The Economics of Annual Legume and Double Legume Cover Cropping in Southern Manitoba

by

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A Thesis submitted to the Faculty of Graduate Studies of

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in partial fulfillment of the requirements of the degree of

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The undersigned certify that they have read the Master's Thesis/Practicum entitled:

The Economics of Annual Legume and Double Legume Cover Cropping in Southern Manitoba

submitted by

Ashleigh McLellan

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The Thesis/Practicum Examining Committee certifies that the thesis/practicum (and oral examination if required) is:

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Abstract

Plants require nitrogen for healthy growth and development. Legume plants have a unique characteristic whereby they are able to naturally fix nitrogen from the atmosphere for their own growth and development. Some of this nitrogen then remains for use by subsequent crops. Using historical data from crop producing farms in southern Manitoba, this study quantifies the economic savings that could be realized by using legumes to supply nitrogen in a cereal-oilseed based rotation. Stochastic budgets are developed for four alternative crop rotations and the returns associated with each are evaluated using the utility-based risk ranking methods of stochastic dominance and stochastic efficiency. It is found that including a legume cover crop in a cereal-oilseed based rotation can reduce the amount of nitrogen required by a subsequent crop and in turn increase the net returns associated with the complete crop rotation.

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Chapter 1: Introduction

1.1 Problem Statement

Since 1992, manufactured nitrogen fertilizer prices in Canada and particularly Manitoba have been increasing (Statistics Canada 2008). Increasing fertilizer prices are an important and relevant issue for agricultural producers, as the cost of fertilizer continues to negatively impact the overall farm net returns. Farmers are dependent on nitrogen to produce both higher yields and greater protein content in grain crops, resulting in a more valuable end product (Trautmann, Porter, and Wagenet 2009). Plants that do not receive enough nitrogen fertilizer tend to become yellow and stunted as well as have small flowers and fruits.

Producers in Manitoba are relying more and more on synthetically produced nitrogen to fulfill their nitrogen requirements and maximize their yields. Since 1960, commercial fertilizer sales in Manitoba have been on the rise (Honey 2008). Commercial fertilizer sales peaked in 2003 at an all-time high of 1 million tonnes, costing producers approximately $251 million. Since 2003 fertilizer prices have greatly increased causing farmers to reduce their application rates. In 2006, fertilizer use in Manitoba fell to 838,000 tonnes, but still cost farmers approximately $405 million. Prices continued to increase in 2007 and producer fertilizer costs increased by 31% to $532 million.

1.2 Objective

The objective of this research is to determine the profitability for southern Manitoba grain and oilseed producers of incorporating annual grain legumes and legume cover crops into a typical cereal-oilseed based crop rotation. Legumes fix nitrogen from the atmosphere for their own production, some which remains after harvest for use by subsequent crops. The legume crop thus will provide an alternative source of fertilizer to synthetically produced nitrogen fertilizer. Producers would benefit financially through a reduction in the application of commercially produced nitrogen fertilizer. Additional gains would be expected to positively impact producers and the environment through a reduction in pesticide applications, increased yields, and reduced income variability.[1] However, there are additional costs that must be considered in the production of legumes, including inoculation, labour, and higher seed costs. Sources of risk from price, yield, and nitrogen variability are incorporated into the analysis.

1.3 Thesis Outline

Chapter 2 gives a detailed background of crop production in southern Manitoba as well as a description of the commercial nitrogen fertilizer industry, the use of legumes in crop production as an alternative source of nitrogen fertilizer, and the consequences of synthetic nitrogen fertilizer use upon the environment. Chapter 3 reviews the literature on legume cropping in southern Manitoba, stochastic simulation models, and economic studies incorporating legumes into various types of cropping systems. Chapter 4 focuses on the theory of decision analysis in agriculture involving risk. In Chapter 5, the methodology used to evaluate the alternative crop rotations is presented, including a detailed description of the data, budgets, simulation model, and evaluation methods. Chapter 6 presents the results of the simulation and explores the implications for farmers

[1] Legumes are expected to reduce income variability as legume prices and grain prices tend to be inversely correlated.

in southern Manitoba. In the final chapter, a discussion of the conclusions established from the simulation procedure is presented. This chapter also explains the limitations of this study and suggests areas for future research.

Chapter 2: Background

2.1 Introduction

This chapter begins by introducing the agricultural environment surrounding the model farm developed in this thesis, followed by an explanation of the commercial nitrogen fertilizer industry and its current economic impact on producers in southern Manitoba. Later sections provide a discussion of the alternative sources of nitrogen fertilizer (i.e. legume crops) upon which this thesis is based. This discussion includes a description of how these crops contribute nitrogen to the cropping system as well as the indirect agronomic benefits they offer to crop rotations. This chapter concludes by summarizing the impact that synthetic nitrogen fertilizer is having on the quality of the environment in Manitoba.

2.2 Nitrogen Use in Crop Production

Farmers have been successfully producing grain and oilseed crops on the Canadian prairies for over 100 years. When early settlers came to Canada, the uncultivated soils were highly fertile and rich in organic matter. Therefore, input use was minimal, as it was not necessary to apply additional nitrogen fertilizer when producing agricultural crops (Pauly 2008). Over time, continuous cropping and the use of intense tillage practices in combination with little to no added nitrogen fertilizer depleted the soil of important nutrients. Continuous crop rotations deprive the soil of important nutrients, which are often not replenished. At the same time, a reliance on high tillage operations results in a significant loss of topsoil through soil erosion. The soil's key nutrients are contained in this top layer of soil. If an agricultural system is to remain productive and sustainable in the long-term, an adequate supply of these essential nutrients must be maintained. As nitrogen is among the most important of these nutrients, nitrogen fertilizer has become an essential input in any successful cropping system. Successful agricultural crop production requires the application of various inputs, including (but not limited to): fuel, labour, pesticides, and fertilizers. These inputs help producers achieve higher yields, which generally lead to greater overall net returns. Specifically, nitrogen fertilizer is an important crop input required by plants to form amino acids and protein (Canadian Organic Growers 2001). Plants that do not receive enough nitrogen fertilizer tend to have a stunted growth resulting in a poor yield and consequently a lower economic return.

2.3 Agriculture in Manitoba

Canada is an important contributor in the global agricultural market. Of Canada's total land area, 5% is devoted to agricultural production (Statistics Canada 2009). On a global scale, 3% of the world's agriculturally productive land is found in Canada. Canada produces a wide variety of crops, ranging from cereal grains such as wheat, oats, and barley, to oilseeds including canola and flax, as well as legumes and pulses such as soybeans, fababeans, lentils, and peas. Among the Canadian provinces, the Prairie provinces of Alberta, Saskatchewan, and Manitoba produce a large portion of Canada's total agricultural output: in 2006, 4,701,010 hectares of land in Manitoba were devoted to crop production. This represents 13% of Canada's total land area cultivated for crop production. Manitoba is considered a major crop-producing province as 11,616,450 acres of the total land area in the province is used for crop production. The major crops produced in Manitoba include: spring wheat, canola, alfalfa, barley, and oats (MAFRI 2006b). Of the 19,054 farms in Manitoba in 2005, 6,773 (36%) were reported as primarily grain and oilseed farms.

The research reported in this thesis is based on a hypothetical grain farm situated in southern Manitoba. The field trial sites from which the majority of the data were gathered to conduct this study are located in two areas of southern Manitoba: Carman and Glenlea. Both these sites are located in the rural municipality of Dufferin, which is located in the so-called Pembina Valley. Appendix A shows a map of these areas. The population in the rural municipality of Dufferin is approximately 2,200 (MAFRI 2007). This area is characterized by its rich black soils, which are among the best type of soil for agricultural crop production. As a result, a variety of agricultural crops are produced in this area of the province. Major crops that are frequently cultivated include potatoes, corn, peas, beans, lentils, sunflowers, flax, canola, and a host of cereal grain crops such as wheat, oats, and barley. The growing season (April though November) in this area has a 30-year average of 1,704 growing degree days,[2] 2,891 crop heat units, 419 mm of precipitation, and an average expected frost date of early to mid September. In the Morden area (south of the Carman trial site) there are approximately 662 growing degree days and 87 mm of rain available after growing a winter wheat crop. In order to grow a

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[2] Growing degree-days provide a measure of the growth and development of plants during the growing season (OMAFRA 2003). The number of growing degree-days for any given area is determined by first estimating the mean temperature for the day by adding the daily minimum and maximum temperatures and dividing the result by two. The daily growing degree-day estimate is obtained by subtracting the base temperature (5 degrees Celsius) from the mean temperature. Lastly, the daily growing degree-days estimate is added up over the growing season, whereby a larger number typically indicates greater plant development.

successful late season cover crop, it is believed that there must be at least 400 growing degree days available (Martens, Hoeppner, and Entz 2001).

Manitoba Agricultural Services Corporation (MASC) outlines the average number of acres seeded to various crops throughout the province and designates a percentage to each municipality in relation to the other rural municipalities. Table 1 shows the estimated average acres of each crop considered in this study for the rural municipality of Dufferin.

Table 1. Classification of the average acres and crop intensity of crops in the rural municipality of Dufferin

Crop	Average Acres by Municipality	Crop Intensity
Spring Wheat	Upper Middle 20% (25,200 – 34,400)	Lowest 20% (1.3 – 16.0)
Oats	Top 20% (5,000 – 29,300)	Top 20% (6.1 – 30.9)
Canola	Top 20% (20,400 – 51,400)	Lower Middle 20% (10.7 – 13.5)
Winter Wheat	Upper Middle 20% (1,100 – 1,800)	Trace (less than 1%)
Peas	Upper Middle 20% (1,400 – 2,700)	Lower Middle 20% (1.3 – 1.6)
Lentils	Top 20% (2,200 – 8,600)	Upper Middle 20% (1.9 – 2.5)

Crop Intensity compares the average of the municipal acres to the total possible production acres in the municipality.
Source: http://www.mmpp.com/mmpp.nsf/mmpp_static_maps.html

2.4 Legume Production in Manitoba

The production of pulses in Manitoba dates as far back as the 1800s (Honey 2008). From the 1880s to the early 1900s, small areas of peas were seeded in Manitoba and used as pig feed. However not until the 1990s did production of peas in Manitoba grow significantly. In 1998, 260,000 acres were seeded to peas and production was recorded at a record level of 8.3 million bushels. The production of fababeans and lentils also began to increase at the turn of the 21st century with 10,600 and 6,300 acres being seeded in 2001 to each crop respectively. At this same time, approximately 75-100% of Canada's fababean crop and 1-2% of Canada's black lentil crop came from production in Manitoba. In 2002, Manitoba also produced approximately 57% of Canada's dry bean crop valued at $88 million. Now, producers in Manitoba are increasing the number of acres seeded to beans and are producing a wide variety of beans including white/navy, pinto, black, dark red and light red kidney, red Mexican, and cranberry beans. Soybeans are also an important crop to Manitoba's farm economy as in 2003, 2006, and 2007, Manitoba produced between 7 and 8% of Canada's soybean crop. Although most farms in Manitoba are classified as being wheat, other grains and oilseeds, or cattle, the major concentration of pea and lentil production in Manitoba is in the southwestern region.

2.5 Nitrogen Fertilizer

It was only after World War II that synthetic nitrogen fertilizer became a major input in agricultural crop production (Honey 2008). This was due to the creation of the Haber-Bosch process, which allowed for nitrogen in the atmosphere in the form N_2 to be converted under high pressure and extreme temperatures into a plant usable form. Plants need nitrogen to be in the form of nitrate (NO_3^-) or ammonium (NH_4^+) in order to use it for growth and protein production (Canadian Organic Growers 2001). Over time, farmers became heavily dependent on commercially produced nitrogen fertilizer as it presented them with a low-cost input that significantly increased not only crop yields but also the overall quality of the crop.

Only a limited number of alternatives to synthetically produced nitrogen fertilizer are available to crop producers. One option is to not apply any nitrogen fertilizer to the crop. However, given the limited amount of nitrogen available naturally in the soil, this is not an economically sound decision as crop yields and crop returns would be significantly compromised. Producers could also recycle plant residues in the cropping system to allow for nutrients to be returned to the soil and thus reduce the need for future nitrogen applications (Canadian Organic Growers 2001). Another option would be to apply natural sources of nitrogen such as animal manure, as this would increase the amount of nitrogen in the soil. Lastly, producers could choose to incorporate nitrogen-fixing crops into the crop rotation. These crops form a symbiotic relationship with soil bacteria that allows them to convert the nitrogen (N_2) from the atmosphere into the plant usable form, NH_3 (ammonia).

2.6 Price of Synthetically Produced Nitrogen Fertilizer

In 1998, Korol and Larivere estimated that fertilizer accounts for approximately 10% of the Canadian farmer's total input costs. In Manitoba, it is estimated that nitrogen fertilizer comprises between 13% and 25% of grain producers' total production costs (MAFRI 2009). Since 1992, prices of nitrogen fertilizer in Manitoba have been on the rise (Statistics Canada 2008). This increase in nitrogen prices can be explained by two main factors: the price of natural gas and the price of food.

The price of natural gas affects nitrogen prices because the atmosphere is composed of 80% nitrogen in the form N_2 (nitrogen) (IFDC 2008a). In 1909 the Haber-Bosch process, a scientific process that allows nitrogen from the atmosphere to be converted into the plant usable form NH_3, was developed. In this process, nitrogen from the atmosphere is combined with hydrogen from natural gas under extreme pressure and high temperatures to produce anhydrous ammonia. The resulting anhydrous ammonia is either used directly as a source of nitrogen fertilizer or used as an input in the production of other forms of nitrogen such as ammonium nitrate or urea.

In the production of ammonia, natural gas is both the largest and most expensive component. It accounts for between 70% and 90% of the cost to manufacture nitrogen (Wenzel 2004). Furthermore, there is no available substitute for natural gas in the production of ammonia. Recently, there has been an increase in the demand for natural gas, as it is a source of energy not solely used in the production of ammonia. This increase in demand accompanied by an inability to store and distribute natural gas cheaply has resulted in an increase in price.

When the demand for food increases, there is an increase in the demand for agricultural crops (IFDC 2008b). An increase in demand for agricultural commodities results in an increase in the price of these products. When crop prices are on the rise, producers want to achieve higher yields. Therefore producers will apply more nitrogen fertilizer per acre with the intent of increasing yields.

2.7 Legumes as an Alternative Source of Synthetic Nitrogen

Using nitrogen fixing plants and practices such as cover cropping to supply nutrients in the cropping system is not a new practice. The use of legumes and cover cropping to provide nutrients to the soil has been dated as far back as the 1900s (Kryzanowski 1993). However, today producers in Manitoba are becoming increasingly reliant on synthetically produced nitrogen fertilizer to fulfill their nitrogen requirements and maximize their yields.

Legume crops can help alleviate producers' increasing demand for synthetic nitrogen fertilizer because they have the ability to use the nitrogen present in the earth's atmosphere in its current state. This is due to the presence of nitrogen-fixing bacteria, Rhizobium, which is either naturally present in the soil or added to the soil by inoculating the legume seed prior to planting (Lindemann and Glover 2003). Soil tests can be used to determine if the appropriate strain of Rhizobium is present in the soil. However, if a legume species is being seeded on a parcel of land for the first time it is highly unlikely that the correct strain of bacteria will be present (Canadian Organic Growers 2001). If a legume has been produced for several years on the same section of land, there is a greater chance that the correct strain of bacterium will be present in the soil in a sufficient quantity and thus inoculation will not be required. The nitrogen-fixing bacteria live on the legume roots in small growths called nodules (a unique characteristic of legume plants) (Lindemann and Glover 2003). When the bacteria are present on the nodules, they will convert N_2 into NH_3. The legume plant then absorbs the NH_3 produced by the bacteria. When a legume plant fixes nitrogen, this nitrogen does not go directly into the soil. The nitrogen produced actually remains within the plant. When the legume plant dies, its vegetation decomposes and returns the excess absorbed nitrogen back to the soil. Therefore, legumes will fix nitrogen to fulfill their own nutrient requirements during their growth and development as well as contribute additional nitrogen to the soil that can be used by subsequent crops. When an annual grain legume is included in the rotation, it is harvested for seed. Therefore, a smaller amount of its vegetation is not left to decompose on the soil surface. In this case, only a limited amount of nitrogen is returned to the soil through the plant's remaining stalks, leaves, and roots. A cover crop, however, is not harvested and all of its vegetation is left to decompose on the soil surface.

Two annual legume plants are considered in this analysis: black lentil and field pea. The nodules formed on annual legume plants are only short-lived and are thus replaced several times throughout the growing season (Lindemann and Glover 2003). In addition, once the plant begins to fill its pods, the nodules no longer fix nitrogen as all the plant's energy is devoted to seed formation. The amount of nodules present on a legume plant varies by species. Similarly, some legume species are better at fixing nitrogen than others. In some cases, a legume plant may not fix any nitrogen at all. The legume plant will fix very little to no nitrogen if an inefficient strain of Rhizobium is present in the soil, if inadequate nutrition is provided to the plant, if the plant is in the pod filling stage, if high levels of nitrogen are present in the soil, or if the plant is stressed. In order to be certain the legume has adequate access to an efficient strain of Rhizobium, the seed should be inoculated prior to seeding. When there is a large amount of nitrogen present in the soil, the legume will not fix its own nitrogen as it takes less energy for the plant to absorb nitrogen from the soil than to fix nitrogen from the atmosphere. Therefore, management practices can heavily impact nitrogen fixation. Producers can fertilize, inoculate, and/or irrigate to increase nitrogen fixation. However, several factors that are out of the producer's control such as temperature, pests, and weather can inhibit nitrogen fixation.

2.8 Additional Benefits of Legumes

Incorporating annual grain legumes and legume cover crops into a grain rotation is important not only in terms of reducing the financial impact of increasing fertilizer prices on producer net returns, but also in terms of offering several other benefits that, in the long-term, may contribute to reduced input costs and greater net returns. Table 2 outlines the non-nitrogen, agronomic benefits related to including legumes in any cropping systems.

Table 2. Agronomic benefits of annual legumes and legume cover crops

Agronomic Contribution of Legume	Description
Reduced Soil Erosion	Soil that is left bare is highly susceptible to becoming eroded from wind and water (Sustainable Agriculture Network 1998). The above ground biomass of a cover crop provides ground cover and helps to reduce to impact of raindrops hitting the soil. Raindrops loosen soil particles and leave them susceptible to being carried away by wind and water.
Conservation of Soil Moisture	During its production period, a cover crop uses excess soil moisture, thus preventing it from being leached away (Unger and Vigil 1998).
Increased Availability of Moisture to Subsequent Crops	When a cover crop is terminated, its residues are left on the soil surface (Zentner et al. 2002). These plant residues hold water and prevent evaporation. This retained moisture is available to the following crop and can be beneficial during times of drought.
Reduced Nitrate Leaching and Runoff	Nitrate losses are reduced by cover crops as excess nitrogen is immobilized in the plant's tissue (Entz et al. 2001). Nitrate leaching and runoff releases sediments, nutrients, and chemicals into non-point sources of water (Sustainable Agriculture Network 1998). Nitrate leaching also represents an unproductive use of resources as this nitrogen is no longer available for crop use.
Interruption of Disease Cycles	Rotations that include a more diversified range of crops are less likely to be susceptible to disease, as different crops tend to be susceptible to different diseases (Sullivan 2009).

Reduced Pesticide Costs	Pesticide costs are reduced as legumes can: host microbial life that discourages disease, create an inhospitable soil environment for many soil borne diseases, and encourage beneficial insect predators and parasitoids that can prevent insect damage (Sustainable Agriculture Network 1998).
Increased Soil Organic Matter Levels	Cover crops build soil organic matter levels in the soil (Sustainable Agriculture Network 1998). Organic matter improves soil structure, increases the infiltration and water-holding capacity of the soil, allows for more efficient storage of nutrients, and increases the cation exchange capacity of the soil.
Reduced Risk	Including a legume in a grain rotation increases the overall diversity of that system (Zentner et al. 2002). Highly diversified rotations are less risky as the prices of grain and legume crops tend to be negatively correlated.
Weed Suppression	Cover crops provide ground cover and thus act as a canopy and intercept light (Martens, Hoeppner, and Entz 2001). This in turn inhibits the growth of unwanted plant species. Cover crops also use up soil resources such as water and nutrients making them competitive with weeds. Further, they alter the temperature of the soil, which impacts weed infestations.
Increased Soil Aggregation	Legumes improve soil aggregation and this is beneficial as well aggregated soils has better structure, workability, erodibility, aeration, and water infiltration and retention (Campbell, Myers, and Curtin 1995).
Reduced Energy Demand	Legume crops fix their own nitrogen requirements and add nitrogen to the cropping system. Therefore less energy is used in the cropping system, as less nitrogen needs to be applied. Further, it

	requires more energy to make nitrogen fertilizer than it does to make legume seed.
Increased Nutrient Availability	When a legume plant decomposes, the nutrients that it accumulated over the growing season are slowly released into the soil and made available to the following crop (Sullivan 2009)
Reduced Soil Salinity	Legumes have extensive roots systems, which means they can access greater amounts of subsoil moisture that in turn reduces soil salinity (Martens, Hoeppner, and Entz 2001)

2.9 Environmental Impact of Nitrogen

There is a growing concern over the impact that the application of synthetic nitrogen fertilizer is having on the environment. When farmers apply nitrogen fertilizer to their crops there is an increased risk of nitrate leaching and volatilization. Leaching is a result of both over-application of nitrogen by producers and poor nitrogen utilization by crops (Canadian Organic Growers 2001). When the nitrogen fertilizer is leached from the field, there is an increased potential for the fertilizer to end up in major bodies of water.

