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

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Abstract: 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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Introduction

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.

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.

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

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

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.

The research reported in this paper 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. 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.

Nitrogen Fertilizer & Legumes

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.

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.

Budgets & Stochastic Simulation

Budgets 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) outlines the three basic and most commonly used types of budgets: whole-farm, enterprise, and partial. The budget for the crop rotation model in this paper is based on individual enterprise budgets for each crop. This type of budget 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.

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.

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). 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 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.

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.

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).

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 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).

Data

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 Canadian Wheat Board (CWB).[2] 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 in dollars per tonne.

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.

Crop yields were obtained from Manitoba Agricultural Services Corporation (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. The crop yields applied in the crop rotation model were obtained for Manitoba agricultural risk area number 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.

[2] 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.

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.[3] 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 (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.

[3] 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.

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. 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.

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.

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.

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).

Model & Scenarios

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.

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. Table 1 provides a visual representation of the alternative crop rotations.

Table 1. 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

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 (1)

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

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 (2) and (3)

$$\text{Net Present Value} = TR_i / (1 + R)^T \qquad (2)$$

$$\text{Net Present Value} = TC_i / (1 + R)^T , \qquad (3)$$

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.

Two methods of stochastic efficiency analysis, Stochastic Dominance with Respect to a Function (SDRF) and Stochastic Efficiency with Respect to a Function (SERF), were utilized to rank the simulation results of the net returns associated with the alternative crop rotations. 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 Coefficient of Absolute Risk Aversion (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.

Model Verification and Validation

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.

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.

Results

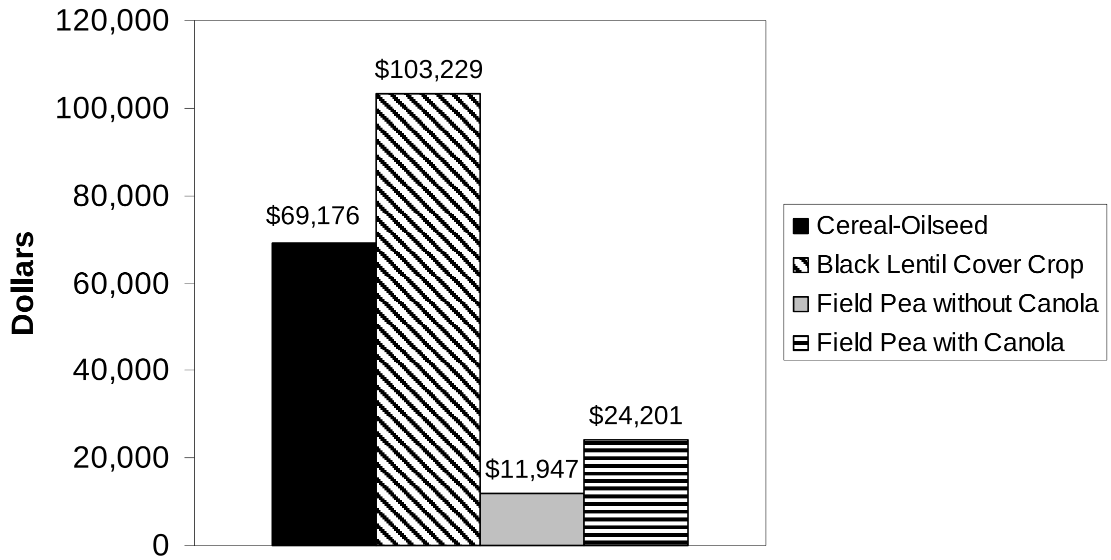
Twelve years of historical observations were compiled for the random variables in the model, i.e. crop and nitrogen prices, crop yield, and nitrogen application levels. Using this historical data, a multivariate empirical distribution was estimated for each of the individual random variables. In turn 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 2. The mean, standard deviation, coefficient of variation, minimum, and maximum values are given for each of the variables.

