903	0.1708	0.2484	***0.0523***	***0.0930***
Forecasted price/bushel	8.9093	8.1680	8.4650	8.7490	***6.6540***	***6.7560***
Forecasted % increase					***0.2997***	***0.3196***
Durbin-Watson Statistic					***2.6900***	***1.7700***

Appendix B. Enterprise Budgets

Blitzer, M.J. "No-Till Corn." University of Kentucky, Cooperative Extension Service. http://www.ca.uky.edu/agc/pubs/agr/agr100/agr100.pdf

"Crop Enterprise Budgets." Colorado State University Extension. Agriculture and Business Management. http://www.coopext.colostate.edu/abm/cropbudgets.htm

Ehrensing, D.T., S.O. Guy, 2008. "Camelina."Oregon State University Extension Services, *Oilseed Crops*. http://extension.oregonstate.edu/catalog/pdf/em/em8953-e.pdf

"Estimated Costs of Crop Production in Illinois." 2003. University of Illinois, Farm Business Management. http://www.farmdoc.illinois.edu/manage/enterprise_cost/2003_crop_budgets.pdf

"Fertilizer Use and Price." USDA Economic Research Service. Data Sets. Accessed 20 April 2011. http://www.ers.usda.gov/Data/FertilizerUse/

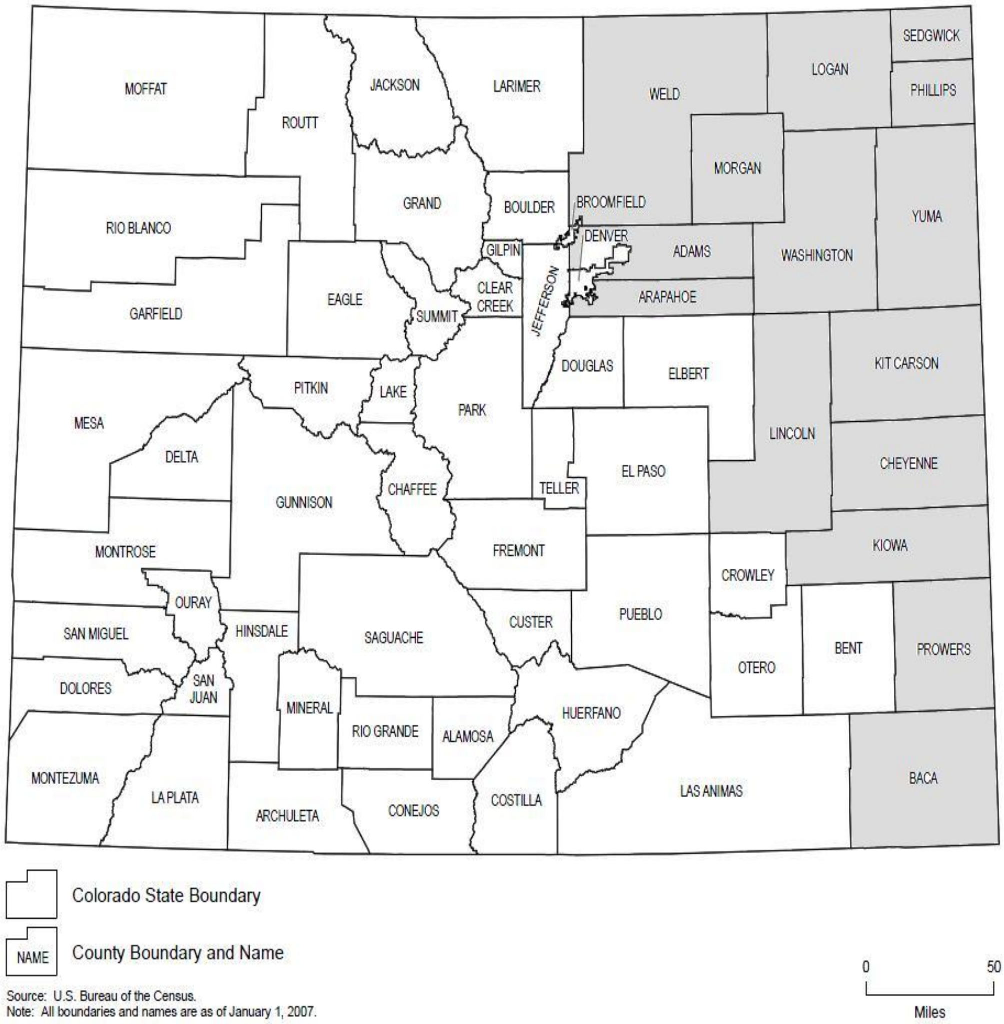
Painter, K., and E. Miller. "Crop Rotation Budgets, Over 18" Precipitation Zone, Under Direct Seeding (No-Till), Eastern Washington." Washington State University. http://extecon.wsu.edu/pages/Enterprise_Budgets