Specifically, in Manitoba, there is a growing concern regarding the quality of the water in most major bodies of water. Agricultural production in the area of lake Winnipeg's watershed is suspected to be responsible for some of the nitrogen polluting the lake (CBC 2009). When nitrogen is leached away from agricultural production sites and into water sources, it feeds the growth of large algal blooms and macrophytes in surface water. This process is referred to eutrophication, which has become a major water quality issue in Manitoba as the death and decomposition of algae in the water consumes a large quantity of the oxygen already present in the water. This is dangerous as it limits the amount of oxygen available for fish and other aquatic species living in the water. As a result, the biological life in the water is greatly reduced and potentially eliminated. This can have devastating effects on fisheries, recreation industries, and aquatic life.

Table 3 outlines the major consequences of algal blooms and macrophytes in surface water, as presented by Manitoba Conservation (2000).

Table 3. Impact of excess algal blooms and macrophytes

Impact	Description
Growth of Opportunistic Species	Excessive growth of algal blooms and macrophytes will alter the structure of the ecosystem in which they are present thereby allowing for the growth of opportunistic species. When these new species emerge there is a decrease in the biological diversity across the entire ecosystem.
Reduced Levels of Dissolved Oxygen	When algae and macrophytes die-off, the decay process uses up large amounts of dissolved oxygen. This in turn negatively impacts the survival of aquatic animals such as fish and invertebrates that rely on an adequate supply of dissolved oxygen for survival. Low oxygen levels in the water are also a cause for concern as reduced oxygen leads to the release of phosphorous from sediment. A higher level of phosphorous in the water increases algal growth.
Production of Harmful Toxins	The algal blooms associated with eutrophic waters are often dominated by species of blue-green algae. Some of these species are known to produce extremely harmful nerve and liver toxins. The presence of these toxins will reduce the suitability of the water supply for domestic, livestock, and recreational use because there is a health risk that the water will be dangerous to all humans, household pets, and livestock that use the water for drinking as well as for those who use the water for recreational purposes. In addition, it is believed that the harmful toxins produced by the blue-green algae can be transferred up the food chain and could have negative consequences for wildlife populations including fish and water birds.

Reduced Drinking Water Quality	A large amount of algal blooms in a drinking water source can also potentially clog-up treatment plant filters and add an unpleasant taste, odour, and appearance to the finished water
Reduction in Recreational Use of Water Sources	A large amount of algal blooms are also described as being visually unpleasing and thus can result in a substantial decrease in the use of the surface water for recreational purposes.

The nitrogen that ends up in Manitoba's major bodies of water comes not only from agricultural fertilizer but also from human and animal waste. The Lake Winnipeg Stewardship Board estimated that the nitrogen loading in lake Winnipeg alone in 1970 was 62,000 metric tonnes (Welch 2008). By 2001 this figure had increased by 55 percent leading to a recorded level of 96,000 metric tonnes of nitrogen in lake Winnipeg. From an environmental perspective nitrate leaching is harmful as it pollutes water sources. From a societal perspective, nitrate leaching is not desirable as it results in an inefficient use of resources because the nitrogen that is leached from the cropping system could have been used to feed growing crops.

2.10 Risk Management

Risk management is an important tool in agricultural production. Incorporating natural sources of nitrogen such as annual legumes and legume cover crops into grain and oilseed rotations helps farmers to reduce risk in their farm operation. Specifically, these crops allow them to deal with the risk and uncertainties regarding the price and supply of nitrogen fertilizer. By adopting these production strategies, farmers will become less reliant on commercially produced nitrogen fertilizers for successful crop production. Relying on commercially produced nitrogen fertilizer can be risky as many factors outside the producers control influence both the supply and price of this input. Since the production of nitrogen fertilizer relies on ammonia production, which is in turn tied to the price of natural gas, there are many factors that will increase the volatility of the price of natural gas. These forces that affect the price of natural gas and in turn nitrogen fertilizer are generally out of the control of the producer. These factors include: tightening of the world supply and demand of natural gas, embargos on natural gas, and other political events.

By incorporating legumes into a grain rotation, the diversity of the rotation is increased. Increasing the diversity of any crop rotation is viewed in itself as being a form of risk management. When diversity exists in a crop rotation, yield and income become more stable as these types of rotations tend to produce higher yields and have a lower incidence and buildup of pests and diseases.

Chapter 3: Literature Review

3.1 Introduction

There is an extensive body of literature covering the issues relevant to this research question. The first section of this chapter reviews the studies that have confirmed through various field experiments that the agronomic conditions in southern Manitoba are suitable for legume crop production. The second section presents the various studies that have been conducted regarding the economic potential of including legumes in non-legume based crop rotations. These studies used both deterministic and stochastic models to evaluate the various cropping systems. The last section discusses the agricultural economic studies that have used stochastic simulation models and utility-based risk ranking procedures to evaluate new and different agricultural production strategies.

3.2 Feasibility of Legume Production in Southern Manitoba

Martens, Hoeppner, and Entz (2001) studied the feasibility of including a double-cropped[3] legume into a rotation with both a winter wheat and fall rye crop. Two legume crops, black lentil and chickling vetch, were seeded following a winter wheat and fall rye harvest and their establishment and dry matter production was assessed. It was found that including either of the double-cropped legumes into a winter cereal-based cropping system would be feasible in southern Manitoba. In addition, Martens, Entz, and Hoeppner

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[3] Double-cropped legume cover crop is the term used to describe a grain crop and a legume crop that are produced in sequence on the same field without over lapping.

(2005) studied the fertilizer replacement value that both double-cropped black lentil and chickling vetch legume cover crops could provide to a subsequent oat crop. The oats were direct seeded into the plots previously containing a legume cover crop and were not treated with any nitrogen fertilizer. Comparing the oat yield following a legume to the oat yield following a non-legume control, it was found that black lentil had a fertilizer replacement value of 23 kg N ha^{-1} in the following oat crop while chickling vetch contributed a value 29 kg N ha^{-1}. Therefore this study established that these double-cropped legumes provide valuable amounts of nitrogen to a subsequent oat crop when produced in southern Manitoba.

The potential of including an annual grain legume into a wheat-based rotation in southern Manitoba was studied by Przednowek et al. (2004). Four legumes and one non-legume (flax) were seeded in two locations in southern Manitoba, Brandon and Carmen. After these four crops were harvested a spring wheat crop was seeded and no nitrogen fertilizer was applied. It was found that of all the legumes tested (field peas, soybeans, dry beans, and chick peas) field peas provided the greatest rotational benefits to the subsequent spring wheat crop.

3.3 Economic Analysis of Legume Cropping Systems

The economic effects of legume cover crops on farm net returns were evaluated in the United States by Frye, Smith, and Williams (1985). This study paired four cover crops with three different levels of nitrogen fertilizer and evaluated the benefit on a main corn crop. Deterministic budgets for corn production under each alternative were created to calculate the direct cash costs of production. The most economical system was determined by calculating net returns over direct expenses. It was found that the highest main crop yield was achieved when a cover crop was used in conjunction with synthetic nitrogen fertilizer. In addition a legume cover crop with some level of applied nitrogen fertilizer reduced the variability in net returns.

Lichtenberg et al. (1994) determined the economic benefit of including a legume cover crop in a corn rotation by estimating continuous crop nitrogen response functions for various cover crop systems. Once the response functions were estimated, they were used to derive profit-maximizing nitrogen applications under different price conditions. Yields from a three-year study of corn following four different cover crops and four nitrogen fertilization rates were evaluated. Regression analysis was used to estimate and evaluate the quadratic functions for corn yield. The nitrogen response functions were plotted and net revenue was calculated at the nitrogen level that produced the greatest yield. It was estimated that between 2% and 5% of the profit-maximizing nitrogen application rate in corn could be reduced by incorporating legume cover crops in the rotation.

Roberts et al. (1998) evaluated four legume cover crop treatments each with five different levels of applied nitrogen for their yield effect on a main corn crop. The four production alternatives were evaluated by estimating quadratic yield response functions. These functions were used to predict the profit-maximizing nitrogen application rates, yields, costs, and net revenues above variable, fixed equipment, and overhead costs. The authors found that between 16% and 23% of the profit-maximizing nitrogen application rate in corn could be reduced by incorporating legume cover crops in the rotation. Further, it was concluded that without any applied nitrogen, the legume crops could fix enough nitrogen to increase corn yields. Lastly, as more nitrogen was applied to the legume crop, the yield benefits of using legume cover crops decreased.

The three studies discussed above suggest a positive economic outcome when legume crops are included in various crop rotations. However, they failed to include sources of risk and uncertainty present in agricultural crop production such as the impact of weather variability on net returns. The research reported in this thesis does not suffer from this deficiency.

Giesler, Paxton, and Millhollon (1993) studied the effects of incorporating various winter legume cover crops into an annual cotton production system. The authors applied Stochastic Dominance with Respect to a Function (SDRF) to determine the most economical cropping system among three different cover crop systems and two conventional systems. The stochastic dominance ordering in that study was based on the expected net returns of each system as well as the risk attitude of cotton producers. The study concluded that within every one of the sixteen different risk intervals, a cover crop strategy was always ranked highest. Similarly, in all sixteen intervals a conventional treatment was never preferred to a cover crop treatment.

Larson et al. (1998) evaluated the potential of incorporating various winter legume cover crops into an annual no-tillage corn production system, using two different cover crop treatments and one no cover treatment, each with five varying levels of nitrogen fertilizer. The effects were measured on the resulting annual net returns of a corn crop. The authors utilized stochastic dominance ordering to determine the most risk-efficient system for a broad range of both risk seeking and risk averse corn producers. It was concluded that for a wide range of both risk averse and risk seeking corn producers, a vetch winter cover crop with 150 pounds per acre of applied synthetic nitrogen would maximize expected net revenue. The authors also established that it is unlikely both extremely risk averse and extremely risk seeking producers would choose to incorporate winter legumes into their production system.

3.4 Agricultural Risk Analysis Methods

Several studies have applied similar risk analysis methods to analyze a variety of risky agricultural production decisions. Kramer and Pope (1981) utilized stochastic dominance to determine the resulting benefits to agricultural producers from participating in farm commodity programs. The authors found that the decision to participate in farm commodity programs was heavily influenced by the producer's subjective probability and risk attitude. In addition, this analysis established that stochastic dominance is a practical and inexpensive tool for making decisions in an environment heavily characterized by uncertainty.

Labarta et al. (2002) conducted a study to evaluate the tools required to conduct an analysis regarding alternative potato production systems in Michigan. The study focused mainly on incorporating manure and cover crops into potato-based production systems. Within this analysis the benefits and costs of utilizing cover crops were examined, various types of budgets were explained, and stochastic dominance procedures were applied to determine the most risk-efficient potato production system.

Wilson, Gustafson, and Dahl (2006) utilized stochastic dominance to simulate payoffs for various crop insurance and contracting strategies. The resulting distributions of net returns were analyzed using both Stochastic Efficiency with Respect to a Function

(SERF) and SDRF to determine the most risk efficient crop insurance and contracting strategy for malting barley producers in the U.S. Northern Plains. Using SERF and SDRF also allowed the authors to compare the effects of risk aversion on preferences. Their model analyzed net returns by incorporating risk through variability in yield, price, quality, and acceptance of a barley crop. With the use of a stochastic dominance model, the authors found the efficient choices for dryland growers were highly dependent upon risk attitude. On the other hand, the efficient choices for irrigated growers were not at all dependent upon the risk attitude of the producer.

Ribera, Hons, and Richardson (2004) compared the economics of conventional tillage and no-tillage systems on three commercial crops in southern Texas. The authors estimated the empirical distributions of net income for the alternative tillage systems using a simulation model and the Monte Carlo sampling procedure. Since the alternative tillage systems included sources of risk, Certainty Equivalents (CEs) were utilized to rank the various systems and calculate the individual risk premiums in each case. Using these ranking procedures, it was concluded that in three out of five crop rotations considered, a risk neutral decision maker would prefer no-tillage to conventional tillage. Furthermore, if the decision maker is assumed to be risk averse, the no-tillage cropping system was selected over the conventional tillage system for all five rotations.

Lien (2001) utilized a stochastic budgeting model to evaluate five different management and investment strategies for a case farm in Norway to find a strategy that would increase the overall net profit of the farm. The stochastic budgeting approach allowed for risk and uncertainty to be included in a study that may have otherwise used a deterministic budget and sensitivity analysis. The distributions of the risky variables accounted for stochastic dependency among these variables. A Subjective Expected Utility (SEU) approach was applied, as the belief that the right probabilities to use for the decision analysis come from the decision maker's own subjective probabilities. The distributions were sampled using the Monte Carlo sampling procedure and the risky strategies were evaluated using both Cumulative Distribution Functions (CDFs) and SDRF. It was found that a strategy involving investing in a new livestock shed was extremely risky and the most advisable alternative was for the producer to abandon the milk production in the future when the milk quota price increases and to become a part-time farmer, strictly focusing on cereal production.

A stochastic simulation model was used by Weisensel and Schoney (1989) to compare three variables: 1) the annual farm income available for family living, income taxes, and capital acquisitions; 2) the total income available for capital acquisition and investment; and c) net worth. These three variables were applied to two alternative crop rotations, one wheat-based rotation and one wheat rotation including a lentil crop, on a representative farm in Saskatchewan. CDFs were simulated and evaluated using three efficiency methods: First-Degree Stochastic Dominance (FSD), Second-Degree Stochastic Dominance (SSD), and SDRF. The simulation results estimated the lentil rotation to be more profitable but at the same time bring greater income variability. Based on risk attitudes, it was concluded that risk averse farmers in Saskatchewan would be highly unlikely to include a lentil crop in a wheat rotation. However, risk preferring producers would be more likely to adopt the lentil rotation versus the wheat rotation.

Duke et al. (2009) used simulation to determine the viability of incorporating canola into a continuous wheat rotation in the Southern Plains of the United States. A program was used to simulate the net returns of four different production systems based on yield distributions and fixed cost estimates. Yields were obtained subjectively from producers in the area who grew both canola and wheat for at least three years. A phone survey was also conducted among these same producers to obtain estimates of future canola and wheat yields. The producers were asked to provide an estimate of a low, average, and high yield so a triangular distribution could be estimated. Crop budgets were based both on research and producer experience. Costs that were similar among both wheat and canola crops were excluded from the budgets. One hundred growing seasons were simulated and the rotation incorporating a canola crop was predicted to provide the greatest net return. This same rotation was also estimated to have a 34% probability of a negative net return in one growing season. It is still inconclusive whether the yields estimated by producers provide an accurate estimate of future yields. Thus the result of this type of study may be overly optimistic.

From the literature discussed above, it can be established that legume crop production is suitable to the agricultural climate in Manitoba and that these crops can contribute a substantial amount of nitrogen to the system. As well, the use of stochastic simulation whereby methods of stochastic efficiency are used to evaluate various production alternatives are established methods for making decisions in agriculture where sources of risk and uncertainty define the production environment.

Since it has been established that legumes can contribute a significant amount of nitrogen to various cropping systems in southern Manitoba, the economic potential of these cropping systems needs to be assessed. This question has been previously evaluated in the United States in mono-cropping systems, but legume crops have not been economically studied simultaneously as an annual crop and a cover crop.

Chapter 4: Theory

4.1 Introduction

Chapter 4 presents the theory of decision making under risk from which the crop rotation model is based. An appropriate economic framework is necessary to accurately determine the most appropriate production alternative for a producer with an assumed level of risk preference; the purpose of this chapter is to establish and explain this framework. The first section defines the concept of risk and outlines the various sources of risk that influence agricultural crop production. Section two explains the three major levels of risk preference; while the third section discusses the utility theory that forms the basis for the methods for ranking risky alternative choices. In the final two sections, the theory behind the specific risk ranking methods of CEs and stochastic efficiency is explained.

4.2 Risk

Agricultural decisions are made in an environment highly characterized by risk and uncertainty. When a producer is presented with various alternatives and must make a decision, it is difficult for them to accurately determine which is the correct choice to make. According to Hardaker et al. (2004a), a "good" decision is one that is consistent with what the decision maker believes about the uncertain aspects surrounding the decision in addition to the decision maker's preferences for the alternative consequences.

In agricultural economic analysis, many definitions of risk and uncertainty have been established. Hardaker et al. (2004a) define risk as undertaking any action involving uncertain consequences. Uncertainty is defined distinctively from risk as imperfect knowledge. Lien (2001) provides two additional interpretations of risk: the chances of bad outcomes and the variability of outcomes. Uncertainty is not analogous or equivalent to risk. Uncertainty, unlike risk, is value-free and the possible outcomes of an uncertain decision can be portrayed by a probability distribution (FAO 1997). When it comes to farming, decisions that are uncertain are those for which the producer has no control over. Therefore, an uncertain decision is one for which there is no single sure outcome and forces beyond the farmer's control affect and determine the outcome of these decisions.

Taking a risk involves exposure to a chance of injury or loss (Hardaker et al. 2004a). In farming, some farm management decisions can be taken with no need to account for the risks involved. However, some farm decisions are very risky and will warrant giving more attention to the choice among the available alternatives. Risk is present when the uncertain consequences of a decision are viewed by the decision maker as being significant because they will affect their overall well being. When speaking specifically in terms of farming, uncertainty is always present while risk may or may not be (FAO 1997).

Farming, along with most other business sectors, is exposed to risk from the economic, social, policy, and political environment. Hardaker et al. (2004a) presents six specific types of risks observed in agricultural production. Production risk comes from the unpredictable nature of weather and uncertainty about the performance of crops and livestock. Production risk also includes the fact that prices of farm inputs and outputs are rarely known for certain when production decisions must be made. Price risk comes from unpredictable currency exchange rates. Institutional risk is risk that the government usually brings on with the introduction of various rules and policies. For example, a policy restricting the amount and type of pesticides that can be applied during a cropping season would be a form of institutional risk. Within institutional risk is sub-categories of political risk (risk of unfavourable policy changes), sovereign risk (risk that foreign governments will fail to uphold commitments such as trade agreements), and relationship risk (risk streaming from issues between business partners or other trading organizations). Human/Personal risk is a risk that develops within those operating the farm. Crises such as death and/or divorce of those operating the farm may threaten the existence of the operation. If one of the owners becomes seriously ill, production could be lost or significantly altered, which may in turn reduce returns. Losses in this category may also be a result of carelessness by the farmer or farm workers in using inputs such as machinery or handling livestock. Business risk is the combination of production, market, institutional, and personal risk. This type of risk affects the business independently of how it is financed. Business risk impacts the farm business performance in terms of the net cash flow generated or net farm income earned. Financial risk results from the method used to finance the farm. There is risk when the farm uses borrowed funds to provide some of the capital for the operation of the farm. In this case, some of the operating profit must be allocated towards meeting the interest charges on the borrowed funds. Similarly, financial risk exists when: funds are borrowed and interest rates unexpectedly rise, the loan is called-off by the lender, and there is a limited or lack of availability of loan finance when required by the farm. The FAO (1997) also includes 3 external sources of risk in agriculture production. Natural environment risk is risk from short-term weather conditions (drought, flood, frost, and storms) and long-term climate factors (climate change leading to increases in variability from issues such as the Greenhouse Effect). Natural hazards such as earthquakes, landslides, wildfires, and ever-changing incidences of pests and diseases are also included as sources of natural environment risk. These risk factors directly impact yields, which further indirectly impact prices through a change in supply. Economic environment risks come from uncertainty about market demand and supply which in turn influences prices of inputs and outputs, inflation and interest rates which affect long-term planning, and productivity resulting from the availability of new technology. Social environment risks are risks that occur over the long-term, as the availability and competence of farm labour is affected by changes in lifestyle and education. Other social events such as war are included in this type of risk as they could also severely impact a farm operation.

In simulating crop rotations, prices, yields, and net farm returns are exposed to risk. Any decision in a simulation model that involves risky consequences is referred to as a risky prospect. Risky consequences are a combination of a decision and its related outcomes. The outcomes are risky due to events or states of nature over which the farmer has no control. For example, the farmer has no control over the price of inputs such as fertilizer or outputs such as crop prices.

4.3 Risk Aversion

Several variables in agricultural crop production make net returns risky and uncertain. Crop prices could fluctuate during production and after harvest, which could increase or decrease returns (Pindyck and Rubinfeld 2006). Similarly, weather is unpredictable and uncontrollable. Excess or deficient amounts of moisture could reduce crop yields and crop quality, further reducing the amount received for a harvested crop.

Individuals' attitudes toward risk affect many of the decisions they make. There are three categories commonly used to characterize a decision makers' attitude toward risk: risk averse, risk neutral, or risk preferring (Pindyck and Rubinfeld 2006). An individual who is risk averse is said to prefer a level of income that is certain compared to a risky income with the same expected value. Such a person has a diminishing marginal utility of income or wealth. An individual who is risk averse can be described by their willingness to pay a certain amount of wealth to avoid the risk involved in a gamble. Similarly, the greater the variability of income, the more the person would be willing to pay to avoid the risky situation. In agriculture, it is assumed that the majority of farmers are risk averse. This assumption is based on the observed behaviour of the majority of farmers (Hardaker, Huirne, and Anderson 1997). For instance, farmers are willing to buy production insurance and adopt farming systems that are more diversified than what might seem best based solely on profit. For an individual who is risk averse, losses are weighted more heavily than gains. When a decision maker exhibits a risk neutral attitude they are defined as being indifferent between a level of income that is certain and an uncertain income with the same expected value. If the individual displays a preference for risk or a "risk loving" attitude, they are said to prefer an uncertain income to a level of income that is certain, even if the expected value of the uncertain income is less than that of the certain income.