Table 2. 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

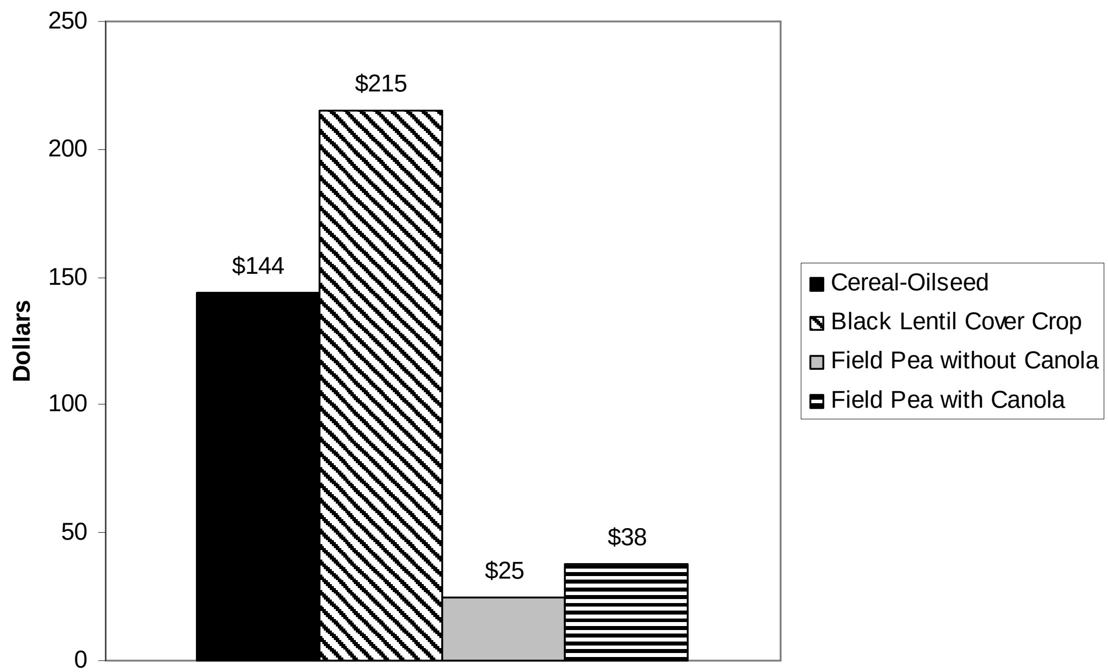
Figure 1 plots the estimated mean net present value of return for each alternative crop rotation and Figure 2 plots the per acre net present value of return of each individual crop rotation. These figures show the mean net present value of return associated with each crop rotation is positive. There 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 1. 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.