Sharp, R., D. Kaan. "Risk and Resilience in Agriculture." Colorado State University. http://agecon.uwyo.edu/RnRinAg/RnR%20Section%202/Enterprise%20Budgeting.pdf

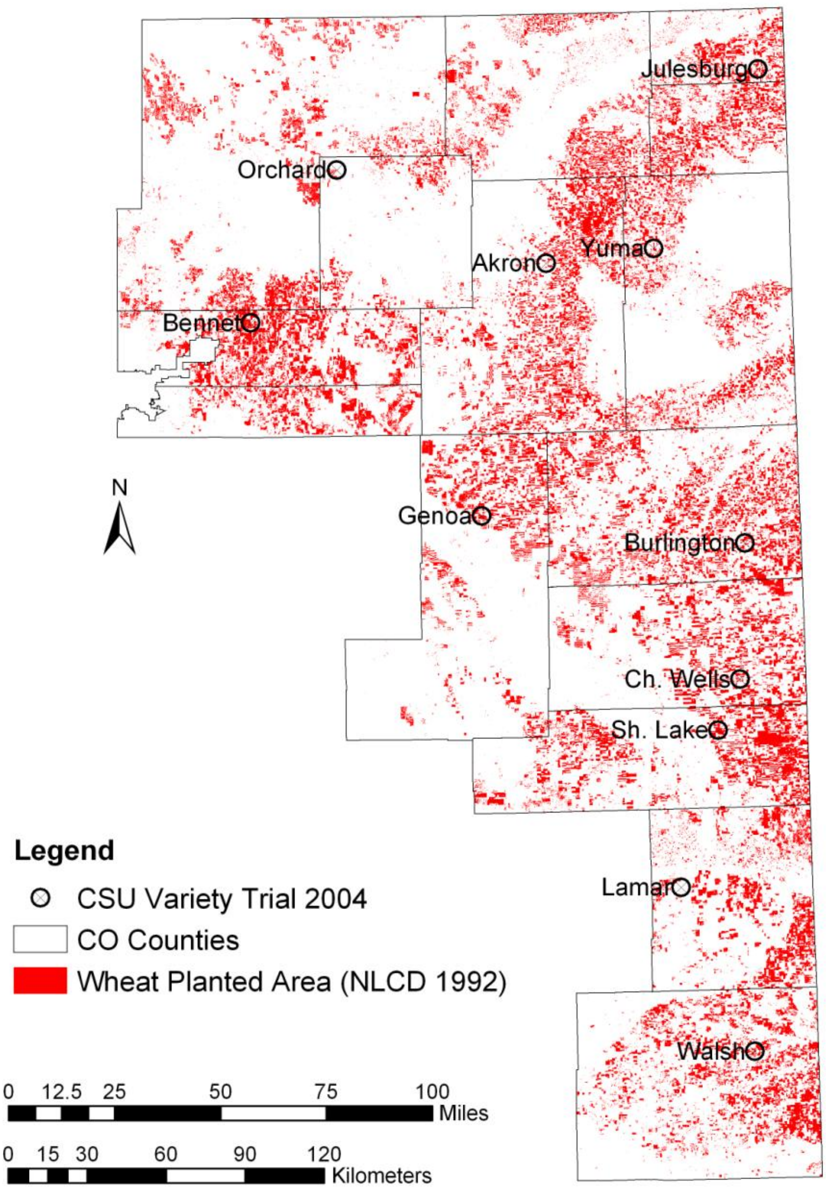
Ward, B. 2010. "Ohio Farm Custom Rates 2010-Part 1." The Ohio State University Extension. http://delaware.osu.edu/topics/agriculture-and-natural resources/OhioFarmCustomRates2008.pdf

___. 2009. "Corn Production Budget. No-Tillage Practices." The Ohio State University Extension. http://aede.osu.edu/Programs/FarmManagement/Budgets/crops-2009/corn-no-till2009UAN.pdf

Appendix C. Map of Colorado with Highlighted Counties Demonstrating Eastern Colorado Wheat Production



Appendix D. Cutout of Highlighted Counties from Appendix C with Wheat Planting Areas Highlighted



Source: Federico Pardina, Colorado State University.