The general assumption of risk aversion is that more money is preferred to less and is mathematically represented by

$$U^{(i)}(w) > 0, \quad (1)$$

where $U^{(i)}(w)$ is the i-th derivative of the utility function U and w represents wealth. If the first derivative of the utility function is positive, then it is the case that the decision maker prefers more to less and is thus risk averse (Hardaker et al. 2004a). Similarly, if the second derivative of the utility function is negative, this also implies the decision maker is risk averse. If the second derivative of the utility function is equal to zero the decision maker is assumed to be risk neutral, and if it is positive they are characterized as having a risk preferring attitude.

The inclusion of the level of the farmers risk preference is an important factor in any agricultural study. Risk averse behaviour by agricultural producers not only impacts the decisions made by these individuals but also further impacts society: if a farmer is risk averse, they may prevent the efficient allocation of farm resources (Hardaker et al. 2004a). For instance, if a farmer has an aversion to risk, they may be slow to adopt new and improved but untried technologies. Economic models that include risk are valuable as they are able to provide a better prediction of an individual producer's behaviour.

Not only can decision makers be defined as risk averse, risk neutral, or risk preferring, they can also be classified based on their degree of risk preference. For example, two decision makers may both be classified as risk averse but one may be *more* risk averse than the other. The degree of a person's risk aversion depends on the nature of the risk and on the person's income. One method of measuring the degree of risk aversion is to measure the curvature of an individual's utility function (Hardaker et al. 2004a). Since a utility function is defined only up to a positive linear transformation, measuring risk aversion using the decision maker's utility function can be fairly difficult to accomplish. Therefore, a measure needs to be used that is constant for a positive linear transformation.

Arrow (1965) and Pratt (1964) developed a more simplistic means for estimating the degree of risk aversion given the fact that the utility function is only defined up to a positive linear transformation. The degree of risk aversion can be measured by the coefficient $R_a(w)$ or equivalently the absolute risk aversion function represented by equation (2)

$$R_a(w) \equiv \frac{-u''(w)}{u'(w)}. \tag{2}$$

Within equation (2), it is implied that the absolute risk aversion coefficient will decrease as the level of wealth increases. This is because it is assumed that individuals are more willing to take on risk as their level of wealth increases. This equation demonstrates the negative ratio of the second and first derivatives of the utility of wealth ($U(w)$) function. If the resulting sign of equation (2) is positive, it is implied that the decision maker is risk averse (Jehle and Reny 2001). A negative sign implies they have a preference for risk, and a value of zero indicates a risk neutral attitude. In addition, the resulting coefficient obtained from equation (2) measures the curvature of the utility function and is not altered by any positive linear transformation of the utility function. Adding a constant will also have no effect on the numerator or the denominator. The numerator and/or denominator will only be affected when they are multiplied by a constant but regardless their ratio will remain unchanged.

The absolute risk aversion function, $R_a(w)$, merely provides a local measure of risk aversion. Therefore, at different levels of wealth, the degree of risk aversion will vary (Hardaker et al. 2004a). Arrow (1965) and Pratt (1964) provided three different classifications as to how the degree of risk aversion varies with increasing levels of wealth. A utility function will display either constant, increasing, or decreasing absolute risk aversion over some domain of wealth if and only if, over that interval, $R_a(w)$ remains constant, increases, or decreases with an increase in wealth (Jehle and Reny 2001). The first classification, Decreasing Absolute Risk Aversion (DARA), imposes the restriction that the decision maker is less averse to taking small risks at higher levels of wealth (Jehle and Reny 2001). The second case, Constant Absolute Risk Aversion (CARA) states that the decision maker does not have a change in their willingness to accept a gamble at higher levels of wealth. In this second case, preferences are unchanged if a constant amount is added to or subtracted from all payoffs (Hardaker et al. 2004a). In addition preferences among risky prospects are unchanged if all payoffs are multiplied by a positive constant. The final classification, Increasing Absolute Risk Aversion (IARA) describes the case where the more wealth the decision maker has, the more averse they become to accepting the same small gamble.

When there is no information available regarding the decision maker's exact risk preference or level of risk aversion an assumption must be made. Arrow (1965) suggested using the relative risk aversion coefficient, $R_r(w)$, to define risk preference and a value of 1.0 as the most common attitude toward risk. The constant relative risk aversion function for $R_r(w) = 1$ is equivalent to $U = \ln(w)$, which is the "everyone's utility function" according to Bernoulli (1738). However, Anderson and Dillon (1992) found that this was too strong of an assumption and proposed a scale for classifying the degree of risk aversion, based on the magnitude of the relative risk aversion coefficient. Table 4 presents the classifications of risk aversion they proposed.

Table 4. Classification of risk aversion

$R_r(w)$	Degree of Risk Aversion
0.0	Risk Neutral
0.5	Hardly Risk Averse at All
1.0	Somewhat Risk Averse (Normal)
2.0	Rather Risk Averse
3.0	Very Risk Averse
4.0	Extremely Risk Averse

If from the classification above, a value for $R_r(w)$ can be established that is assumed to be more or less constant for a local variation in wealth then a value of $R_a(w)$ can also be derived using equation (3)

$$R_a(w) = R_r(w) / w . \quad (3)$$

Hardaker et al. (2004a) suggest that the choice of the exact form of the utility function is rarely important in decision analysis provided the degree of risk aversion is consistently represented. Therefore, if the risk aversion coefficients are derived using the classification presented in Table 4, then they can be used with reasonable confidence in almost any utility function.

4.4 Expected Utility

Decision analysis is the term used to describe the various methods that have been developed to analyze alternative choices that involve risk (Hardaker, Huirne, and Anderson 1997). When a decision involves risky consequences, a framework must be developed such that the various alternatives can be compared. This framework is termed Decision Analysis Under Risk. When the decision maker must choose an alternative that is not certain (i.e. the decision involves risk), the term risky choice is used to imply that a choice must be made between the probability distributions of each of the risky alternatives (Anderson, Dillon, and Hardaker 1977). Therefore, utility theory plays a key role in decision analysis under risk. According to Anderson, Dillon, and Hardaker (1977), the decision analysis framework provides a "practical means whereby preferences are crystallized and consistent choice is simplified." A utility function provides a means of encoding a decision maker's preferences. It also ensures consistency of preferences in an analysis involving more than one choice (Anderson, Dillon, and Hardaker 1977). In decision analysis or equivalently when making a choice among risky prospects, the objective is to select the alternative that provides the greatest expected utility (Hardaker et al. 2004a).

The central theorem of utility analysis is known as either Bernoulli's principle or the expected utility theorem. As far back as 1738 Bernoulli wrote about the SEU hypothesis, which states that in order to assess risky alternatives the decision makers' utility function for any given outcome is required (Hardaker et al. 2004b). The expected utility theory is the most commonly used framework for analyzing decision making under risk. Utility is used to measure a person's preference for the possible consequences of a risky decision (Hardaker 2004a). The shape of the utility function reflects and defines an individuals' attitude toward risk. A concave utility function represents an aversion to risk while a convex function represents a risk preferring attitude. Producers with a linear utility function are said to have a risk neutral attitude toward risk. Decision analysis is often complicated by the fact that for a single risky choice different individuals will have varying attitudes toward the level of risk represented by that decision. However, Hardaker et al. (2004b) state that the SEU hypothesis continues to be the most suitable theory for the assessment of risky choices. The SEU hypothesis is based on four principle axioms (Hardaker et al. 2004a). The first axiom, ordering, implies that a person either prefers one of two risky prospects (a_1 and a_2) or is indifferent between them. The second axiom, transitivity, follows from ordering but expands to include an additional risky prospect, thus a_1, a_2, and a_3. Transitivity states that if a person prefers a_1 to a_2 (or is indifferent between them) and prefers a_2 to a_3 (or is at the same time indifferent between them), then this same individual will either be indifferent between or prefer a_1 to a_3. The third axiom, continuity, infers that if an individual is faced with a risky prospect involving both a good and bad outcome, this individual will take the risk only if the chance of getting the bad outcome is low enough. This axiom can also be explained by saying, if an individual prefers a_1 to a_2 to a_3 then a subjective probability $P(a_1)$ exists that is not zero or one. Further, a probability exists where this individual is indifferent between a_2 and a lottery yielding a_1 with a probability $P(a_1)$ and a_3 with a probability $1 - P(a_1)$. Lastly, the independence axiom states that the preference between a_1 and a_2 is independent of a_3. That is, if a_1 is preferred to a_2, and a_3 is a separate risky prospect, then a lottery with a_1 and a_3 as outcomes will be preferred to a lottery with a_2 and a_3 as outcomes when $P(a_1) = P(a_2)$.

The SEU hypothesis (Bernoulli's principle) can be established based on these four axioms. These axioms measure both preference and subjective probability (Hardaker et al. 2004a). If a decision makers' preferences are consistent with these four axioms, a utility function, U, can be established for that decision maker that associates a single utility value $U(a_j)$ with any risky prospect a_j. The utility function U associates a single real number with any risky prospect. In turn, the utility function has three basic properties. First, utilities can be used to rank risky alternatives. Therefore the alternative with the highest utility can be assumed to be the preferred option. This is represented by stating,

$$\text{if } a_1 \text{ is preferred to } a_2 \text{ then } U(a_1) > U(a_2). \quad (4)$$

Secondly, the utility of a risky prospect is in fact the decision maker's expected utility for that prospect. This can also be defined by equation (5)

$$U(a_j) = \sum_i U(a_j|S_i)P(S_i). \quad (5)$$

Here the expected value is calculated from the utility values of the consequences weighted by the corresponding subjective probabilities. Lastly, the utility function is only defined up to a positive linear transformation. In other words it has an arbitrary origin and scale.

The SEU hypothesis is important as it unities the three foundations of decision making under risk (FAO 1997). Decision analysis is based on the SEU theory because the chances of bad versus good outcomes can only be evaluated and compared if the decision maker's relative preferences for such outcomes are known (Hardaker et al. 2004b). The SEU hypothesis states that the decision maker's utility function for these outcomes is needed to assess risky alternatives because the shape of the utility function is what defines the decision maker's attitude toward risk. The FAO (1997), further states that the SEU hypothesis is significant in decision analysis as it brings together three important elements of risky decision making. These three elements include: the decision maker's personal preferences about possible outcomes, the decision maker's personal degrees of belief in the occurrence of these possible outcomes, and the decision maker's personal responsibility and accountability for whatever decision is taken (through the use of their own personal preferences and probabilities). Since the expected utility theorem brings together these aspects of decision making, it allows for risky prospects to be ranked in order of preference. The risky prospect with the highest expected utility is determined to be the most preferred choice.

In agricultural economics studies where there are alternative risky decisions and an assumed utility function, the SEU hypothesis is valuable because it states that the level of utility can be calculated depending on the degree of risk aversion (r) and the stochastic outcome of the output variable x. This is computed using equation 6

$$U(x,r) = \int U(x,r)f(x)dx \,. \tag{6}$$

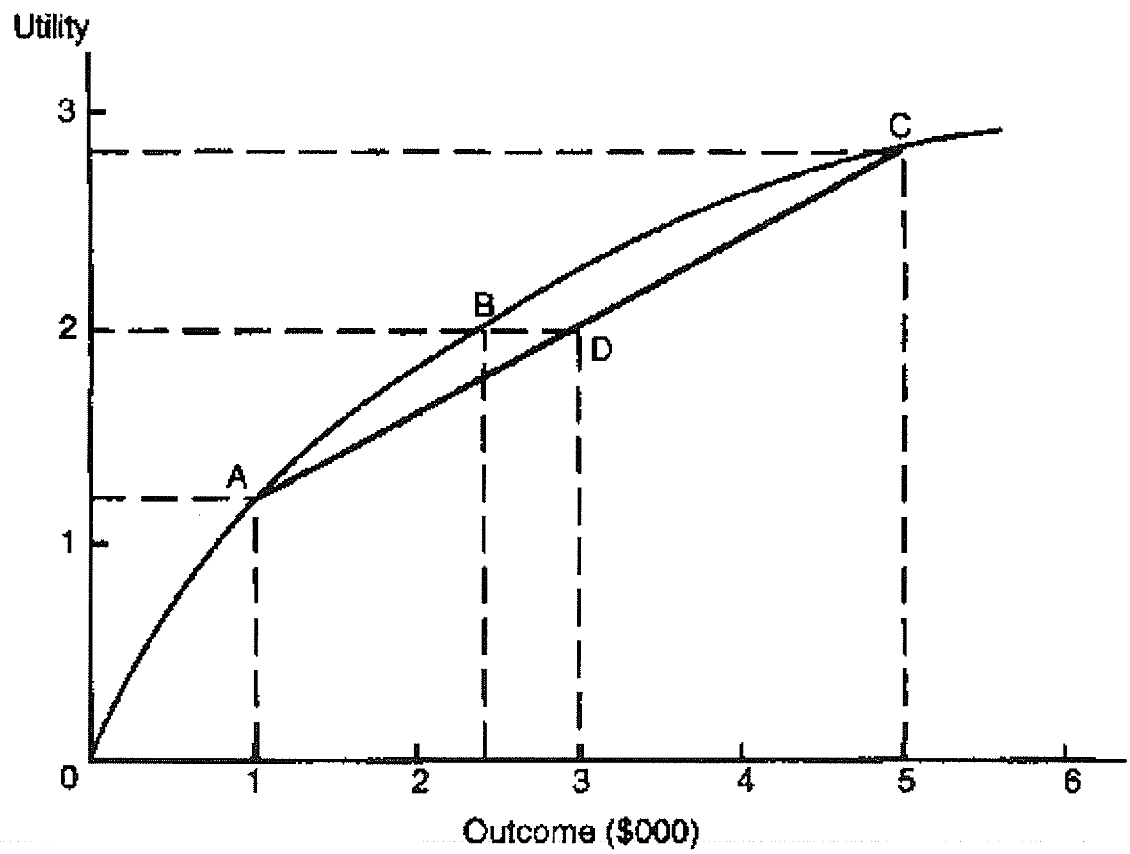
Following this computation, U is calculated for selected values of r in the range of r_1 to r_2. In addition, CEs can be established for every value of U by applying equation 7

$$CE(x,r) = U^{-1}(x,r) \,. \tag{7}$$

4.5 Certainty Equivalents

Using the SEU theory, the concept of CEs can be inferred. When decision analysis is based on financial outcomes, it is useful to compare CEs with the expected value of the risky prospect to determine the risk attitude of the decision maker (Hardaker et al. 2004a). When a decision maker is faced with a decision with risky payoffs, there is a sum of money for sure that would make the decision maker indifferent between either taking the risk or accepting the sure sum of money. This sure sum of money is referred to as the Certainty Equivalent. The CE is the lowest price for which the decision maker would be willing to sell a desirable risky prospect or equivalently, the highest amount that the decision maker would be willing to pay to get rid of an undesirable risky prospect. For the same risky alternative, the CE can vary between individuals because, in general, people have different attitudes towards risk. Figure 1 is used to provide a graphical representation of the theory of CEs. This type of graph is another tool that can be used to explain or depict an individual's attitude toward risk.

Figure 1. Certainty equivalent



Adapted from: FAO (1997)

Figure 1 displays a concave utility curve representing the utility function of a risk averse individual. Within this same figure, two risky alternatives are presented: the first is a possible gain of $5,000 with a probability of 0.5 and the other is a possible gain of $1,000 also with a 0.5 probability. The expected value of this gamble (risky prospect) is $3,000. The expected utility of this same risky prospect is 2 (this is displayed by the line connecting points B and D). In addition, this utility value corresponds to the expected value on the X axis (outcome). Therefore the expected value of the risky prospect is $3,000 and the expected utility is 2. The CE is $2,400. The risk premium for this decision maker is the difference between the CE and the expected value, or $600.

Using CEs to rank risky alternatives is equivalent to ranking them by expected utility (Hardaker et al. 2004a). This implies that risky prospects will be ranked in the order that is preferred by the decision maker. Further, as stated above, the calculated difference between the CE and the expected value is the risk premium. The risk premium is used to measure the willingness to pay to avoid risk. The calculated risk premium is the amount by which the decision maker prefers one alternative over another. The risk premium includes the combined costs of the effects of risk and risk aversion. If the CE is less than the expected value of the risky prospect (the risk premium is greater than zero), the decision maker is said to be risk averse. Similarly, if the CE is greater than the expected value (the risk premium is less than zero) then the decision maker is said to exhibit a preference for risk. If the CE is equal to the expected value (the risk premium is zero), the decision maker is assumed to be indifferent towards risk.

4.6 Efficiency Criteria

In applied research, risk is generally represented by a probability distribution. The probability distributions associated with various risky choices are often quantitatively compared using methods of stochastic efficiency. These methods are highly accepted as means of evaluating risky alternatives, as they only require two assumptions regarding a decision makers' preference for risk (FAO 1997). These assumptions include the decision makers' level of risk aversion and the associated functional form of the utility function.

Efficiency criteria are beneficial as they allow for analysts to rank risky alternatives when a decision makers' utility function is either unknown or unavailable (Hardaker et al. 2004a). Consequently, assumptions must be made regarding individuals' preference for risk as well as the nature of their utility function. In addition, methods of stochastic efficiency often require bounds to be placed on the level of risk aversion. When an efficiency analysis is being conducted and the subjective probability distributions cannot be obtained from or verified with decision makers, the next best alternative is to use abundant, relevant data so that the distributions derived from this data will be reasonably uncontroversial and widely accepted. When assumptions regarding the utility function and level of risk aversion can be applied to a decision maker, there will be a resulting efficient set and inefficient set in which the various alternative risky choices can be placed. The decisions placed in the inefficient set are those that are preferred less to those in the efficient set. The efficient set contains only the risky choices that are not dominated. The more assumptions that can be inferred about preferences the smaller the efficient set will be. Equivalently if nothing can be assumed about preferences, then decisions that are efficient cannot be identified. Given the following two conditions hold, the efficient set will hold the most advisable alternative for the decision maker. The first condition that must hold is that the individual's preferences must be consistent with the assumptions made about the nature of the utility function in deriving the risk efficient set. The second condition is that the individual's subjective probability distributions for outcomes are identical to those assumed for the analysis.

Stochastic dominance, which is a form of SEU analysis, is a stochastic efficiency method used to compare alternative risky decisions (FAO 1997). It is a form of efficiency analysis that encompasses ranking methods such as: FSD, SSD, Third-Degree Stochastic Dominance (TSD), SDRF, and SERF. Stochastic dominance is one of the preferred methods for ranking risky alternatives in applied agricultural research, as it is more realistic and not as discriminating between risky alternatives as are some other methods such as direct utility comparison. Stochastic dominance is used in place of the SEU functions, as it does not require any specific single-valued utility functions to be elicited directly from individual decision makers (Hardaker et al. 2004b). Stochastic dominance is also preferred as it relies on general rather than specific features of the decision maker's utility function. Making use of the SEU hypothesis in applied research can be very difficult as it is almost impossible to obtain an individual decision maker's actual utility. Stochastic dominance can be employed in situations where it is difficult to obtain a decision maker's exact preferences or in situations where more than one decision must be made.

First-degree stochastic dominance has the fewest restrictive preference assumptions of all the stochastic dominance methods. As stochastic dominance progresses further into SSD, TSD, SDRF, and SERF, more restrictive preference assumptions are incorporated (Anderson, Dillon, and Hardaker 1977). Therefore the results of FSD will have a more general applicability while the results of the more restrictive forms of stochastic dominance such as SDRF will be more constrictive in application. FSD is based on the assumption that more is preferred to less. This is also referred to as the assumption of a monotonically increasing utility function where the first derivative of the utility function is strictly positive, $U_1(x) > 0$. Once an efficient set has been established, identification of the most preferred distribution depends on knowing more about preferences than what is assumed in using FSD. Mathematically FSD can be defined where F_1 and G_1 are a pair of CDFs defined in the range $[a, b]$ and are also associated with two risky alternatives, F and G. F_1 is related to its Probability Density Function (PDF), $f(x)$, by equation (8)

$$F_1(R) = \int_a^R f(x)dx . \tag{8}$$

In terms of FSD, F dominates G if $F_1(R) \leq G_1(R)$ for all possible R in the range of $[a, b]$ with at least one strong inequality. The inequality is that the < holds for at least one value of R. This efficiency criterion, along with all subsequent efficiency criterions is transitive. This implies that if F dominates G and G dominates H, F must dominate H.

Second-degree stochastic dominance is used to eliminate distributions from the FSD set that are inefficient. SSD adds the assumption that the decision maker has an aversion to risk. In terms of the utility function over the range of $[a, b]$, the basic assumption surrounding SSD is that the utility function is monotonically increasing and strictly concave, or equivalently $U_1(x) > 0 \text{ and } U_2(x) < 0$. Equation 9 represents SSD mathematically for a distribution F_1

$$F_2(R) = \int_a^R F_1(x)\,dx\,. \tag{9}$$

With the application of SSD, the distribution F is said to dominate G in SSD if $F_2(R) \leq G_2(R)$ for all possible R with at least one strong inequality.