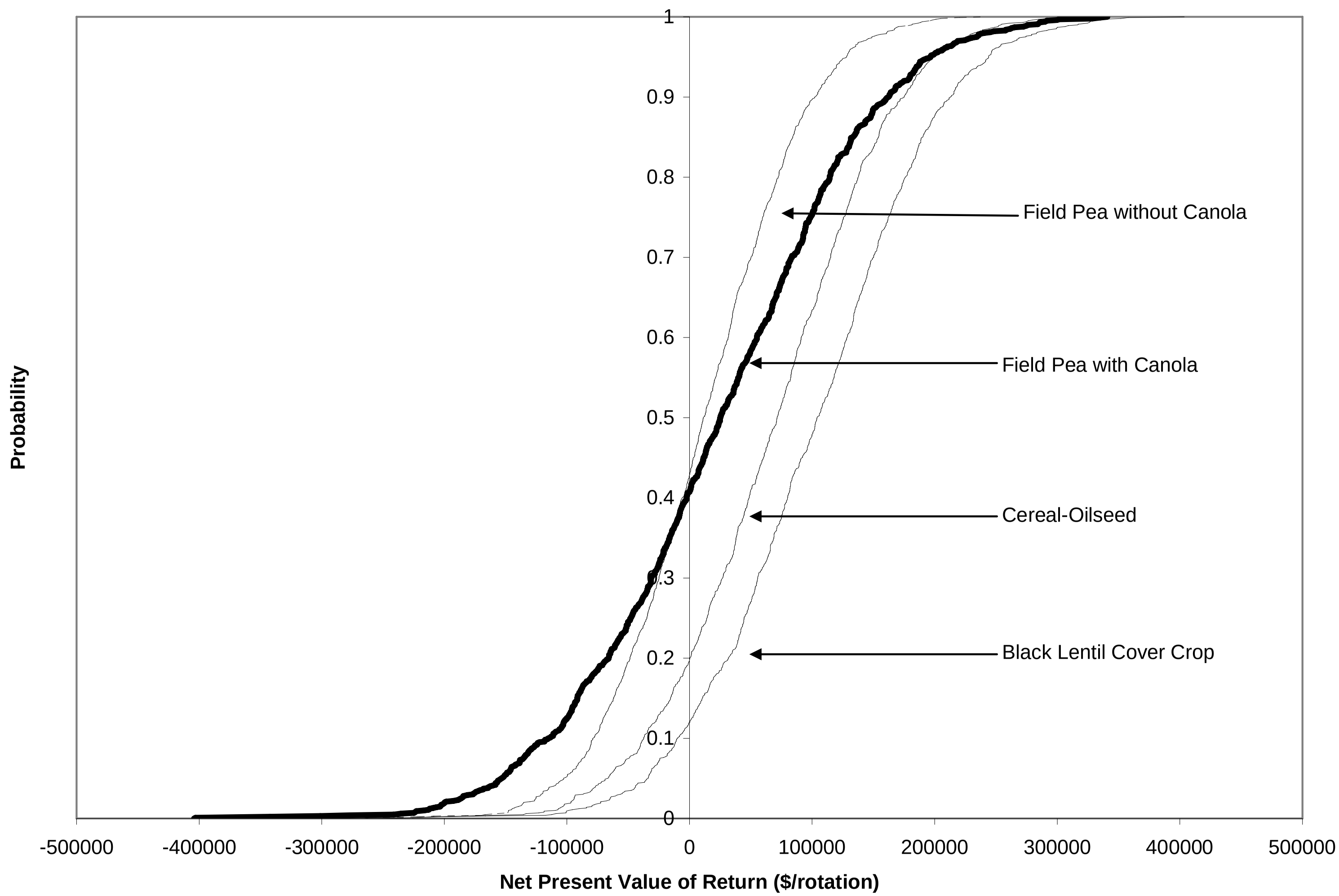
Figure 2. Mean per-acre net present value return for each alternative crop rotation



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

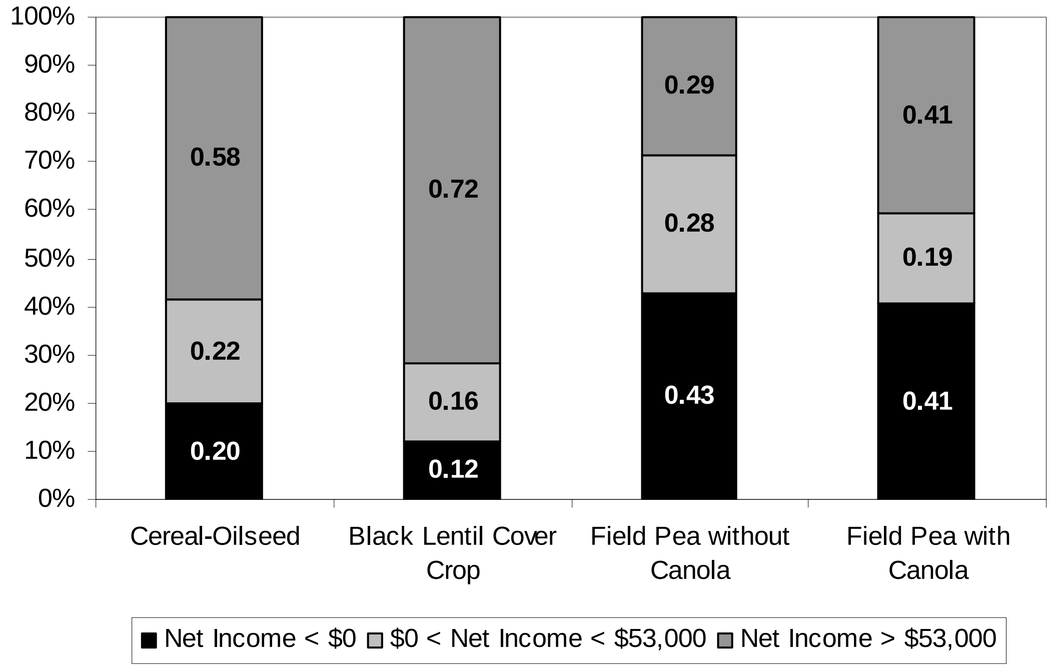
Figure 3. **Cumulative distribution functions of the net present value of returns**