Appendix E. Directions to Replicate the Simulated Crop Rotation Budget in Simetar® using Microsoft Excel®

1. Establish size of farm in cell A1.
2. Establish percent share of fallow in cell B1.
3. Establish diesel fuel price in cell C1.
4. Establish total yield in cell A2. Command= triangle(0,0,1200).
5. Establish labor cost. Command= 9.20*A1*B1.
6. Establish hauling cost. Command= 7.14*(A2/2000)*A1*B1*B2 (calculated in step 10).
7. Establish cost of seeding. Command =uniform(12,14)*A1*B1.
8. Establish cost herbicide application. Command= (-11.50)*A1*B1.
9. Establish cost of nitrogen fertilizer per acre. For application rate, command=triangle(0,0,40). For nitrogen fertilizer cost, form two arrays of nitrogen prices per ton from 1993-2010 and corresponding average annual diesel fuel price per gallon from 1993-2010. Command=empirical distribution button, input ranges are the nitrogen price array and diesel price array. Choose percent deviation from trend. Scroll down to correlation matrix. CUSD matrix is calculated by command=CUSD(correlation matrix). Stochastic Deviate is calculated by command=emp(nitrogen prices in sorted deviations from trend array, f(x) in sorted deviations from trend array, CUSD matrix). Next, regress nitrogen prices against diesel prices. Predict nitrogen prices by multiplying the slope of the regression by

predicted diesel fuel price level, and add to intercept. Next, multiply predicted nitrogen price by (1+Stochastic Deviate). Divide by 2000 to covert from tons to lbs.

10. Establish oil content percentage in cell B2. Employ the same CUSD process with a 0.96 correlation between total oil content percentage and yield.
11. Establish additional diesel fuel purchases in cell A4. Command=2009*C1.
12. Amortize additional diesel purchase in cell A5. Command= (A4*.04)/(1-(1.04^-10))*3.
13. Establish total additional diesel purchase costs. Command=A5*C1.
14. Sum steps 6-10 and step 13 in cell A7.
15. Establish loan rate in cell A8. Command=uniform(5,10).
16. Establish additional cost of loan. Command= ((A7*(A8/12))/(1-(1+A8/12)^(-6)))/2.
17. Establish cost of lost wheat. Command= triangle(0,28.80,57.61)*A1*B1.
18. Establish storage costs. Command=(((5000*0.04))/(1-(1-0.04)^10))*3
19. Total costs= sum steps 16-18.
20. Establish cost of meal in cell B3. Command=triangle(175,380,452)/2000.
21. Establish revenue from the sale of meal. Command=B3*A2*(1-B2).
22. Establish savings from offset diesel fuel costs in cell C2. Command=C1*8088 (if A1*B2*A2*B1>8088, otherwise C1*A1*B2*A2*B1.
23. Establish total savings from offset diesel fuel. Command =C2*C1.
24. Sum step 21 and step 23.
25. Subtract step 19 from step 24 in cell D1.
26. Simulate cell D1.

Appendix F. Distribution Types Assigned to Each Variable in the Simulated Crop Rotation Budget Model (only independent variables with either a uniform or triangular distribution are listed)

Seeding Rate:	Uniform Distribution
Nitrogen Fertilizer Application Rate:	Triangular Distribution
Camelina Yield:	Triangular Distribution
Seed Oil Content Percentage:	Triangular Distribution
Loan Interest Rate:	Uniform Distribution
Price of Camelina Meal:	Triangular Distribution
Loss of Subsequent Wheat Production:	Triangular Distribution
Seed Crushing, Cleaning, and Filtering Cost:	Uniform Distribution