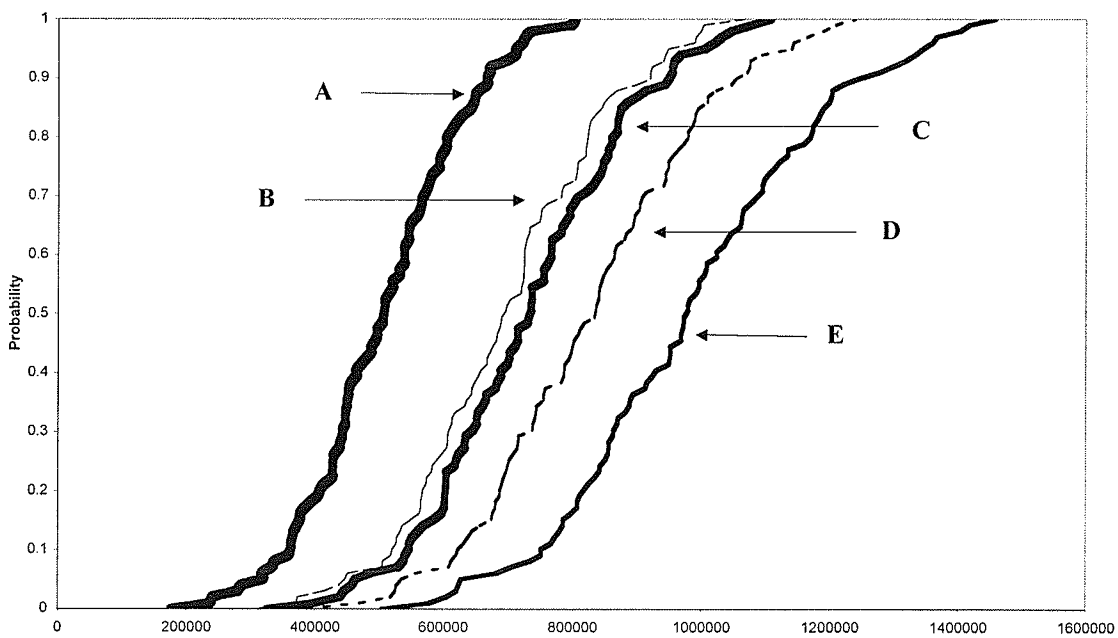
The additional assumption in TSD is that the third derivative of the utility function is positive, $U_3(x) > 0$. This assumption infers that as individuals become wealthier they become less averse to risk. TSD requires the definition of another type of cumulative function, represented by equation 10

$$F_3(R) = \int_a^R F_2(x)\,dx\,. \tag{10}$$

The distribution F dominates G in the sense of TSD if $F_3(R) \leq G_3(R)$ for all possible R with at least one strong inequality. In addition, if $F_2(b) \leq G_2(b)$, where b is the upper range, or equivalently, $E_F(x) \geq E_G(x)$, the distribution F is TSD over the distribution G.

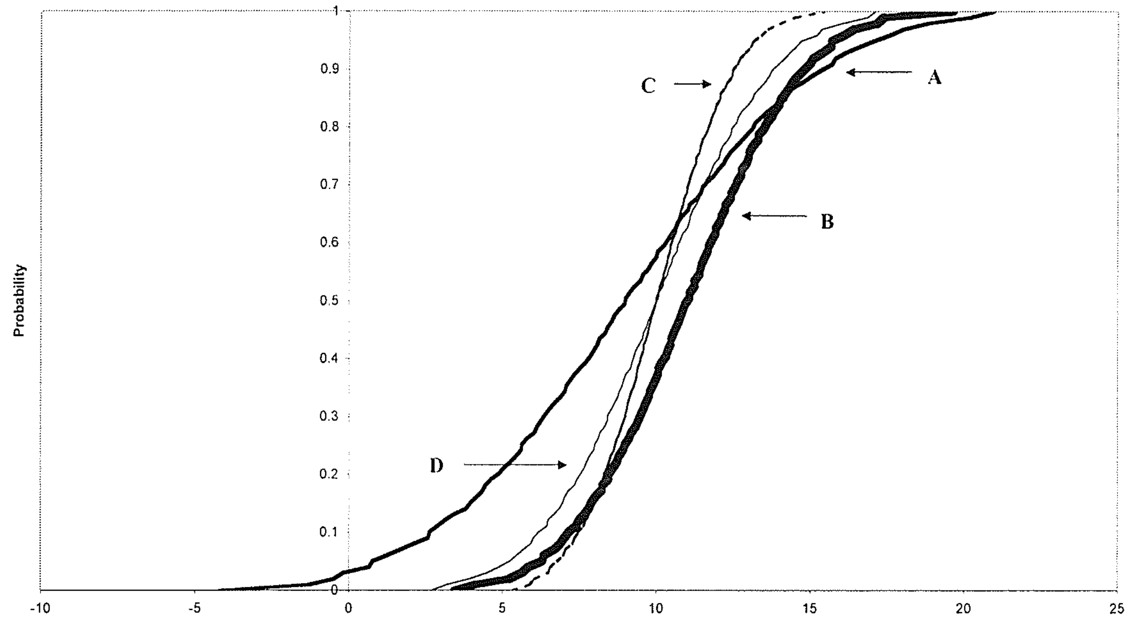
The results of a stochastic simulation model comparing alternative risky choices can be graphed on a CDF chart. A CDF chart is produced as it allows for both, full distributions of the alternatives to be compared and the stochastic efficiency methods to rank the various alternatives. The CDFs for each risky alternative are plotted on one output chart. If the CDFs do not cross, the alternative that lies the furthest to the right is assumed to be the preferred scenario, as it is associated with the highest level of return. Equivalently, the distribution that lines the furthest to the left is the least preferred choice. This is the method by which the FSD alternative is determined. If the CDF lines do cross, an FSD set can no longer be determined and a more discriminating method of stochastic dominance must be applied. Following FSD, SSD is the next most discriminating efficiency method. The SSD rule is that a distribution function, F_1, dominates another distribution, G_1, if it lies more to the right in terms of differences in area between the CDF curves. Therefore the difference between distributions must be summed over all iterations performed. Figure 2 plots the resulting CDFs associated with five risky alternatives. In this figure the distribution labeled "E" is FSD as it lies unanimously to the right of all the other distributions. In Figure 3 a FSD alternative cannot be determined as the CDFs of all the alternatives cross at some point over the relevant range of outcomes. However, using the SSD criterion, CDF "B" is established as being the preferred alternative.

Figure 2. Graphical representation of first-degree stochastic dominance



Source: Adapted from Richardson (2008)

Figure 3. Graphical representation of second-degree stochastic dominance



Source: Adapted from Richardson (2008)

Hardaker et al. (2004a), outline two methods of efficiency criteria, SDRF and SERF that are used more frequently to rank risky decisions in applied research as they have even stronger discriminatory power than FSD, SSD, and TSD. The stronger discriminatory power of SDRF is achieved through the introduction of bounds on the absolute risk aversion coefficient within a SSD analysis (Meyer 1977). The SDRF method is applied to decision makers who have a degree of risk aversion that falls within the specified bounds of $r_1 \le r_a \le r_2$ (where r_1 and r_2 are typically positive numbers) (Hardaker et al. 2004a). SDRF then uses a pairwise comparison between alternatives to discover whether one alternative dominates another. SDRF also requires assumptions to be made regarding the form of the decision makers' utility function. With an assumed utility function, $U(w)$, and an associated risk aversion coefficient in the bounds of $r_L(w) \leq r_a(w) \leq r_U(w)$, equation (11) is analyzed for all values of $r_a(w)$

$$\int [F_2(w) - F_1(w)] U'(w) dw , \qquad (11)$$

where F_i is the risky alternative and $U'(w)$ is the first derivative of the utility function U(w). If the minimum of equation (11) for all values of $r_a(w)$ within the specified range is positive, then the SDRF method states that $F_1(w)$ dominates $F_2(w)$. Similarly, this implies that the utility of $F_1(w)$ is greater than the utility of $F_2(w)$ for all decision makers who have a risk preference that falls within the defined bounds of $r_a(w)$. Further, if the minimum turns out to be zero, this implies that a decision maker is likely to be indifferent between the two alternatives. Lastly, if the minimum is negative, a decision maker prefers $F_2(w)$ to $F_1(w)$. Using equation (11) and replacing the first term $F_2(w) - F_1(w)$ with $F_1(w) - F_2(w)$, this equation can be used to determine if there is dominance of $F_2(w)$ over $F_1(w)$.

In applied research, the decision maker is generally assumed to have a negative exponential utility function. It is also agreed in the literature that either eliciting or inferring the decision maker's bounds on their risk aversion coefficients may be simpler than obtaining full utility functions. The bounds set on the absolute risk aversion coefficient (r_a) in FSD are $-\infty < r_a < +\infty$ and in SSD, $0 < r_a < +\infty$.

Stochastic efficiency with respect to a function is a risk ranking method that is consistent with the SEU hypothesis and is often utilized instead of SDRF as it offers a more simplistic and enhanced method of ranking risky alternatives. SDRF establishes an efficient set by only selecting the alternatives that are dominated in a pairwise comparison (Hardaker et al. 2004b), and as a result it is less likely to establish the smallest possible efficient set. On the contrary, a smaller efficient set is far more likely to be produced when using the SERF method. This method selects the efficient alternatives by simultaneously comparing them with all other alternatives. The SERF ranking procedure works by using a range of risk preferences and associating each preference with a utility efficient alternative. Unlike SDRF, SERF does not find a subset of dominant alternatives. SERF is arguably superior as it compares the alternatives in terms of CEs over the desired range of risk preference. SERF is one of the many efficiency analysis methods that can be used when there is no available information regarding the decision makers' preferences. Therefore, similar to SDRF, SERF requires an assumption regarding the specific form of the utility function and associated measure of risk aversion (Hardaker et al. 2004a). Possible utility functions include the power utility function, the logarithmic utility function, and the negative exponential utility function. However, in the case of SERF, the choice of utility function is less likely to affect the results than does the choice of utility function when the SDRF method is used (Hardaker et al. 2004b). Any utility function can be used in the SERF analysis as long as the inverse function can be calculated.

For each of the specified risky alternatives and the assumed form of the utility function, the function for utility in terms of risk aversion and the stochastic outcome, w, is defined by equation (12)

$$U(w, r(w)) = \int U(w, r(w)) \partial F(w) = \sum_{i=1}^{m} U(w_i, r(w)) P(w_i), r_1(w) \leq r(w) \leq r_2(w). \quad (12)$$

This equation defines the SERF method, which is carried out in three steps. Hardaker et al. (2004b) outlines these steps as first selecting points on the individual CDFs associated with each of the various alternatives for a finite set of values of the outcome measure (w). Secondly, each of these values needs to be converted to its utility by using the assumed utility function, in this case the negative exponential utility function, and selected value of the risk aversion coefficient. Lastly, the resulting utilities are multiplied by their associated probability to produce an estimated of the weighted average of the utilities of outcomes.

When the SERF method is used to rank the risky alternatives, CE values are also computed. To determine the value of the CE, the inverse of the utility function is calculated. If the form of the utility function is assumed to be negative exponential, the CE is defined by equation (13)

$$CE(w, r_a(w)) = \ln\left\{\left(\frac{1}{n}\sum_{i}^{n}\exp(-r_a(w)w_i)\right)^{-\frac{1}{r_a}(w)}\right\}, \tag{13}$$

where $r_a(w)$ is the specific absolute risk aversion coefficient, n is a random sample of size n, and w is the risky alternative. The utility results are converted to CEs, as CEs tend to be easier to interpret. Further, this method allows for the inclusion of the expected money value of each alternative where $U(w, r(w))$ is undefined for $r(w) = 0$. In the SERF sense, the alternative with the highest or equal highest CE value for a given value in the range of $r(w)$ is considered utility efficient and all other alternatives are thus dominated.

Chapter 5: Methodology

5.1 Introduction

Chapter 5 explains the methodology used in this thesis. The first section explains the types of budgets available for use by farmers and provides a detailed description of the budgets created for the model farm. The second section explains the concept of simulation models and how they can be applied in economic studies. There are several different types of distributions available for modeling variables in a simulation model and these are presented and explained in section three. In the fourth section, the historical data upon which this model is based is provided along with the sources from which this data were collected. In addition, this section provides a detailed description of how the various data were applied in the farm simulation model. The fifth section presents the farm model developed for this thesis and the calculations required to solve the crop rotation problem. In the final section, the methods used to rank the alternative crop rotations are presented and discussed.

5.2 Budgets

Budgets provide a foundation for decision analysis in farm management. These tools are useful to farm managers as they help them to organize and manage the farm in a way that is consistent with production goals and objectives (Doye 2008). There are several types of budgets available to farm managers, each used for achieving different goals and objectives. In this model, it is assumed that the farmer's main objective is to maximize the net return from the selected crop rotation. Doye (2008) outlines the three basic and most commonly used types of budgets: whole-farm, enterprise, and partial. The whole-farm budget provides a brief description of the major physical and financial features of the entire farm business, and are used to identify the individual parts of the total farm business and determine how these parts operate both on an individual basis and together as a whole. A partial budget is used in analyzing the resulting effect(s) of changing one specific part of the farm operation. Thus the partial budget only considers the revenue and expense items that will change when there is an isolated change in production. The enterprise budget provides an illustration of what is expected from specific production practices when producing a certain amount of product, and includes revenues obtained, expenses incurred, and the fixed and variable costs of production.

The budget for the crop rotation model is based on individual enterprise budgets for each crop. This specific type of budget was selected since it is the most beneficial in terms of assisting producers to decide which is the best production method to undertake on a farm. It provides both an estimate of overall profitability and resource requirements (Doye 2008). Enterprise budgets are useful to producers when deciding whether to invest in a new production technology as they provide a quick and basic view of the risk involved in the farm's current production activities. They are often used to help producers make both short and long-term economic decisions regarding the farm's production and operation. Lastly, they are advantageous as they allow producers to analyze various production options before resources are committed.

Doye (2008) lists the various components that should be included in a crop enterprise budget. Production should be determined by multiplying the quantity produced by the actual or estimated price; price estimates need not include government program payments, especially if the payment is not tied to crop production. All costs listed in an enterprise budget must fall into one of two categories: fixed or variable. Fixed costs, which do not vary with output, are input items prorated over a period of one year and include buildings, machinery, equipment, and the related costs attributed to these items such as taxes, depreciation, interest, and insurance. Variable costs change with the level of output and include input items used during one production period such as seed, fertilizer, labour, machinery, and repairs. Overhead costs that are not specifically allocated to any one individual production activity associated with the farm operation are often excluded from enterprise budgets. Overhead costs can be either fixed or variable and include items such as: electricity, accounting services, and telephone expenses. Each crop budget in this analysis is formulated as an income statement, showing all revenues and costs associated with the production of a specified crop. Within the individual crop budgets, a net return is estimated. The summation of the individual net returns associated with each crop in the rotation determines the overall net return for the rotation.

An enterprise budget uses point estimates of price, yield and the various cost parameters. This in turn provides a single estimate of the farm's net return for that production year. This basic enterprise budget assumes certainty, however many factors outside the producers control can cause variability in several of these estimates. A more accurate portrait of crop production can be painted by incorporating risk in some of the budget variables; these variables become random or stochastic variables. Accounting for risk in some of the budget variables is referred to as stochastic budgeting. Therefore, in order to account for risk in crop production, stochastic budgeting is applied to the enterprise budgets developed for the individual crops produced on the model farm.

Stochastic budgets are identical to any other budget except that they recognize risk by attaching probabilities of occurrence to the possible values of the stochastic variables (FAO 1997). In turn, a probability distribution of possible budget outcomes is generated. Generally, the probabilities used in the stochastic budget are obtained directly from the decision maker, but in the crop rotation model, direct producer probabilities are not used, as it is too difficult and time consuming to obtain realistic and accurate subjective probabilities. Therefore, the risk aversion coefficients defined by Anderson and Dillon (1992) are used in the stochastic budgets as a means of estimating the decision maker's risk aversion coefficient for the parameter of the utility function.

The enterprise budgets developed for each individual crop contain deterministic values for the variable and fixed cost parameters. Crop and nitrogen prices are stochastic as prices of farm inputs and outputs are rarely known when farmers must make a decision about how much of which crops to plant and what quantities of inputs to purchase. The markets for farm inputs and outputs are highly competitive and unpredictable; in turn, market prices are determined outside the farmers' control. Crop yields are stochastic as crop yields are heavily impacted by unpredictable incidences of pests and disease as well as weather forces such as temperature, rainfall, and frost. Lastly, nitrogen application rates are stochastic as again the residual level of nitrogen remaining in the soil after a crop is harvested is strongly affected by variables such as moisture and temperature, which cannot be controlled by the farmer. Since crop yields, nitrogen application levels, and prices are stochastic in this model, the values associated with these variables are represented by probability distributions rather than fixed point estimates.

5.3 Simulation

Simulation is a risk management tool that can be applied to various agricultural problems to aid farmers to make decisions in an environment characterized by risk and uncertainty. Simulation is commonly used in applied research to study the properties of a real system (Hardaker et al. 2004a), as it allows "what if" type questions that include risk to be answered without having to perform expensive and time consuming field trials or laboratory experiments (Richardson 2008). Simulation allows researchers to obtain instantaneous results to questions involving long-term planning horizons. With the use of simulation models, alternative management decisions can be tested without changing current production practices. In addition, more than one management alternative can be considered in each simulation model.

Richardson (2009) defines a simulation model as "an organized collection of data and equations to mathematically calculate the Key Output Variables (KOVs) in a real system, given changes in exogenous or management variables." A complete simulation model is comprised of four components: exogenous variables (some subject to risk), variables within the manager's control, equations necessary to calculate the KOVs as a function of both the exogenous and control variables, and output summaries and charts of the simulation results.

Simulation models can generally be defined as either deterministic or stochastic (Richardson 2008). A deterministic model does not consider risk whereas a stochastic framework incorporates risk by solving the model a large number of times and using one value of an independent variable to produce a sample of outcomes for the dependent variable Y. The risk is thus contained in the X variable. In order to accurately compare the profitability of legume and non-legume rotations in southern Manitoba, a stochastic simulation is used to generate a probability distribution of the net returns associated with each alternative crop rotation. A stochastic simulation model was selected for this analysis as crop production is exposed to several risky variables that cannot be controlled by the producer. Using stochastic simulation to generate a distribution of the KOV allows decision makers to observe how specific input variables in production can affect the risk associated with their decisions.

A stochastic simulation model adds risk to the random variables and allows the most likely outcome of the model to be observed. In order to estimate the most likely outcome, the number of iterations to be performed in the simulation procedure must be specified. Each time the model is solved it produces an estimate of the KOV. The combination of all the simulated values of the KOV produces an estimate of the probability distribution of the KOV and thus provides a measure of the risk associated with this variable.

Each time the model is solved, a random number is drawn from the probability distributions associated with the random input variables. This process is commonly known as the sampling of the input distributions and is the basis of stochastic simulation. Once a sufficient number of iterations have been performed, the distribution of the output variable will converge to a stable distribution. In order to select random values from the input distributions associated with the stochastic variables, either the Monte Carlo or Latin Hypercube sampling method is utilized. Of these two common sampling procedures, the Latin Hypercube method is used to sample the random input variables in the crop rotation model. This method was selected over the Monte Carlo sampling technique because it divides the distribution into fixed intervals and randomly selects at least one value from each interval (Richardson 2008). On the contrary, the Monte Carlo method will select random values from the overall probability distribution and therefore have a tendency to over-sample some areas of the distribution and under-sample others. In addition, the Latin Hypercube sampling procedure only requires the number of iterations to be approximately between 500 and 1000 whereas, the Monte Carlo sampling technique usually requires an ever greater number of iterations to obtain an unbiased sample.

To ensure the results of the simulation procedure are consistent, the stochastic simulation model uses a pseudo-random number generator. The pseudo-random number generator ensures that each time the model is simulated it generates the same sequence of random numbers by always starting with the same seed value to initiate the random number sequence (Richardson 2008). It also ensures that the same sequence of random numbers is utilized in each simulated scenario.

Before a random variable can be simulated in the stochastic simulation model, the parameters for that random variable must be estimated. This allows for the probability distribution associated with that variable to be defined. By dividing a random variable into its two component parts - the deterministic component, which represents the systematic variability and the stochastic component, which represents the random variability - the parameters for the stochastic variables can be determined (Richardson 2008). Parameter estimation, allows for these component parts to be quantified. When the random variable is simulated, the deterministic part of the variable is calculated while the stochastic portion is simulated.

Richardson (2008) outlines several methods for separating the component parts of a random variable. Specific to this model, a simple trend regression was performed by measuring the effect of the dependent random variable (Y) on the independent variable, time (X), holding all other factors fixed. If the slope coefficient is statistically different than zero or equivalently if the associated t-statistic is greater than 2.0, it is assumed that the data series is distributed with a trend. If the random variable is distributed with a trend, the deterministic component is the trend predicted values for X given by equation (14)

$$\hat{X}_i = \hat{a} + \hat{b}T_i \text{, for any } T_i . \tag{14}$$

The stochastic component is the residuals from trend given by equation (15)

$$\hat{e}_i = X_i - \hat{X}_i . \tag{15}$$

If the random variable does not demonstrate a trend, the deterministic component is the mean of the historical values, ($\bar{X} = (\sum X_i)/N$) and the stochastic component is the residuals from the mean, $\hat{e}_i = X_i - \bar{X}$.

The results obtained from a simulation model provide an estimate of the true probability distribution for the KOV in question. The results of the simulation model provide a close approximation of the true distribution of the variable in question, but not the true estimate. It is important for those considering the simulation results to remember that the forecasts of such models are not perfect. When the preferred alternative is put into actual production, the outcome may not be exactly as predicted by the model.