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 4). 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 4 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 4. 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 utility-based ranking procedures applied to the results of the simulation model include: FSD, SSD, SDRF, CE, SERF, and risk premium.

As described earlier, 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 3.

Table 3. 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 4 provides the results of the SDRF ranking.

Table 4. 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.

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. 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 5 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.

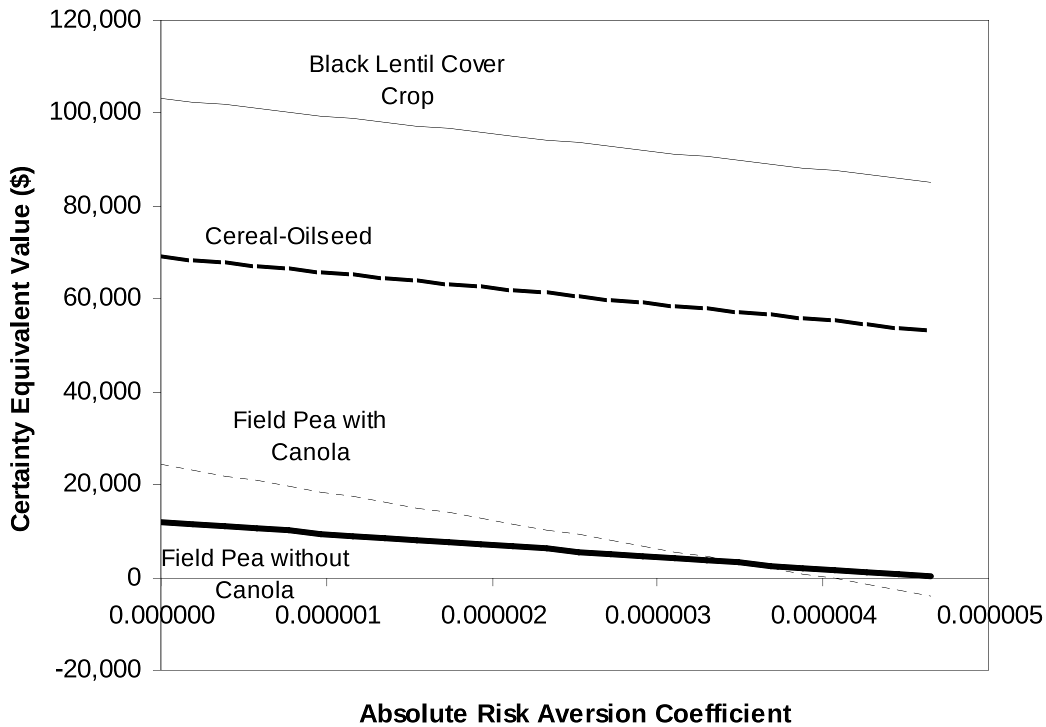
Table 5. Stochastic efficiency with respect to a function results with associated crop rotation rankings

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 5. 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 5. 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.

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 5 shows how the CEs differ between crop rotations and Table 5 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 6 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 6. 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 6, 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 6, 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.

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 $\pm$ 15%, $\pm$ 20%, and $\pm$ 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.

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.Crop rotation studies have 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.

Conclusions

The results of this research 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. 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.

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