The crop rotation model is simulated using Simetar; an Excel Add-In computer program developed by James Richardson, Keith Schumann, and Paul Feldman at Texas

A&M University. This program allows modelers to conduct risk analysis by supplying them with the necessary tools to build and evaluate a complete simulation model.

5.4 Distributions

Since agricultural decisions must be made in an environment heavily characterized by risk, it is not realistic to make production decisions by selecting the alternative with the greatest economic return, without considering risk. When risk is present, the economic return for each alternative is represented by a distribution, not a fixed-point estimate. In a risky environment, the distribution of returns for each possible alternative should be simulated and decisions should be based on the resulting distributions. If the risk associated with a given variable is such that a probability distribution cannot be estimated, then this variable is no longer considered risky. Instead, this variable is considered to be uncertain (Richardson 2008).

There exist two broad categories of probability distributions: parametric and non-parametric. When parametric distributions are utilized, the researcher assumes the data comes from a specific probability distribution and thus makes inferences regarding the estimated parameters of that distribution (Richardson 2008). Common parametric distributions include the uniform and normal distribution. Nonparametric distributions, which include the discrete uniform and empirical distribution, are applied to variables for which the information available regarding their distribution is unknown. Therefore, nonparametric (as the name suggests) refers to distributions for which the researcher knows nothing about the parameters of the variable. These distributions are often processed from both low quality and small samples. Nonparametric distributions are advantageous as they allow the data to define the shape of the distribution. In other words, nonparametric distributions do not force an assumed distribution on the variable of interest. When using a nonparametric distribution it is not necessary to estimate the parameters that describe the distribution.

It is important that the correct distribution be used to model stochastic variables. If the wrong parametric distribution is selected to represent the actual distribution, the stochastic efficiency analysis will likely produce poor and inaccurate results. Often, the empirical distribution is used to model stochastic variables in agricultural simulation models. The empirical distribution is selected as it compares favorably to parameterized distributions.

There are three further classifications of probability distributions: continuous and discrete, open and closed, and univariate and multivariate. A continuous distribution is one that does not break or jump from its minimum to its maximum (Richardson 2008). Therefore these distributions are represented by smooth continuous lines. By contrast, a discrete distribution is nonparametric and will break or jump at least once over the entire distribution. If a distribution does not have a finite endpoint other than positive and negative infinity, it is classified as an open distribution; one example is the normal distribution. A closed form distribution is one that does have specified end points. The univariate distribution is used to estimate a function with either one random variable or several random variables that are not correlated. If a model has more than one random variable and there exists some level of correlation amongst these random variables, a multivariate distribution is appropriate.

In most agricultural models, several of the input variables are stochastically dependent and include risk. To determine if the input variables are stochastically dependent, a correlation matrix of the random variables is calculated; the coefficients in the correlation matrix estimate the strength of the linear relationship between two random variables (Hill, Griffiths, and Judge 2001). The output values computed in the correlation matrix fall somewhere between -1 and 1. The closer the absolute value of the correlation coefficient to 1, the stronger the linear relationship between the two random variables. The correlation matrix computed for the crop rotation model confirmed some degree of linear correlation between the random variables. Although some correlation coefficients are very close to zero, this does not imply that these two random variables are independent. A value of zero simply means that there is no linear relationship between the two variables (Hill, Griffiths, and Judge 2001). However there may still be a non-linear association between the two variables.

In order to preserve the historical correlation among the stochastic variables (nitrogen prices, crop prices, crop yields, residual nitrogen, and nitrogen application levels), the probability distributions associated with these random variables are estimated as multivariate empirical probability distributions. Multivariate distributions are used when there is more than one random input variable in the model and these random variables are statistically dependent on one another (Richardson 2008). Generally when performing an agricultural economics analysis where more than one random variable is considered, there will be some significant correlation among the variables. Any procedure used to simulate random variables must ensure that the historical relationship among all random variables is maintained in the simulated variables (Richardson, Klose, and Gray 2000). If the correlation among variables is ignored, the results of the simulation will be biased (Richardson 2008). The results of the simulation model will be biased by either overstating or understating the variance and mean of the KOV.

The multivariate empirical distribution is generally applied when there are between seven and ten historical observations (Richardson 2008). Assuming the data are distributed empirically avoids forcing a specific distribution on the variables and does not limit the ability of the model to deal with correlation and heteroskedasticity (Richardson, Klose, and Gray 2000). It is also a closed-form distribution, so it eliminates the possibility of the simulated values exceeding values observed in history (Ribera, Hons, and Richardson 2004). In other words, negative yields and prices will not be observed. The multivariate empirical distribution allows for the use of non-normal distributions and an across commodity and across time correlation matrix to generate correlated stochastic error terms that can be applied to any forecasted mean (Richardson 2008).

5.5 Data

Historical data was used to develop the crop rotation model, to estimate the deterministic costs associated with each crop, and to estimate the probability distributions associated with the random input variables.

5.5.1 Prices

Producers in western Canada who grow milling wheat and designated barley must sell through the Canadian Wheat Board (CWB), which assumes the role of marketing these grains for western Canadian producers. The CWB purchases grain from producers in western Canada and purports to market it for the best possible price both in Canada and throughout the world (CWB 2009). Producers are provided with an initial payment, which provides a price floor and purports to protect producers against extreme volatility observed in grain markets. When producers deliver their grain, they receive an initial payment that is guaranteed by the Canadian government. The CWB transports, stores, and sells the grain within Canada and abroad. At the end of the crop year, after all initial payments, marketing, financial, and administrative costs have been accounted for, the CWB distributes the remaining balance on sales to producers. In turn, the final amount received by producers is termed the total payment and is the price assigned to both spring wheat and winter wheat within the analysis.

The single-desk selling and price pooling nature of the CWB removes some of the risk associated with wheat and barley prices received by producers in western Canada. Price pooling is used by the CWB to distribute the risks associated with price increases and price decreases in the marketplace (CWB 2009). Producers are partially protected against the risk of price drops that might occur before their crop is harvested and delivered. The board ensures that producers will receive the same total payment regardless of when their grain is delivered. The total payment received by producers is based on the total net pooled returns. The total net pooled returns are calculated from the final weighted average price spreads, which are computed by multiplying the monthly price spread by the amount of grain sold by the CWB during this same month. This method of calculating payments ensures that lower grades of grain do not receive higher payments than higher grades. The total net pooled returns provide the relative market values that the market has placed on the different grades of grain sold by the CWB during the crop year.

There are numerous different classes of wheat; when a producer markets wheat it is given an associated numeric grade and protein percentage value. Each class of wheat is based on the grains functional characteristics, which make it suitable in the production of different end products, such as pasta and bread. The grade, reported as a number such as 1, 2, etc., reflects the physical condition of the grain. Factors such as heat stress and sprouted kernels can reduce the grade given to the grain. Generally, a higher price reflects a higher grade and greater protein content, though there are some exceptions to this.

For this analysis, the price of spring wheat and winter wheat was estimated by subtracting a combined deduction of the Freight Consideration Rates (FCRs), elevation, and dockage from the final payment reported by the CWB.[4] Prices for all other harvested crops; oats, canola, and peas were obtained from the Manitoba Agriculture, Food and Rural Initiatives Agriculture Yearbook 2004 and 2006. Prices for all crops are presented in dollars per tonne. Table 5 provides the twelve years of historical crop prices used in the simulation model to calculate parameters for the probability distributions for crop prices.

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[4] Freight Consideration Rates consist of the freight rate and the impact of catchment areas and pooling cost adjustments. The former are set by the Canadian Transportation Agency and the latter are established by the CWB. Rates are determined by filed railroad tariffs (Government of Saskatchewan 2009). Elevation and dockage refers to the price charged by elevators for the handling and cleaning of grain before shipment.

Table 5. Crop prices in nominal Canadian dollars per tonne

Year	Spring Wheat	Winter Wheat	Oats	Canola	Field Pea
1995	229.63	209.59	146.00	368.00	206.00
1996	180.52	157.45	137.00	385.00	219.00
1997	168.45	137.90	125.00	385.00	177.00
1998	164.03	126.89	111.00	345.00	147.00
1999	149.28	108.76	91.00	230.00	144.00
2000	159.73	116.82	92.00	240.00	137.00
2001	171.80	141.47	165.00	310.00	191.00
2002	203.62	160.22	168.00	375.00	204.00
2003	166.68	141.44	127.00	355.00	173.00
2004	157.14	108.50	132.00	285.00	152.00
2005	145.39	90.77	129.00	262.00	130.00
2006	162.26	136.80	140.00	333.00	166.00

The price of nitrogen fertilizer was obtained from Statistics Canada, which provides a monthly 34% ammonium nitrate fertilizer price for Southwestern Manitoba for the years 1992 through 1998. An annual nitrogen fertilizer price in Manitoba was estimated by computing the average of these monthly prices in each respective year. After 1998, Statistics Canada began reporting nitrogen fertilizer prices in Canada using a farm input price index. Using the annual farm input price index for nitrogen fertilizer in Western Canada, with a base year of 1998, an annual fertilizer price was estimated for each year from 1999 through 2006. Appendix B provides the calculation of the nitrogen price index.

5.5.2 Yields

Crop yields were obtained from MASC. MASC is an agricultural agency that offers a variety of services to Manitoba farm producers. These services include providing production insurance, lending options, and management information. MASC is considered the most reliable and accurate source of yield data in Manitoba, as over 85 percent of the cropped acres in Manitoba are enrolled in production insurance (Wilcox 2008). The MASC agency collects information from its clients regarding crop planted, number of acres seeded, and resulting yield. MASC also divides the province into twelve different agricultural risk areas, which are illustrated in Appendix C. The crop yields applied in the crop rotation model were obtained for agricultural risk area twelve, which was selected because it is located in southern Manitoba and includes both legume trial sites from which some of the remaining yield data was collected.

An annual yield was obtained for each crop in the model (except black lentil) by filtering the data to only contain those farms that produced spring wheat, oats, canola, winter wheat, and peas in the years 1995 through 2006. Instead of using an average yield of all the producers in the agricultural region, the annual yield was determined by first computing the coefficient of variation associated with the yields from each individual farm.[5] The yields from the farm with the median coefficient of variation were selected to represent a typical farm in southern Manitoba. This method of selecting a representative yield is not only preferred but also more accurate than simply using an average of all producer yields. An average yield does not produce a realistic crop yield distribution

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[5] The coefficient of variation is simply the ratio of the standard deviation to the mean; it measures the dispersion of the data around the mean.

(Wilcox 2007). The median represents a true midpoint among yields, whereas an average is less likely to represent the midpoint, especially if crop yields are skewed.

Yields obtained from MASC were presented in tonnes. Along with the crop yield, MASC provided the number of acres planted to each crop on each farm. Thus the yields used in the analysis are represented in tonnes per acre. The crop yields were divided by the number of acres planted then further multiplied by 160 acres to obtain an estimate of overall production for the model farm.

Yields for the double-cropped black lentil legume cover crop were not obtained from MASC. In the model developed for this thesis, the lentil crop is not produced as an annual crop where the seed is harvested and sold in a competitive market. Rather, the lentil crop is established to provide ground cover following a winter cereal harvest and to add nitrogen to the cropping system. This crop is only grown from midsummer (July) until the fall frost terminates growth in October. Therefore, the yield of the double-cropped black lentil legume cover crop is simply the amount of aboveground biomass that is produced during this short production period. As a result of the shorter production period, the yield of the double crop does not get as high as the yield of that same crop produced to maturity in an annual production system.

The black lentil yields used in the analysis were obtained from four years of field trials located in twelve different sites throughout southern Manitoba. Researchers in the Plant Science department at the University of Manitoba initiated all black lentil field trials. In all trials, a black lentil cover crop was produced immediately following a winter wheat harvest. At each of the twelve sites, four replications of a black lentil legume cover crop seeded after a winter wheat harvest were performed and the biomass of the black lentil legume was recorded. The black lentil yields used in the model were obtained by selecting the maximum yield among the four replications at each of the twelve trial sites and distributed among the twelve years considered in the model. The maximum yield was used because it is estimated by Entz (2009) that the average double-cropped black lentil legume cover crop biomass yield in southern Manitoba, following a winter wheat harvest, is between 1000 – 1200 kg/ha. The average yield of the four replications was far below the yield figure provided by Entz (2009); thus, selecting the maximum yield among the replications at each of the trial sites allowed for yields to remain close to this estimate.

When a legume is included in the crop rotation, the yield of the following cereal crop is expected to be higher than if that same grain crop is preceded by another grain crop. This is a result of agronomic and rotational benefits provided by legume crops as outlined in Chapter 2. It is estimated by Bourgeois and Entz (2006) that there is a 5% yield increase in a wheat crop following a field pea crop. However, Entz (2009) suggests a double-cropped black lentil legume cover crop does not offer a substantial yield increase in a subsequent oat crop in southern Manitoba. Therefore, for this analysis, the yield of the oat crop following the black lentil cover crop is assumed to be the same as the yield of the oat crop following another grain crop. Table 6 provides the twelve years of historical crop yields used in the simulation model to generate the random crop yields.

Table 6. Crop yields in tonnes per acre

Year	Spring Wheat	Winter Wheat	Oats	Canola	Black Lentil	Field Pea	Black Lentil-Oats	Field Pea-Spring Wheat
1995	0.96	1.64	1.50	0.80	0.49	0.99	1.50	1.01
1996	1.28	1.91	1.57	0.96	0.34	1.02	1.57	1.34
1997	0.92	1.86	1.53	0.66	0.17	0.97	1.53	0.97
1998	1.42	1.83	1.55	0.73	0.12	0.81	1.55	1.49
1999	1.36	2.12	1.73	0.78	0.85	0.68	1.73	1.42
2000	1.46	2.00	1.38	0.67	0.08	0.30	1.38	1.53
2001	0.72	1.81	0.79	0.32	0.10	0.47	0.79	0.75
2002	1.31	1.88	1.13	1.04	0.44	1.13	1.13	1.38
2003	1.62	2.20	2.21	0.90	0.54	1.02	2.21	1.70
2004	1.92	2.24	1.87	0.89	0.09	1.10	1.87	2.01
2005	0.48	0.79	0.27	0.07	0.08	0.17	0.27	0.51
2006	1.44	2.30	1.42	0.98	0.06	1.14	1.42	1.51

5.5.3 Nitrogen Application

The amount of nitrogen required in a crop production system varies depending on the crop(s) produced. Further, the amount of nitrogen that a specific crop requires in a production year varies depending on the yield of that crop because the plant removes some of the nitrogen. As a result, a crop seeded over various years could require a different amount of nitrogen fertilizer each time. To determine the amount of nitrogen fertilizer to apply to a specific crop, a fixed estimate of the amount of nitrogen removed by the total plant (straw and grain) is presented in pounds per bushel. By multiplying this estimate by the crop yield, the applied nitrogen fertilizer level can be estimated. Therefore, for a given crop, the level of nitrogen fertilizer will vary from one crop year to the next. Appendix D presents a sample calculation of the amount of nitrogen required by a spring wheat crop. Both legume crops (black lentil and field pea) do not require an estimate of nitrogen application, as these crops fix all their nitrogen fertilizer requirements.

5.5.4 Nitrogen Contribution

In addition to fixing their complete nitrogen fertilizer requirements, legume crops add residual nitrogen to the cropping system through decomposing residues. Compared to the harvested annual field pea crop, the double-cropped legume cover crop provides more residual nitrogen to the cropping system. This is because more crop residues are left to decompose on the soil surface. Entz (2009) suggests a double-cropped black lentil legume cover crop adds 25 kg/ha of nitrogen for every 1000 kg/ha of above ground biomass produced. Similarly, it is estimated that an annual field pea crop harvested for seed will supply 12 kg/ha of nitrogen for every 1000 kg/ha of biomass produced. The amount of nitrogen required by a crop following a legume is thus estimated by subtracting the nitrogen contribution of the legume crop from the nitrogen application requirement of that same crop. Appendix E provides an example of this calculation using a spring wheat crop.

5.5.5 Production Costs

Individual crop production costs are divided into fixed and variable costs. For every crop except black lentil, Manitoba Agriculture Food and Rural Initiatives (MAFRI) through their Guidelines for Estimating Crop Production Costs estimated these cost for 2006. Variable costs included expenses such as seed and treatment, fertilizer, pesticides, fuel, and labour; the estimated cost of nitrogen was removed from the MAFRI budgets. Fixed costs include variables such as storage, depreciation, and land investment. Production costs associated with black lentil are significantly lower, as this crop only requires input costs associated with the purchase of seed and treatment, fuel, and labour. These are the only costs incurred in the production of a cover crop. The seed and treatment costs associated with the black lentil legume cover crop were obtained from MAFRI (2006a) while the seeding costs were obtained from the Saskatchewan Ministry of Agriculture (2008). Appendix F provides the budgets for all crops considered in the simulation model.

5.6 The Model

The simulation model is composed of five major component parts. The first part is the input data, which contains the deterministic enterprise budgets for each of the crops considered in the alternative rotations. This part also contains the stochastic random variables: crop prices, crop yields, nitrogen prices, nitrogen application levels, and residual nitrogen levels. The second component is the estimation of the parameters for the stochastic variables to be simulated; the third outlines the four crop rotations to be simulated. Specifically, this is comprised of the base cereal-oilseed rotation, the two annual grain legume rotations, and the double-cropped legume cover crop rotation. The fourth part is the simulation model, where the deterministic and stochastic variables are used in simulation and a distribution of the net present value of farm returns for each of the four crop rotations is produced. The final part is used to produce a summary of the output and present the various charts and graphs of the resulting distributions of net returns. In this final component, sensitivity tests are performed.

5.6.1 Scenarios

A hypothetical farm in southern Manitoba is assumed and a single rotation on one field within the farm is simulated in Simetar. Four rotations are simulated and the resulting net returns are compared. The field size seeded to each crop is one-quarter section or 160 acres. It is assumed that the entire production is sold after harvest (at the current available price) and there is no carryover from one year to the next. Each rotation is considered to be a separate scenario in the simulation model. The first scenario is the base case where a cereal-oilseed rotation typically observed in southern Manitoba is simulated without the incorporation of a legume crop. This rotation is composed of three crops: spring wheat, canola, and oats. All the nitrogen used in this rotation comes strictly from the application of synthetic nitrogen fertilizer. The second scenario includes a double-cropped black lentil legume cover crop in a wheat-based rotation. The rotation begins when a winter wheat crop is seeded in the late summer or early fall. The following summer, the winter wheat crop is harvested and the black lentil cover crop is seeded. This crop is left to be killed by fall frost. The legume vegetation will be left to decompose on the soil surface. The rotation continues as per usual in the spring when an oat crop is seeded then canola. The final two scenarios incorporate an annual pea crop into an oat-based rotation. One rotation begins when an annual field pea crop is seeded in the spring. This crop is harvested in the late summer early fall. The rotation continues the following spring when a spring wheat crop is sown followed by an oat crop. The other field pea rotation is exactly the same as the previous except that it extends to include a canola crop. The canola crop is included as it is more realistic and more likely that regardless of the outcomes, producers in Manitoba will still choose to include a canola crop in their rotation. Wilcox (2007) found that when analyzing the distribution of crop rotations (i.e. the composition and diversification of rotations in Manitoba), canola was always found to be included in the rotation. The reader is referred to Table 7 for a visual representation of the alternative crop rotations.

Table 7. Simulated crop rotations

	Year 1			Year 2			Year 3			Year 4		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
Rotation 1	SW^{S}		SW^{H}	O^{S}		O^{H}	C^{S}		C^{H}			
Rotation 2		WW^{S}			WW^{H}, BL^{S}		O^{S}		O^{H}	C^{S}		C^{H}
Rotation 3	FP^{S}		FP^{H}	SW^{S}		SW^{H}	O^{S}		O^{H}			
Rotation 4	FP^{S}		FP^{H}	SW^{S}		SW^{H}	O^{S}		O^{H}	C^{S}		C^{H}

Note: SW = Spring Wheat seeded, O = Oats, C = Canola, WW = Winter Wheat, BL = Black Lentil, FP = Field Pea, ^{S} = Seeded. and ^{H} = Harvested

5.6.2 Model Calculations

The KOV for this model is the net return from a specified crop rotation. There are four different crop rotations to be simulated where the resulting net return from each rotation is compared against the other alternative rotations to determine the most profitable option for producers in southern Manitoba. The revenue from each alternative crop rotation is assumed to be strictly obtained from the sale of the crops produced in that rotation. Net returns are calculated using the profit function shown in equation (16)

$$\text{Net Returns} = \sum_{i=1}^{n}\left[\left(Y_i \times A_i\right)\left(P_i\right)\right] - \left[FC_i + VC_i + (N_i \times NP) \times A_i\right], \qquad (16)$$

where Y_i is the stochastic yield (in tonnes per acre) of the i^{th} crop, A_i is the acres planted, P_i is the stochastic price per tonne, FC_i is the fixed costs per acre, VC_i is the variable costs per acre, N_i is the stochastic amount of nitrogen (in tonnes per acre) to be applied, and NP is the stochastic price per tonne of nitrogen. The first term in equation (16) represents the revenue derived from the rotation. The second component of this equation represents total costs associated with the same rotation. Twelve historical observations were utilized to obtain the random variables in the model. A random number is produced for each variable in each year. From this, a value of net return is calculated in each of the associated twelve years data collection. Using the twelve values of net returns, a distribution of the KOV is estimated by computing the net present value of the twelve values of total receipts and total costs associated with each rotation. The net present value of the total receipts and costs associated with each year are calculated using equations (17) and (18)

$$\text{Net Present Value} = TR_i/(1+R)^T \qquad (17)$$

$$\text{Net Present Value} = TC_i/(1+R)^T, \qquad (18)$$

where TR_i is the total revenue earned in year i, TC_i is the total cost incurred in year one, R is the discount rate, and T represents time. The single overall estimate of the KOV (net present value of returns) was estimated by summing the twelve estimates of total farm receipts and subtracting them from the summation of the twelve estimates of total farm costs. Appendix G provides a sample of this calculation for the cereal-oilseed rotation in year one.

5.7 Risk Ranking Calculations

Two methods of stochastic efficiency analysis, SDRF and SERF, were utilized to rank the simulation results of the net returns associated with the alternative crop rotations. The calculations required in the application of these two risk ranking methods are outlined in Chapter 4 and were computed within the simulation program, Simetar.

As discussed in Chapter 4, both the SDRF and SERF methods require an assumption regarding the shape of the decision makers' utility function and associated measure of risk aversion. Generally, it is suggested that the CARA function, or equivalently the negative exponential utility function, be used when the actual utility function is unknown. The negative exponential utility function implies a range of the absolute risk aversion coefficients, r_a, to define the degree of risk aversion.

The level of risk aversion specified for this analysis was from 0 to 0.00000465. The range is determined by using the method proposed by Hardaker et al. (2004a), whereby the range of relative risk aversion coefficients (0 – 4) is divided by the beginning net worth of the farm. The beginning net worth of the hypothetical farm is assumed to be equivalent to the average net worth of a Manitoba farm in 2006.

Chapter 6: Results

6.1 Introduction

This chapter presents the results of the simulation model based on the information presented in both the theory and methods chapters. In the first section the results of the tests used to verify and validate the model are presented. The second section analyzes the results of the simulation and ranks them based on the summary statistics and presents graphical representations of the results, including CDFs. Sections four, five, and six present the results of the risk ranking methods used to determine the most preferred crop rotation. In the final section, the results of the sensitivity tests performed on the simulation model are given.

6.2 Verification and Validation Tests

In order to ensure the simulation model will produce accurate and appropriate forecasts, it must be validated to ensure completeness, accuracy, and forecasting ability (Richardson 2008). Checking the accuracy of the model involves two parts: model validation and model verification. Model verification is used to ensure all equations in the model are entered correctly. In order to verify the model using Simetar, it must be set to expected value mode. This way all stochastic variables in the model equal their mean. Model validation is used to ensure the random variables are simulated properly and demonstrate the appropriate properties of their parent distribution. There are several tests that can be performed to validate the model. In order to perform any of these tests the model must be simulated and the simulated stochastic variables for at least 100 iterations must be gathered (Richardson 2008).

Given that this is a multivariate empirical model, Hotelling's T-Squared Test was used to test whether the simulated vector of means for the multivariate distribution is equal to the vector of means for the original distribution. Hotelling's T-Squared test failed to reject the null hypothesis that the assumed mean is equal to the mean of the random variable. In other words, the simulated means were found to be statistically equal to the input means described in Chapter 5.

A correlation test was also performed using a Student's t-test to check each coefficient in the historical correlation matrix and the simulated matrix. This test is used to determine if the historical correlation matrix used to simulate the multivariate distribution is appropriately reproduced by the simulated variables. Since none of the correlation coefficients for any two simulated variables were statistically different from the historical correlation coefficient, at the one percent significance level, it can be concluded that multivariate distribution is modeled correctly.

The model was validated by visually inspecting the minimum and maximum random values to ensure they were reasonable given the assumed means. Also, the minimum and maximum fractional deviates in the empirical probability distributions were validated visually to ensure they are practical. These tests are not rigorous but suggest the model was developed correctly. Visual inspection is the only means of validating the coefficient of variation, the minimum, and the maximum of the simulation model. In this case, the model is visually inspected to ensure the coefficient of variation, minimum, and maximum of the simulated values are equal to the historical data.

Lastly, the model was verified by placing it in expected value mode. This ensures all the stochastic variables in the model equal their means. In expected value mode, the random variables did not equal their means; however, Richardson (2008) notes that when random variables are distributed empirically, it is not expected that they will all equal their means. Empirically distributed random variables have values just slightly larger or smaller than their means.

6.3 Summary Statistics

Twelve historical observations were utilized to estimate parameters for the random variables in the crop rotation model. Table 8 presents the summary statistics for these random variables. The mean, standard deviation, minimum, median, maximum, skewness, and kurtosis are given for each variable.

Table 8. Summary statistics for model random variables

Variable	Mean	Std. Dev.	Min.	Median	Max.	Skew.	Kurt.
Spring Wheat^{Y}	1.24	0.38	0.48	1.33	1.92	-0.41	-0.02
Winter Wheat^{Y}	1.88	0.38	0.79	1.90	2.30	-2.03	5.47
Oats^{Y}	1.41	0.48	0.27	1.52	2.21	-0.94	1.65
Canola^{Y}	0.73	0.27	0.07	0.79	1.04	-1.42	1.77
Black Lentil^{Y}	0.28	0.24	0.06	0.15	0.85	1.19	0.81
Field Pea^{Y}	0.82	0.32	0.17	0.98	1.14	-0.96	-0.45
Black Lentil-Oats^{Y}	1.41	0.48	0.27	1.52	2.21	-0.94	1.65
Field Pea-Spring Wheat^{Y}	1.30	0.40	0.51	1.40	2.01	-0.41	-0.02
Spring Wheat^{P}	171.54	22.70	145.39	165.36	229.63	1.59	2.56
Winter Wheat^{P}	136.38	29.61	90.77	137.35	209.59	0.99	1.98
Oats^{P}	130.25	23.16	91.00	130.50	168.00	-0.18	-0.26
Canola^{P}	322.75	53.93	230.00	339.00	385.00	-0.54	-1.22
Field Pea^{P}	170.50	28.26	130.00	169.50	219.00	0.27	-1.25
Nitrogen^{P}	309.72	53.96	227.82	295.78	381.01	0.05	-1.70
Spring Wheat^{NR}	0.04	0.01	0.02	0.05	0.07	-0.41	-0.02
Winter Wheat^{NR}	0.07	0.01	0.03	0.07	0.08	-2.03	5.47
Oats^{NR}	0.04	0.01	0.01	0.04	0.06	-0.94	1.65
Canola^{NR}	0.05	0.02	0.00	0.05	0.07	-1.42	1.77
Black Lentil-Oats^{NC}	0.01	0.01	0.00	0.00	0.02	1.19	0.81
Field Pea-Spring Wheat^{NC}	0.00	0.00	0.00	0.00	0.01	1.19	0.81

Note: Y indicates yield, in tonnes per acre, P indicates price, in Canadian dollars per tonne, NR indicates nitrogen requirement, in tonnes per acre, NC indicates nitrogen contribution, in tonnes per acre.

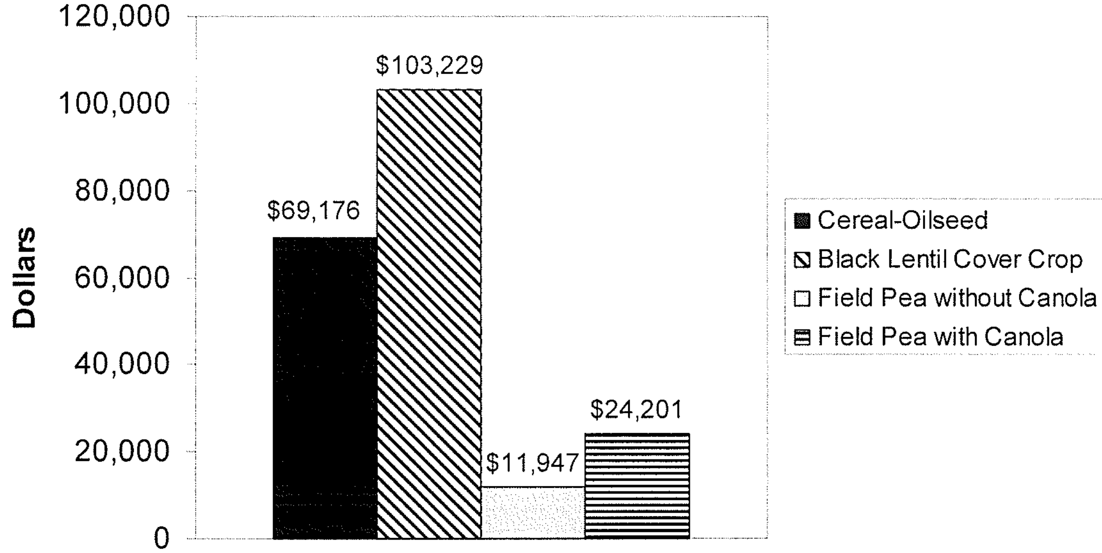
Twelve years of historical observations were compiled for the random variables in the model, i.e. crop and nitrogen prices, crop yield, and nitrogen application levels. Using this historical data, a multivariate empirical distribution was estimated for each of the individual random variables. In turn a stochastic variable was estimated for each of the random variables and was applied in the deterministic budget. The stochastic budget was used to calculate the net present value of total revenue and total costs associated with each of the alternative crop rotations. Subtracting the net present value of total costs from the net present value of total revenue allowed for the present value of net return associated with each rotation to be established. The present value of net return associated with each rotation is the KOV. The resulting summary statistics for the simulation of 1,000 iterations of four alternative crop rotations are presented in Table 9. The mean, standard deviation, coefficient of variation, minimum, and maximum values are given for each of the variables.

Table 9. Summary statistics for distributions of crop rotations, by rotation

Crop Rotation	Mean	Std. Dev.	Coefficient of Variation	Minimum	Maximum
Cereal-Oilseed	$69,176	82,275	119	-$267,265	$316,470
Black Lentil Cover Crop	$103,229	87,491	85	-$249,315	$403,649
Field Pea without Canola	$11,947	71,022	594	-$265,754	$238,453
Field Pea with Canola	$24,201	108,692	449	-$404,240	$340,824

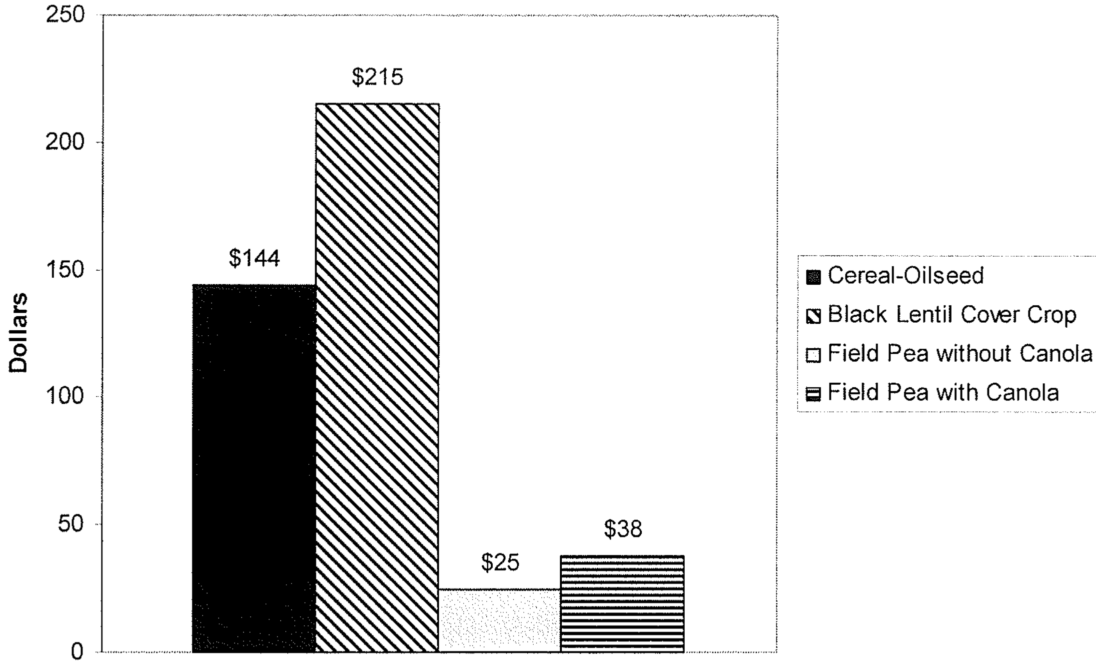
Figure 4 plots the estimated mean net present value of return for each alternative crop rotation and Figure 5 plots the per acre net present value of return of each individual crop rotation. These figures show the mean net present value of return associated with each crop rotation is positive. There is a large positive increase in the net present value return of the cereal-oilseed rotation when a double-cropped black lentil legume cover crop is incorporated into the rotation.

Figure 4. Mean net present value of return for four alternative crop rotations



Using the mean net present value of return, a risk-free ranking of the alternative crop rotations can be established. The double-cropped black lentil legume cover crop produced a greater net present value of return compared to the base cereal-oilseed rotation. In fact, of all the crop rotations considered, it produced the highest average net present value return.

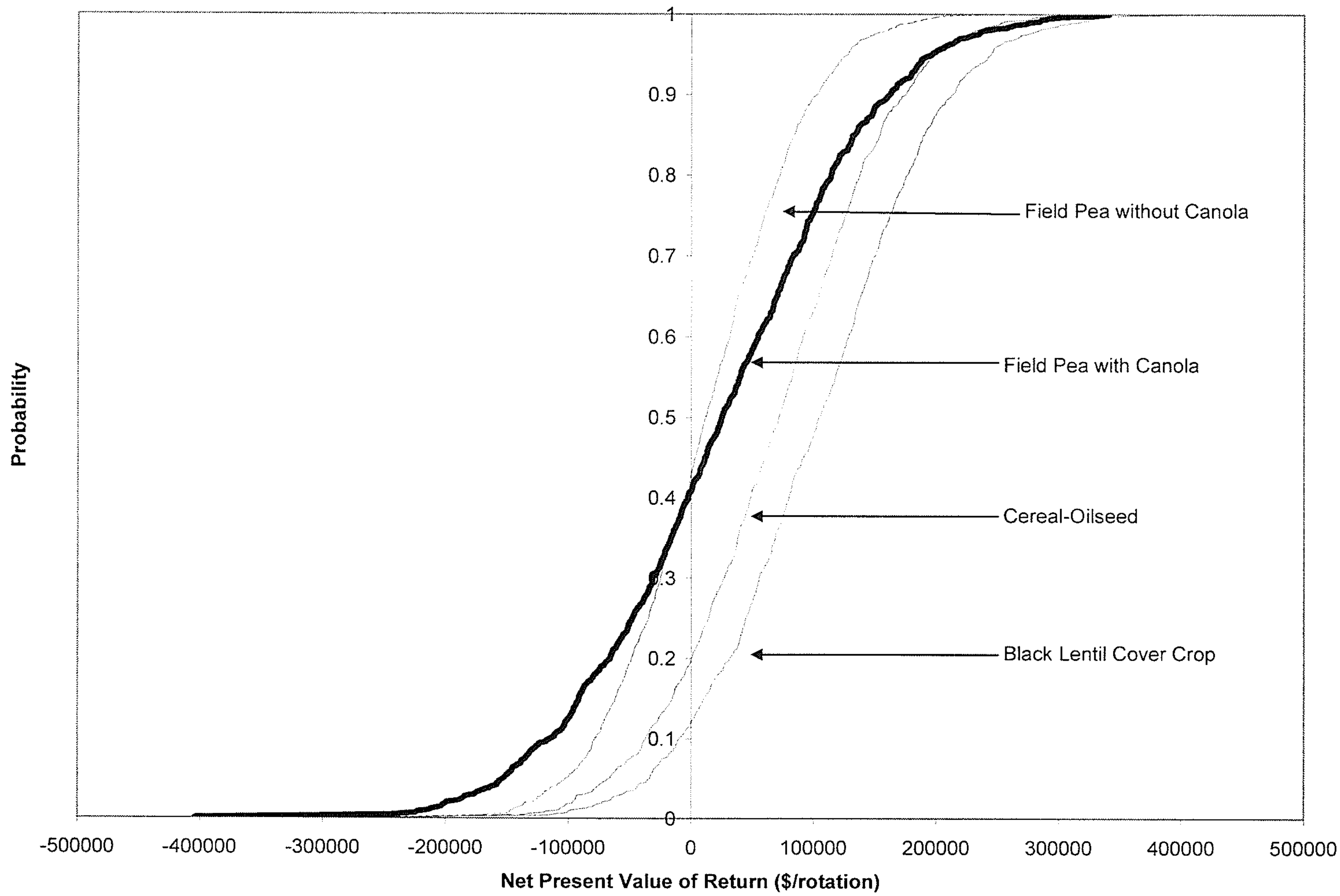
Figure 5. Mean per-acre net present value return for each alternative crop rotation



The double-cropped black lentil legume cover crop rotation is expected to generate a net present value return of $215 per acre. This is a result of the nitrogen contribution of the black lentil cover crop, which reduces the cost of synthetic nitrogen fertilizer. However, this was not the case for both field pea rotations. Based on the mean net present value of returns ranking, the cereal-oilseed rotation that does not include the production of legume crop had the second highest mean net present value return of $144 per acre. The annual field pea rotation that does not include a canola crop was observed to have the lowest mean net present value return of $25 per acre. The annual field pea rotation that includes a canola crop was estimated to generate a rotational net present value return of $38 per acre. The low mean net present value of return associated with both field pea rotations may suggest that including an annual legume crop in a cereal-oilseed based rotation does not reduce nitrogen costs enough for overall profitability of the rotation to increase.

Figure 6 complements the summary statistics for the alternative crop rotations and plots the CDF of the overall net present value return of each crop rotation.

Figure 6. Cumulative distribution functions of the net present value of returns for four crop rotation alternatives

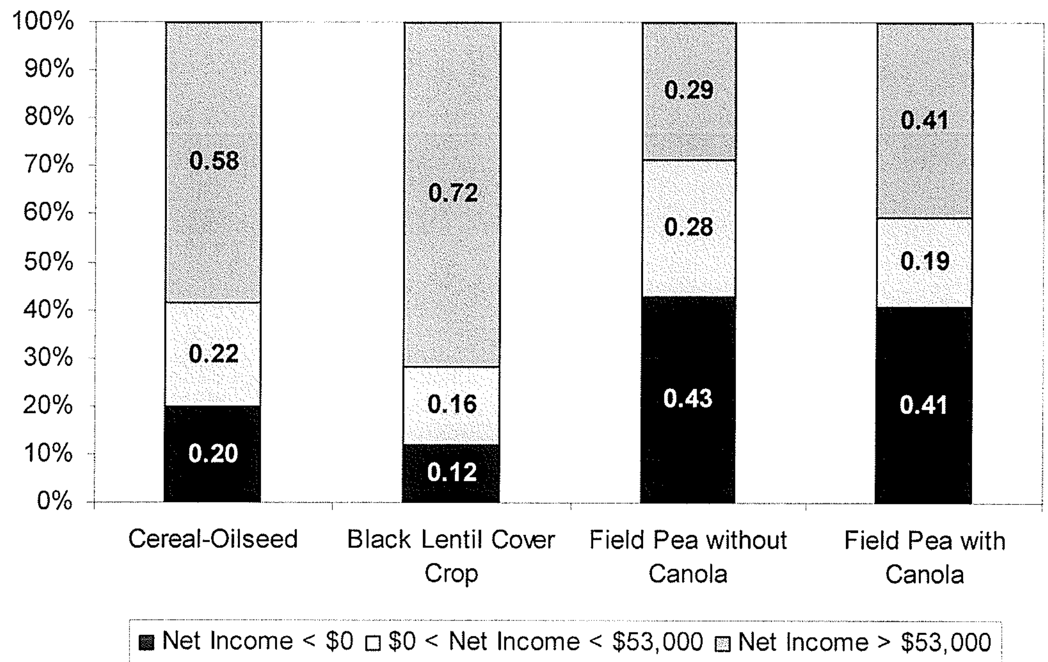


The CDF graph allows the relative risk of each distribution of the net present value of returns to be compared. This graph plots the probabilities from 0 to 1 on the Y-axis and the net present value of return on the X-axis. This CDF graph shows the probability of the present value of net return being below $400,000 for each of the various crop rotations. For example, from Figure 6 it is estimated that the double-cropped black lentil cover crop rotation has roughly a 13% chance of returning a negative profit Referring to the CDF graph, the FSD alternative is the rotation with the highest net present value of return for each risk level. Therefore, the scenario that falls the furthest to the right, the double-cropped black lentil legume cover crop, is assumed to be the preferred alternative selected by the decision maker. It is apparent from the CDFs that when the net present value of return is either above or below zero, there is generally a significant difference between the four crop rotations considered. Since two of the present value net return CDFs cross at some point in the graph, the FSD ranking method cannot be used to assess which rotation would be preferred by the risk averse decision maker.

Using the results of the simulation model, the probabilities of target values can be estimated for each of the crop rotations. These estimates tell the decision maker their probability of earning a net present value of return that is less than a specified target value. The decision maker is expected to select the scenario that has the lowest probability that the overall net present value of return will fall below a pre-determined net return level. Based on the probabilities of target values, the black lentil cover crop scenario would be the preferred alternative, as the net present value of the return associated with this rotation is expected to fall below zero only 12% of the time (Figure

7). The worst case is observed in the annual field pea rotation without the inclusion of a canola crop where the net present value of return is estimated to fall below zero 43% of the time. This may suggest that in addition to generating the highest mean net present value of return, the cover crop rotation may also be inherently less risky as it has the lowest probability of negative returns compared to all the other rotations. Figure 7 provides a graphical representation of each individual rotation achieving a net present value of return above $53,000 and at the same time failing to achieve a net present value of return above zero.

Figure 7. Comparison of target probabilities for four alternative crop rotations



Ranking the alternative crop rotations based on the rotational means provides a ranking of the alternative crop rotations using point estimates, which does not depict the entire distribution of the KOV. Also, ranking the alternative crop rotations using the

CDFs and the probabilities of achieving target values is not complete as these two methods ignore farmers' preference for income and risks. Evaluating the results of a simulation model using utility-based risk ranking procedures is often recognized as the superior method of ranking. These procedures are advantageous as they incorporate the decision makers' preference for risk. The theory of expected utility and its role in decision analysis was presented in Chapter 4. The utility-based ranking procedures applied to the results of the simulation model include: FSD, SSD, SDRF, CE, SERF, and risk premium.

6.4 Stochastic Dominance

As detailed in Chapter 4, stochastic dominance is a pairwise comparison of the full distributions of the alternative scenarios. It determines the preferred alternative by calculating the difference between two distributions at each point on the Y-axis or equivalently at each probability level. One of the main drawbacks of stochastic dominance is that it often places multiple alternatives in the efficient set. The efficient set contains the most preferred alternative(s). If the CDFs cross at some point over the range of the upper and lower risk aversion coefficients, the result may be inconclusive rankings.

In the crop rotation simulation model, the alternative scenarios were ranked using SSD. The results of this analysis are presented in Table 10.

Table 10. Results of second-degree stochastic dominance analysis

Crop Rotation	Rotations that are Dominated		
Cereal-Oilseed		Field Pea without Canola	Field Pea with Canola
Black Lentil Cover Crop	Cereal-Oilseed	Field Pea without Canola	Field Pea with Canola
Field Pea without Canola			
Field Pea with Canola		Field Pea without Canola	

The alternative crop rotations are listed in the first column of the table. The rotations that appear in the following columns are those that are dominated by the crop rotation in the first column. For this model, the SSD ranking placed only one rotation in the efficient set, the double-cropped black lentil cover crop. The field pea rotation that does not include a canola crop is the least preferred rotation based on the net present value of returns, as it does not dominate any of the other rotations.

The more discriminating form of stochastic dominance, SDRF, calculates a utility value for each estimate of the present value of returns derived in the simulation procedure. The sum of the weighted utilities is used to rank the various alternatives. For both the lower risk aversion coefficient and the upper risk aversion coefficient, a preferred alternative is calculated. When a risky alternative is preferred at both the lower and upper risk aversion coefficient it is considered to be a part of the risk efficient set. Table 11 provides the results of the SDRF ranking.

Table 11. Stochastic dominance with respect to a function results

	Level of Preference	
Crop Rotation	$R_L = 0$	$R_U = 0.00000465$
Black Lentil Cover Crop	Most Preferred	Most Preferred
Cereal-Oilseed	2nd Most Preferred	2nd Most Preferred
Field Pea with Canola	3rd Most Preferred	Least Preferred
Field Pea without Canola	Least Preferred	3rd Most Preferred

Only one alternative is in the efficient set; the double-cropped black lentil legume cover crop rotation. This is estimated to be the most preferred rotation amongst all decision makers with all degrees of risk ranging from risk neutral to extremely risk averse. If the cover crop rotation is not available or not selected by the producer then the next most preferred alternative would be the cereal-oilseed rotation. The remaining two rotations are indifferent for risk averse decision makers.

It can be observed from the stochastic dominance analysis that simply including a legume in a cereal and oilseed-based rotation is not necessarily more preferred than using synthetically manufactured nitrogen to meet the entire nitrogen requirements of the rotation. The results of this analysis infer that only a double-cropped legume cover crop rotation is more preferred than a cereal and oilseed-based rotation.

6.5 Stochastic Efficiency

The stochastic efficiency method is applied to the crop rotation model as it allows for both a more discriminating ranking of alternatives and the calculation of a CE for each crop rotation. This method requires an assumption regarding the form of the producers' utility function. As explained in Chapter 5, the negative exponential utility function is assumed in this model. In order to use this utility function in SERF a range of absolute risk aversion coefficients must be established. Based on the utility function and absolute risk aversion coefficients, a CE value is calculated for each crop rotation at each of the twenty-five absolute risk aversion coefficients. Calculating CEs not only allows for the optimal rotation to be established at different values of the absolute risk aversion coefficient, but also allows for a dollar value to be placed on the degree of preference that a given rotation has over the others. Table 12 displays the results of the SERF method used to simultaneously compare four alternatives in the range of $r_L(w)$ to $r_U(w)$, which are quantitatively defined by 0 and 0.00000465.

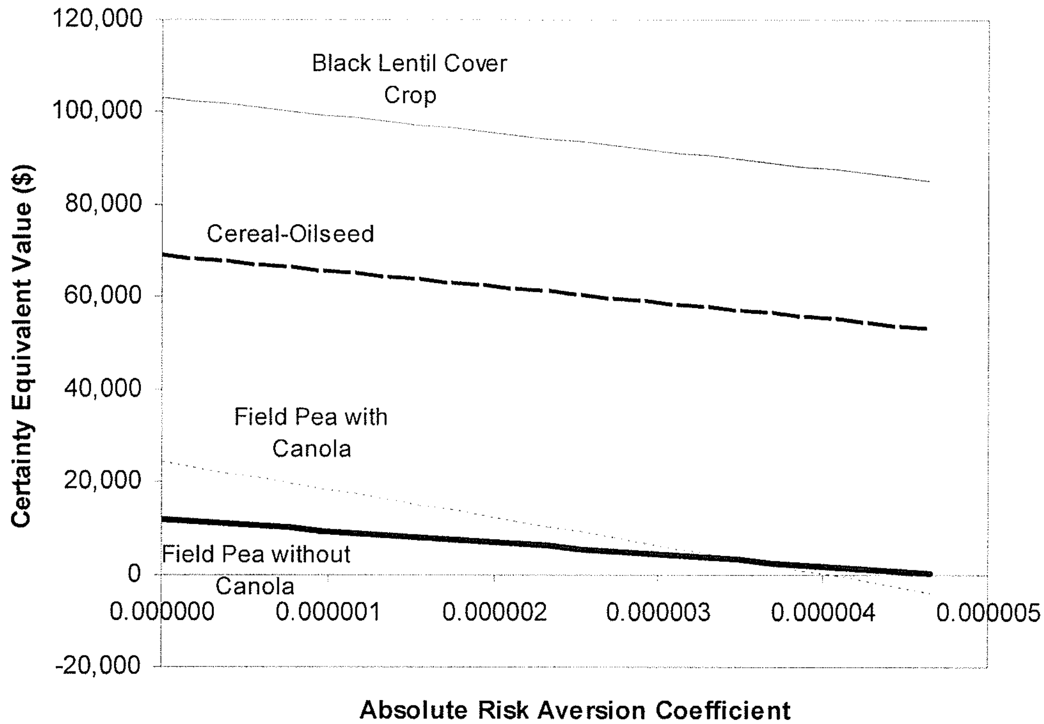
Table 12. Stochastic efficiency with respect to a function results with associated crop rotation rankings

Level of Risk Aversion	Cereal-Oilseed	Black Lentil Cover Crop	Field Pea without Canola	Field Pea with Canola	Ranking
0.00000000	69,175.94	103,229.43	11,947.27	24,200.91	2, 1, 4, 3
0.00000019	68,520.36	102,488.32	11,458.95	23,056.55	2, 1, 4, 3
0.00000039	67,863.82	101,746.59	10,970.33	21,910.11	2, 1, 4, 3
0.00000058	67,206.31	101,004.19	10,481.38	20,761.52	2, 1, 4, 3
0.00000078	66,547.82	100,261.09	9,992.11	19,610.74	2, 1, 4, 3
0.00000097	65,888.33	99,517.26	9,502.49	18,457.70	2, 1, 4, 3
0.00000116	65,227.81	98,772.65	9,012.52	17,302.35	2, 1, 4, 3
0.00000136	64,566.26	98,027.23	8,522.18	16,144.61	2, 1, 4, 3
0.00000155	63,903.66	97,280.96	8,031.47	14,984.42	2, 1, 4, 3
0.00000174	63,239.98	96,533.78	7,540.36	13,821.71	2, 1, 4, 3
0.00000194	62,575.21	95,785.67	7,048.84	12,656.40	2, 1, 4, 3
0.00000213	61,909.32	95,036.56	6,556.91	11,488.40	2, 1, 4, 3
0.00000233	61,242.29	94,286.43	6,064.54	10,317.64	2, 1, 4, 3
0.00000252	60,574.11	93,535.21	5,571.72	9,144.02	2, 1, 4, 3
0.00000271	59,904.74	92,782.86	5,078.43	7,967.45	2, 1, 4, 3
0.00000291	59,234.17	92,029.33	4,584.66	6,787.83	2, 1, 4, 3
0.00000310	58,562.36	91,274.57	4,090.39	5,605.06	2, 1, 4, 3
0.00000329	57,889.30	90,518.51	3,595.61	4,419.02	2, 1, 4, 3
0.00000349	57,214.95	89,761.10	3,100.30	3,229.60	2, 1, 4, 3
0.00000368	56,539.28	89,002.29	2,604.43	2,036.68	2, 1, 3, 4
0.00000388	55,862.27	88,242.01	2,108.00	840.15	2, 1, 3, 4
0.00000407	55,183.88	87,480.21	1,610.97	-360.14	2, 1, 3, 4
0.00000426	54,504.08	86,716.81	1,113.34	-1,564.32	2, 1, 3, 4
0.00000446	53,822.84	85,951.76	615.08	-2,772.52	2, 1, 3, 4
0.00000465	53,140.13	85,184.97	116.17	-3,984.89	2, 1, 3, 4

Note: 1 = Cereal-Oilseed, 2 = Black Lentil Cover Crop, 3 = Field Pea without Canola, 4 = Field Pea with Canola

In addition, a graphical representation of the SERF results is presented in Figure 8. The SERF chart displays the risk aversion coefficients, over the range of $r_L(w)$ to $r_U(w)$, on the X-axis and the CE values are on the Y-axis. The advantage of this chart is it allows for both a quick identification of the efficient set and a visual explanation as to how the preferred alternative(s) changes over the range of risk aversion coefficients.

Figure 8. Stochastic efficiency with respect to a function chart



From the SERF chart it can be deduced that for every risk aversion coefficient from risk neutral to extremely risk averse, the double-cropped black lentil legume cover crop is the preferred alternative as it has the largest CE value. In other words, for all farmers who are risk averse, the double-cropped black lentil legume cover crop is the best production alternative. The CE line for the black lentil cover crop rotation is above all the other CE lines, for all absolute risk aversion coefficients. The two rotations, the field pea with canola and field pea without canola, that fall below the base cereal-oilseed rotation are much less preferred to the base rotation for all levels of risk aversion. If a producer is extremely risk averse and opts to grow one of the field pea rotations, these results suggest that they would prefer the field pea with canola rotation over the field pea without canola rotation. However, any producer who chooses to not adopt either the preferred double-cropped black lentil legume cover crop or the base cereal-oilseed rotation would be acting irrationally. Therefore the two annual field pea legume rotations will not be discussed further as the SERF results suggest that these two rotations should not be considered by any rational decision maker.

6.6 Risk Premium

Risk premiums can also be used to rank the alternative crop rotations. The risk premium, which is calculated as the difference between the CE and expected value, is used to measure the amount by which the decision maker prefers one alternative over another. Figure 8 shows how the CEs differ between crop rotations and Table 12 shows how the value of the CE differs by crop rotation and the risk attitude of the decision maker. The distance between the CE lines represents the degree of conviction or the confidence premium that the dominant strategy has over the other scenarios. At an absolute risk aversion coefficient value of zero, the decision maker would need to be paid $34,053, $79,029, and $91,282 to move from the black lentil cover crop rotation to the cereal-oilseed, field pea with canola, and field pea without canola rotation respectively.

The risk premium ranking tool estimates the perceived premium that each risky scenario provides relative to the base scenario at twenty-five risk aversion coefficient intervals. It determines how the alternative scenarios rank relative to the base scenario at different levels of absolute risk aversion.

Table 13 shows the risk premiums associated with the alternative legume crop rotations as compared to the base cereal-oilseed rotation for risk neutral, normal risk aversion, relatively risk averse, and extremely risk averse producers. For the risk neutral individuals, the risk premium for moving from the most preferred scenario, the double-cropped black lentil legume cover crop rotation, to the second most preferred scenario, the cereal-oilseed rotation, is $34,053 or equivalently a per acre premium of $73. As the level of risk aversion increases to normal risk aversion, the perceived benefit of the double-cropped legume cover crop rotation over the cereal-oilseed rotation is reduced as the risk premium between these two scenarios decreases to $33,545 or $70 per acre. Further as the risk attitude becomes extremely risk averse, the risk premium drops further to $32,045 or $67 per acre.

Table 13. Risk premium values relative to the cereal-oilseed rotation ($)

Level of Risk Aversion	Black Lentil Cover Crop	Field Pea without Canola	Field Pea with Canola
Neutral	34,053	(57,229)	(44,975)
Normal	33,545	(56,215)	(47,925)
Rather	33,044	(55,178)	(50,925)
Extremely	32,045	(53,024)	(57,125)

These results show the effect of moving from a rotation that does not include a legume to one that does. The premiums for adopting a legume cropping system are consistently positive for those who prefer some risk compared to those who are heavily opposed to risk. These positive risk premium values imply that at any level of risk aversion, the decision maker prefers the risky double-cropped black lentil cover crop rotation to the base cereal-oilseed rotation. In the case of the field pea rotation, the risk premium values are negative and thus suggest the amount by which the decision maker would be willing to pay to avoid growing these rotations. Thus from Table 13, it is believed that an extremely risk averse producer would be willing to pay $57,125 to avoid growing the field pea and canola rotation.

As shown by Table 13, as a producer becomes increasingly risk averse, the risk premium associated with the field pea with canola rotation becomes even greater (or equivalently more negative) than the risk premium associated with the field pea without canola rotation. This means that extremely risk averse farmers would have to be paid even more to get them to adopt the field pea with canola rotation over the base cereal-oilseed rotation as compared to risk neutral farmers. In addition, the economic benefit of the four alternative crop rotations changes as the level of risk aversion shifts. This implies the dominant cover crop strategy offers less economic benefit over the base cereal-oilseed strategy as a producer becomes increasingly risk averse. However, this benefit is relatively small and is a result of a farmer's perception of risk regarding the two rotations.

Given the majority of farmers exhibit risk averse behaviour, the declining risk premiums between the cereal-oilseed and the double-cropped legume cover crop rotation is one possible explanation as to why these cropping strategies have not been more widely adopted in southern Manitoba (Hardaker, Huirne, and Anderson 1997). The decreasing risk premiums indicate that as risk aversion increases, the degree of preference for the black lentil legume cover crop rotation over the typical cereal-oilseed decreases substantially.

6.7 Sensitivity Tests

Sensitivity tests are performed on the model to see how responsive the KOV is to a change in any selected input variable. The sensitivity option in Simetar allows the KOV to be simulated over a range of values of an exogenous variable. Within this option, the KOV is simulated by changing the exogenous variable by three different percentage levels. When the sensitivity analysis is performed, the input variable is simulated under these different values while the other non-stochastic variables in the model are held constant. This test allows the analyst to view how the KOV changes with different values of the input variable.

Since the double-cropped black lentil legume cover crop rotation was forecasted to be the most preferred alternative, a sensitivity test was performed on the total costs associated with the production of a black lentil crop. The costs associated with the production of a black lentil cover crop include the price of seed, inoculation, and seeding (labour, fuel, etc). The responsiveness of the present value of net returns for this rotation was tested against a ± 15%, ± 20%, and ± 25% change in the total cost of producing a black lentil cover crop. The results of this test still found the double-cropped black lentil legume cover crop rotation to be the most profitable and preferred rotation. If the cost to produce the black lentil cover crop was increased by 25%, it is estimated that this rotation would still return an average present value profit of $204 per acre, which is $11 per acre less than estimated under the original model parameters. The SERF rankings were not changed for the 25% increase in costs scenario.

A second test was performed to estimate the effect on the net present value of returns from changing the assumed discount rate used in the calculation of the net present value of returns. The original model was simulated assuming a 5% discount rate. The model was re-simulated assuming a 10% discount rate. The effect of an increase in the discount rate significantly lowered the average expected net present value of returns associated with each rotation but left the ranking of the various crop rotations unchanged.

A final sensitivity analysis was performed to test the responsiveness of the KOV to a change in the price of commercially produced nitrogen fertilizer. Two cases were considered; one where the range of nitrogen fertilizer prices was increased by 20% and one where the range of prices was reduced by 20%. In both situations, the ranking of the alternative crop rotations based on the mean net present value of returns remained unchanged. When the price of nitrogen fertilizer was increased, the net present value of returns associated with each rotation were significantly reduced and similarly when the price of nitrogen fertilizer was reduced, the net present value of returns associated with each rotation were notably higher. Further, when the price of nitrogen fertilizer was increased by 20% the risk premiums associated with the black lentil cover crop rotation in comparison to the base cereal-oilseed rotation also increased. This implies that if the price of nitrogen fertilizer were to rise by 20% producers in southern Manitoba would be willing to pay an even greater amount to move from the base cereal-oilseed rotation to the black lentil cover crop system.

As stated in Chapter 2, it was hypothesized that including a legume in a cereal-oilseed based rotation will allow producers in southern Manitoba to increase their net returns by using the nitrogen fixed by the legume to satisfy some or all of the nitrogen requirements of the following cereal or oilseed crop in the rotation. The result of the simulation model, whereby the double-cropped black lentil legume cover crop was estimated to return the highest net present value of returns, failed to reject this hypothesis. The double-cropped black lentil legume cover crop rotation was hypothesized to be more profitable than the cereal-oilseed rotation as it provides the most nitrogen to system. Further, the results obtained in the simulation model are consistent with the results of previous research that has compared the economic outcome of including legumes in non-legume crop rotations. As outlined in Chapter 3, crop rotation studies typically considered including a winter legume cover crop in a non-legume rotation. However, there were no studies which compared the economics of including an annual legume in a non-legume rotation.

Chapter 7: Conclusions and Discussion

7.1 Introduction

This chapter begins by outlining the conclusions that can be drawn from this study of the economic potential of various legume-cropping systems in southern Manitoba. The second section presents the implications of these results for producers and the environment. The unique contribution of this research is its finding that there are alternative crop rotations not presently being adopted by producers in southern Manitoba with the potential to significantly improve farm net returns. The last two sections of this chapter outline the limitations of this research along with some recommendations for future research.

7.2 Conclusions

The production of legume plants, either as cover crops or annual crops, for their nitrogen fixation capabilities is still very limited in southern Manitoba. Few conventional farmers have adopted practices of cover cropping to fulfill a portion of their crop nitrogen requirements. Crop rotations on farms in southern Manitoba tend to be dominated by cereal grains and oilseeds, mostly wheat and canola. Generally, farmers are far more likely to satisfy their crop nitrogen requirements with the use of either manure or synthetically produced fertilizers. Farmers may be reluctant to use legumes for their nitrogen fixation capabilities if they do not understand the benefits of producing such crops, if they have a lack of experience in using these production practices, and/or if they fear increasing production costs by adopting a new production system. However, the results of this analysis suggest that regardless of risk attitude, producers in southern Manitoba may be able to significantly increase their net returns by including a winter wheat crop followed by a black lentil legume cover crop in their cereal-oilseed rotation.

Several methods can be used to study the economics of alternative crop production systems. Given the risky nature of agricultural crop production and the associated variability in net returns, stochastic simulation models are well suited to studying agricultural economic issues. These models allow the random nature of various input variables to be incorporated into the estimation of net returns and identification of the most profitable production system.

Within a stochastic simulation model, there are several methods available for ranking the results of the simulated procedure. Alternative scenarios simulated in the model can be ranked either using point estimates and/or utility based ranking procedures. Both methods were used to rank the alternative crop rotations considered in this analysis. The best method for ranking scenarios is largely dependent upon the situation and the individual decision maker. Ranking the alternative scenarios using more than one method is beneficial as it provides the decision maker with more resources for making a sound decision that is best suited to their individual situation. The results of the simulation procedure should not be interpreted as the best scenario for all producers to adopt. Farm operators are somewhat heterogeneous and come equipped with varying levels of experience, assets and liabilities, as well as risk and income preferences. The results of the simulation are intended to educate producers on the economic characteristics of various production alternatives presented.

The purpose of this study was to determine if legumes could be used to increase the net present value of farm returns associated with a cereal-oilseed based rotation by reducing the amount of nitrogen applied. In addition, the study was used to determine the impact that these various rotations would have for farmers with varying levels of risk preference.

The results of the simulation analysis presented in Chapter 6 compare the net present value of the return of a typical cereal-oilseed rotation observed in southern Manitoba to the net present value of the return of a similar rotation that includes either a double-cropped black lentil cover crop or an annual field pea legume crop. Based on expected utility, the results showed that regardless of the risk attitude of the farmer, the double-cropped black lentil legume cover crop is estimated to provide a greater average net present value of return compared to using a rotation solely comprised of cereal and oilseed crops. For the typical risk averse farmer in southern Manitoba, it is estimated that the legume cover crop rotation will generate on average $71 more net return per acre than a cereal-oilseed rotation. This result is based on the reduced nitrogen fertilizer requirements of a rotation that includes a nitrogen fixing legume crop. Legume plants fix their own nitrogen requirements and return nitrogen to the cropping system for use by subsequent grain crops.

The average net present value of returns associated with both the cereal and cereal-oilseed rotations that included an annual field pea legume crop harvested for seed was estimated to be lower than using the base cereal-oilseed rotation and applying commercially produced nitrogen fertilizer. This result is heavily influenced by the fact that a cover crop (not harvested for seed) adds significantly more nitrogen to the cropping systems compared to a legume crop harvested for seed. A black lentil cover crop returns approximately 25 kg/ha of nitrogen for every 1000 kg/ha of biomass produced (Entz 2009), whereas a harvested annual field pea crop returns only 12 kg/ha of nitrogen for every 1000 kg/ha of biomass produced.

Under the various non-utility ranking methods, the ordering of the various crop remained consistent with the double-cropped black lentil legume cover crop rotation being the preferred scenario followed by the cereal-oilseed, field pea with canola, and field pea without canola rotation respectively. However, when utility-based ranking methods were applied, the ordering of the alternative crop rotations in terms of preference was slightly altered when the level of risk aversion was changed. For producers who have a level of risk aversion defined as either neutral, normal, or rather risk averse, the preferred alternative is the double-cropped black lentil cover crop rotation, followed by the cereal-oilseed, field pea without canola, and field pea with canola, respectively. However as producers become extremely risk averse it is anticipated that producers would prefer the double-cropped black lentil cover crop rotation followed by the cereal-oilseed, field pea with canola, and field pea without canola rotation.

In the sensitivity analysis, an increase or decrease in the total costs associated with the production of the black lentil crop in the preferred double-cropped black lentil legume cover crop rotation had an effect on the forecasted net present value of return associated with this rotation. As expected, changing total costs did not change the final ranking of the alternative rotations. Similarly, when the assumed discount rate applied for the calculation of the net present value of farm returns was increased from 5% to 10%, the estimated average net present value of farm returns associated with each crop rotation significantly decreased but the ranking of the alternative crop returns remained unchanged. Lastly, an increase or decrease in the range of nitrogen prices affected the level of the net present value of returns associated with each rotation but did not alter the ranking of the crop rotations. Therefore, the sensitivity tests suggest the results are robust to changes in the exogenous variables that are most likely to change the ranking of alternatives.

7.3 Implications for Producers and the Environment

These results have implications for risk averse producers in southern Manitoba who are not incorporating legumes into cereal-oilseed rotations. These producers may be able to significantly increase their net returns (by as much as 49 percent) by including a winter wheat and black lentil legume cover crop to their current rotation. With the possibility of increasing net returns, these results offer producers an incentive to adopt a legume cover crop system and reduce their applications of synthetic nitrogen fertilizer. These producers will not only be able to gain economically through higher profit margins, but would also be expected to take advantage of the agronomic benefits associated with legume cover crops. Theoretically, this would increase producer net returns while also indirectly benefiting the health of the environment through reduced applications of potentially harmful agricultural inputs. As stated in Chapter 2, nitrogen fertilizer is in part responsible for the eutrophication and its associated consequences occurring in Manitoba's bodies of water.

The appropriate crop rotation for individual farmers in southern Manitoba is influenced by several factors. For instance, if a producer wishes to reduce their use of synthetic nitrogen fertilizer in order to improve the health of the environment but does not have the experience in producing cover crops and/or winter cereals or does not wish to explore the production of these crops, then it would be advised that they adopt the cereal and annual field pea rotation (assuming they are heavily opposed to risk). However the results of the simulation procedure showed that including an annual legume in a cereal rotation produced a significantly lower net present value of return as the field pea without canola rotation was forecasted to return an average present value return of $25 per acre. On the other hand, if a producer's main goal is to maximize their net returns, it would be suggested that they include a winter cereal and legume cover crop into a cereal-oilseed based rotation.

The estimated net present values of returns for the annual field pea rotations are significantly lower than the black lentil cover crop system; there are several potential reasons for this. Unlike the black lentil cover crop, the field pea crop is harvested and thus returns less nitrogen to the soil for use by subsequent grain crops. Cover crops return more nitrogen to the cropping system as a greater amount of the vegetation, which contains the excess fixed nitrogen, is left on and in the soil. When a legume crop is harvested much of the vegetation and thus the fixed nitrogen is removed with the seed. From Table 5 it can be seen that over the years in which the price data were collected, the price of field peas was very similar to the price of spring wheat. Therefore, in addition to a lower residual nitrogen contribution, the field pea crop did not offer a significant increase in the net present value of returns over the other cereal crops in the rotation. However, of the two field pea rotations, the one that included a canola crop offered a significantly higher mean net present value of returns as the price of canola during these years was well above the associated oat, spring wheat, and field pea prices.

This study takes into account the variability in the amount of nitrogen that is left after a legume is either killed or harvested. The amount of residual nitrogen is heavily dependent on the type of crop and the weather conditions both during production and after harvest or termination. Producers choosing to use these production systems must be aware of how weather impacts the level of nitrogen in the soil and how much nitrogen is expected to be fixed by the specific legume crop. In addition, the amount of nitrogen the legume crop is expected to fix is depended on how much biomass is produced.

If a producer is currently using a cereal-oilseed rotation and wishes to increase their net returns with the incorporation of a winter cereal and legume cover crop sequence, then they must be aware of the implications of this decision. Producing a legume cover crop requires some time investment into acquiring the necessary skills and knowledge to produce a successful crop.

7.4 Limitations

The production of legumes and especially legume cover crops in Manitoba is very limited. Obtaining a large representative yield data set for this type of cropping practice is very difficult as a result. The yields for a double-cropped legume cover crop are not the same as production yields; since the legume seeded immediately following a winter cereal harvest and is only established until the fall frost. Therefore the yield is not as substantial as when the same crop is produced for seed. The yield of this crop is the total aboveground crop biomass produced during this short time period. The crop yields in this analysis were for twelve consecutive years of production. For the twelve years considered in this analysis, there were no equivalent above ground biomass yields for a double-cropped black lentil legume cover crop in southern Manitoba. This is because there is no documentation of any farm in southern Manitoba that has used this production technique for twelve consecutive years. Therefore the black lentil yields were based on four years of field trial data at twelve sites throughout southern Manitoba.

In order to estimate the overall net present value of return associated with each alternative crop rotation, direct quantifiable costs were included in the analysis. However, there are additional indirect costs that were excluded that may have potentially altered the results. Farmers moving from a cereal-oilseed rotation would need to be educated on legume production. Understanding how to appropriately manage these systems and how to market these crops includes an opportunity cost to the producer that is not accounted for. This model also assumes that the producer has all the necessary labour and equipment that would be required to seed and manage these new crops. However, this assumption seems reasonable given the likelihood that any Manitoba producer currently growing grain crops would not be required to make any new capital outlays in order to grow legumes.

For each cropping system (annual legume and legume cover crop) only one type of legume was considered. It is stated in the literature that the residue of different pulses will release different amounts of nitrogen for the same given yield. For example, Barker (2007) estimated that for every 1000 lb/ac of fababean yield, 3.5 lb/ac of nitrogen is expected to be released into the soil. A soybean crop however is estimated to release 4.0 lb/ac of nitrogen for every 1000 lb/ac of above ground biomass produced. In addition, different cereal and oilseed crops have different nitrogen requirements. Therefore, the same analysis could be performed including different crops in the rotations such as barley, fall rye, soybeans, and/or chickpeas. The production of a wide assortment of crops is possible in southern Manitoba; many farmers are producing different crops based on experience, education, and agronomic conditions of their farm. Changing the input crops would likely alter the results of the analysis; however the results would likely show that legumes could be expected to reduce synthetic nitrogen use and increase farm net returns. It would also be important to consider other types of legume cover cropping systems, as a double-cropped legume cover crop must be seeded when the producer has available time, i.e. is not engaged in other production activities. A double-cropped legume cover crop must be seeded in the mid-to-late summer when both cereal and oilseed crops are typically being harvested. A relay cropped legume cover crop system involves seeding a legume such as red clover into an established winter cereal crop in the early spring. Another limitation is that producers could benefit from understanding the variability in the nitrogen contribution of different legume crops and that in turn, soil tests may be required to determine nitrogen levels in the soil. The cost of performing a soil test was not factored into this analysis.

This study did not consider the residual nitrogen effects on second and third generation crops. This is a limitation because it is likely that nitrogen from a legume is still available in the soil to be used for more than one crop year (Sullivan 2009). However, the amount available to second and third subsequent crops is significantly lower than the amount available to the crop immediately planted following the legume.

Nevertheless, whatever residual nitrogen remains would be likely to have a positive effect upon yield and thus net returns.

Based on the net present value of returns alone, simulation results suggest that the next most profitable rotation following the double-cropped black lentil cover crop rotation is the base cereal-oilseed rotation. However, under different simulation parameters the annual legume system may have produced a larger net present value of returns. As discussed in Chapter 2, there are several agronomic benefits associated with legume production that increase the yield of subsequent crops produced on that same section of land previously seeded to a legume crop. The effects of increased cropping diversity, improved soil conditions, and reduced environmental pollution are not fully quantified in this economic analysis. Estimating a quantitative value to represent the benefit obtained from healthier environmental amenities and improved cropping conditions may alter the ranking of the alternative crop rotations. This analysis strictly focuses on producing legume crops for their nitrogen fixing capabilities. The main intent of this study was to estimate the economic savings or losses associated with replacing as much of a following cereals' crop nitrogen requirements as possible with nitrogen produced from the natural fixation of atmospheric nitrogen by legumes. However, it should be noted that one non-economic factor was included in the analysis; the value associated with the estimated yield increases in a grain crop yield following a legume crop documented in the literature.

Lastly, this analysis focused strictly on the economic savings associated with the actual reduced nitrogen fertilizer input. If a crop following a legume requires less nitrogen fertilizer, theoretically this crop would also have reduced expenses in the areas of labour, fuel, and machinery depreciation. This would make the legume cropping systems discussed in this thesis even more profitable.

7.5 Recommendations for Future Research

Future research could place a greater focus/emphasis on quantifying the costs associated with the environmental damage, specifically to Manitoba's major bodies of water, from the leaching of synthetic fertilizers. Placing a dollar value on Manitoba's environmental amenities damaged from synthetic nitrogen use could significantly increase the economic benefit associated with the use of legume crops. In addition, quantifying the costs associated with the harmful effects on the environment resulting from the actual production, transportation, and application of synthetic fertilizers could further increase the costs associated with applying commercial nitrogen fertilizer. Thus accounting for these costs could increase the benefit and return associated with legume production.

Another important future research endeavor would be to expand this analysis into other major crop-producing regions of Manitoba and Canada. There are major bodies of water all over the country that are affected by excess application of synthetically produced nitrogen fertilizers used in agricultural crop production. In addition, producers all over the country are adversely affected by increasing nitrogen fertilizer prices. However, there is great variability in the agronomic conditions in various parts of the country, as well as the types of crops that can be produced. Expanding this research to include these different areas and considering their associated agronomic conditions may find these systems to be even more profitable for certain producers. Also, developing this model to include more crop producing regions may find that the preferred crop rotation varies with the producers' level of risk preference.

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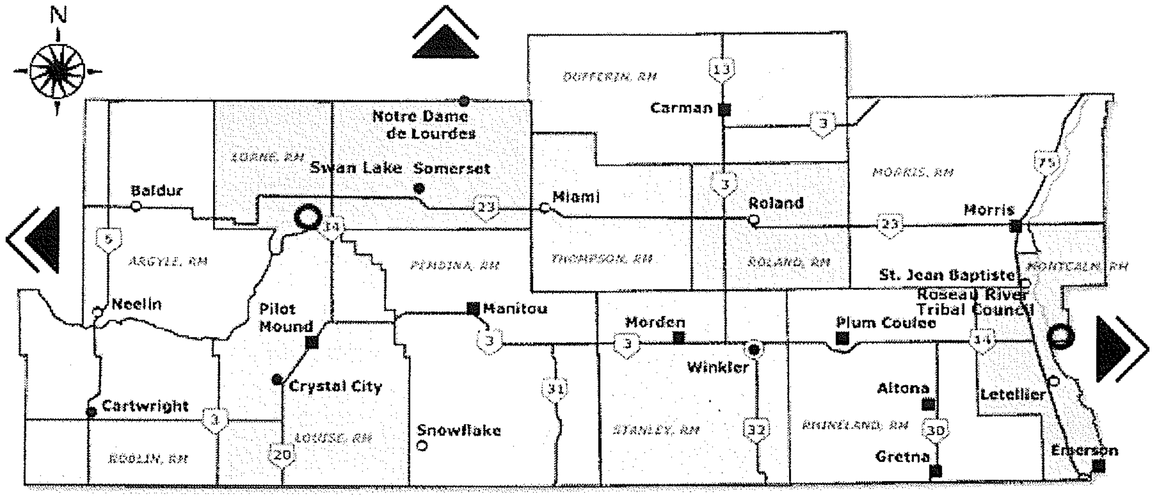
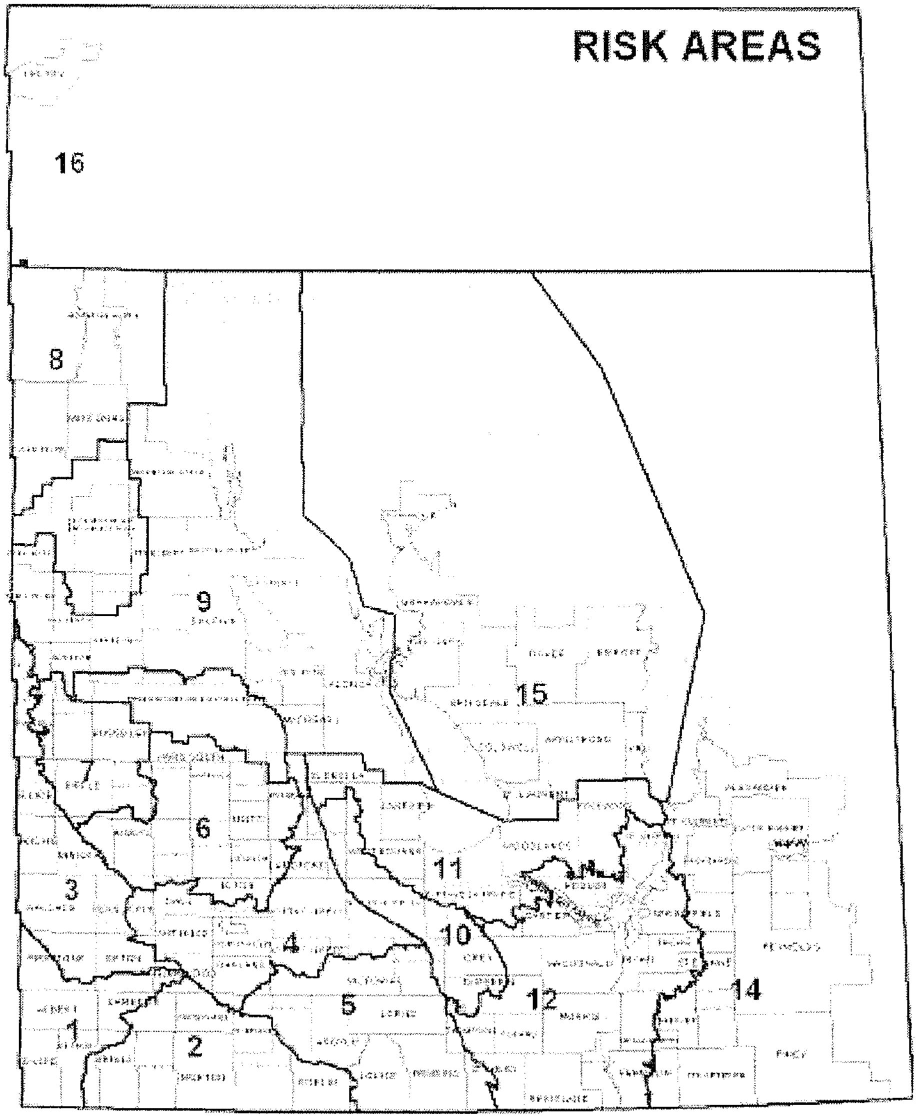
Appendix A: Map of the Rural Municipality of Dufferin, Manitoba



Appendix B: Calculation of Nitrogen Fertilizer Price

Manitoba Annual Nitrogen Price			
Year	Price		
1992	190.89		
1993	204.14		
1994	216.08		
1995	284.63		
1996	306.93		
1997	282.78		
1998	245.40		
Farm Input Price Index for Nitrogen Fertilizer, Western Canada			
Year	Farm Input Price Index Value	New Index Value	Final Nitrogen Price
1998	131.20	1.00	245.40
1999	121.80	0.93	227.82
2000	136.50	1.04	255.31
2001	202.00	1.54	377.83
2002	144.20	1.10	269.72
2003	200.60	1.53	375.21
2004	186.80	1.42	349.40
2005	192.80	1.47	360.62
2006	203.70	1.55	381.01

Appendix C: Map of Manitoba Agricultural Services Corporation Risk Areas



Appendix D: Calculation of Nitrogen Required by a Spring Wheat Crop

Observation	Spring Wheat Yield (bu/ac)	Fixed Estimate of N Removal by Spring Wheat (lbs/bu)	N Application Requirement (lbs/ac)
1	35.43	2.1	74.41
2	47.06	2.1	98.82
3	33.88	2.1	71.15
4	52.14	2.1	109.49
5	49.80	2.1	104.58
6	53.68	2.1	112.73
7	26.39	2.1	55.42
8	48.17	2.1	101.16
9	59.47	2.1	124.88
10	70.50	2.1	148.04
11	17.76	2.1	37.30
12	53.00	2.1	111.31

Appendix E: Nitrogen Requirement of a Spring Wheat Crop Following a Harvested Annual Field Pea Crop

Observation	Field Pea Yield (kg/ha)	Contribution (kg/ha)*	Contribution (lbs/ac)	Spring Wheat N Requirement (lbs/ac)	Spring Wheat N Requirement Following Harvested Field Peas (lbs/ac)
1	2439.48	29.27	26.12	74.41	48.29
2	2519.79	30.24	26.98	98.82	71.84
3	2402.77	28.83	25.72	71.15	45.42
4	2012.33	24.15	21.54	109.49	87.94
5	1676.76	20.12	17.95	104.58	86.63
6	752.73	9.03	8.06	112.73	104.67
7	1154.90	13.86	12.36	55.42	43.06
8	2801.33	33.62	29.99	101.16	71.17
9	2513.06	30.16	26.91	124.88	97.98
10	2728.04	32.74	29.21	148.04	118.84
11	430.20	5.16	4.61	37.30	32.70
12	2824.41	33.89	30.24	111.31	81.07

*based on 12 kg/ha of nitrogen per 1000 kg/ha of biomass produced

Appendix F: Crop Budgets

	Spring Wheat	Winter Wheat	Oats	Canola	Field Pea	Black Lentil
Variable Costs						
Seed and Treatment	10.20	12.00	12.38	27.50	19.38	8.00
Fertilizer	9.57	13.85	8.70	12.45	19.20	-
Herbicide	21.00	5.50	5.50	26.00	20.00	-
Fungicide	9.20	17.50	4.38	25.00	7.75	-
Fuel	13.25	10.90	13.25	13.25	13.80	-
Machinery Operating	10.00	8.00	10.00	10.00	10.50	12.52*
Crop Insurance	5.44	5.53	6.38	8.96	6.08	-
Other Costs	7.50	7.50	7.50	7.50	8.00	-
Land Taxes	5.25	5.25	5.25	5.25	5.25	-
Interest on Operating	3.36	3.63	2.80	4.71	3.02	-
Labour	17.25	17.25	17.25	17.25	19.25	-
Total Variable Costs	112.02	106.91	93.39	157.87	132.23	20.52
Fixed Costs						
Land Investment Costs	24.00	24.00	24.00	24.00	24.00	-
Machinery Depreciation	22.50	22.50	22.50	22.50	22.50	-
Machinery Investment	9.00	9.00	9.00	9.00	9.00	-
Storage	2.63	2.63	2.63	2.63	2.63	-
Total Fixed Costs	58.13	58.13	58.13	58.13	58.13	-
Total Costs	170.15	165.04	151.52	216.00	190.36	20.52

*for the black lentil cover crop, machinery operating includes the cost of labour and fuel to seed the cover crop

Appendix G: Example Calculation of Net Returns for Year 1, Rotation 1 (Cereal-Oilseed)

	Spring Wheat	Oats	Canola
Yield (tonnes)	1.15	1.51	1.06
Acres Planted	160.00	160.00	160.00
Production (tonnes)	184.12	242.19	169.91
Price ($/tonne)	229.64	168.00	385.00
Total Receipts	42,281.35	40,688.10	65,416.13
Fixed Costs ($/acre)	58.13	58.13	58.13
Variable Costs ($/acre)	112.02	93.39	157.87
Total Variable and Fixed Costs	170.15	151.52	216.00
Nitrogen Required (tonnes/acre)	0.04	0.04	0.07
Nitrogen Price ($/tonne)	390.95	390.95	390.95
Total Nitrogen Cost ($/acre)	15.75	15.66	26.57
Total Costs	29,743.40	26,749.50	38,811.19
Total Net Returns	12,537.95	13,938.61	26,604.95
	Rotation Total		
Receipts	148,385.59		
Costs	95,304.08		
Farm Return	53,081.51		
Net Present Value (NPV)	1		
Discount Rate	0.05		
Total Receipts (TR)	148,385.59		
Total Costs (TC)	95,304.08		
NPV TR	141,319.61		
NPV TC	90,765.79		
KOV Year 1	50,553.81		