Economics of Diversified Cropping Systems in the Black and Dark Gray Soil Zones in the Canadian Prairie Region

by

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Abstract

There has been an ongoing trend of increasing Canadian canola production, coinciding with increased intensity of canola in rotations. This contrasts with extensive research that has found significant agronomic benefits from less canola-intensive and more diversified cropping systems. Current producer behavior in terms of increasing frequency of canola in rotations is attributable to the short-term profitability of canola relative to competing crops, although other factors such as participation in business risk management (BRM) programs may also be relevant. Understanding the role that these factors play in determining risk efficient crop rotations is of importance to industry as well as to policy makers.

This study examines the economic trade-offs for alternative crop rotations, through an evaluation of net returns from crop production for representative Alberta and Saskatchewan cropping operations in the Black and Dark Gray soil zones. Production and market risk are incorporated through modeling of stochastic processes for crop yields and prices. Farm-level benefits and costs of rotations are estimated using Monte Carlo simulation and Net Present Value analysis methods. SERF analysis is used to identify risk efficient rotations for different levels of risk aversion. A common cropping rotation, consisting of spring wheat and canola was designed as the base rotation for all representative farms, and alternative cropping systems examined in the study were varied in length, specific crops included (i.e., barley, oats, field peas, flax) and degree of diversification/specialization.

Results suggested all rotations for all three farms generated significantly positive expected wealth, while more specialized crop production were more economically viable due to the short-term economic benefits associated with specialization. The annualized per acre risk premiums required by producers to adopt more diversified crop rotations were approximately $34, $2.30, and $11 in Camrose, Smoky River and Saskatchewan, respectively. Further, SERF results also suggested the advantages of specialized rotations are reinforced by participation in BRM programs, with corresponding increases in the risk premiums required to adopt more diversified rotations. This confirms the role of BRM programs in supporting adoption of more specialized crop rotations by crop producers in the study regions. While including yield effects of previous crops in the rotation did not have a significant impact on results for the risk efficiency analysis, it did highlight the relevance of this type of information on the economic performance of alternative rotations and the benefits (or lack thereof) of more diversified rotations. Lastly, the results from this study support the argument that information on negative productivity factors (e.g., disease event incidence and severity) are needed to provide producers with the knowledge required to make informed cropping management decisions.

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CHAPTER 1: Introduction

1.1 Background

Canola is the most valuable field crop in Canada and is a key source of farm income for crop farmers in Western Canada (Canola Council of Canada, 2016). Each year the canola industry generates approximately $15.4 billion to the national economy as a major exporter (Canola Council of Canada, 2017) and creates a quarter of a million job opportunities throughout the entire production chain (Canola Council of Canada, 2014). Historically, cereal crops such as wheat and barley were primarily grown on Western Canadian farms as essential cash crops.

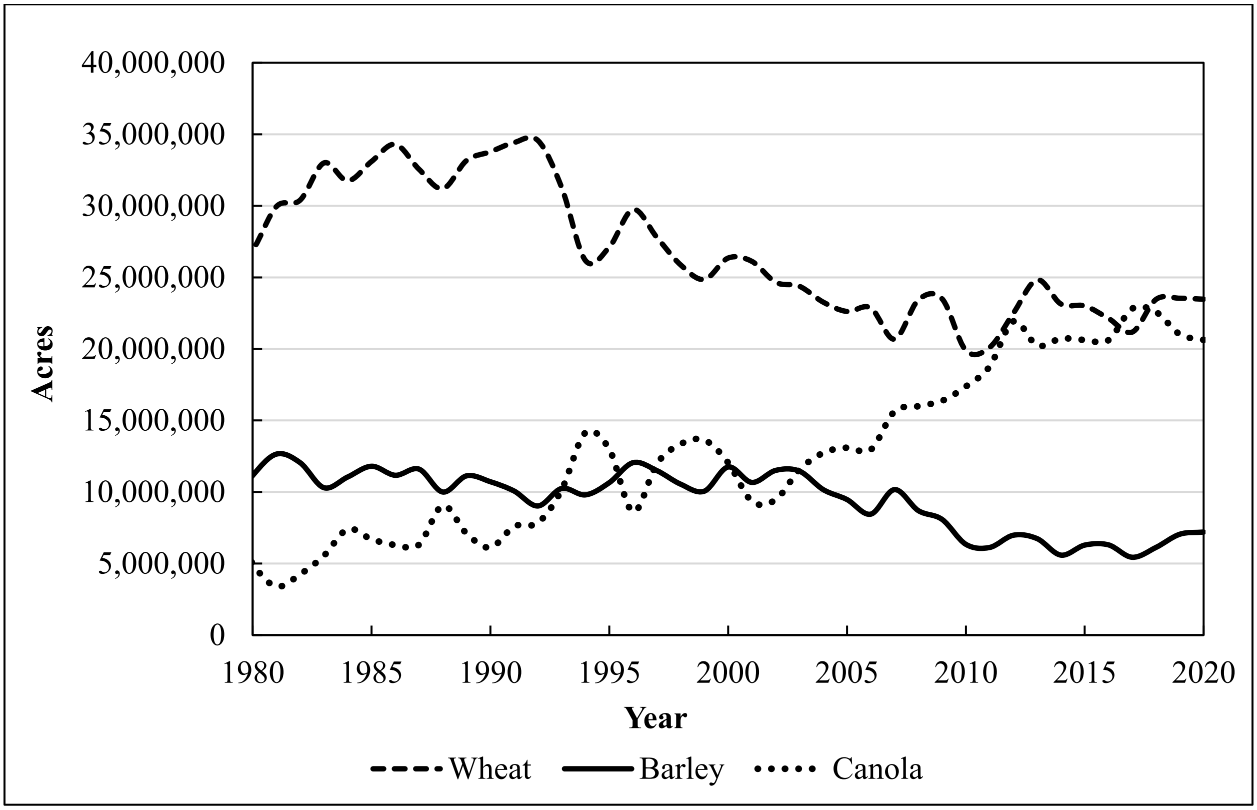

Figure 1.1 Annual seeded area (acres) for wheat, barley and canola in Prairie Provinces of Canada
Source: Statistics Canada (2020)

However, an important shift to grow broadleaf crops including canola and pulses was noticed in the last two decades and the shift has contributed to the diversification in Western Canadian cropping activities. Although, as illustrated above in Figure 1.1, wheat keeps a high position among major field crops, there is an increasing area of land used for canola production, particularly since 2000 (Statistics Canada, 2020). More than 43,000 farmers in the Western Prairies (i.e. Alberta, Saskatchewan and Manitoba) grow canola (Canola Council of Canada, 2016). The international market of Canadian canola is expected to continue to expand since it is predicted that a minimum of 26 million MT of canola will be demanded by 2025 worldwide (Canola Council of Canada, 2016).

Accordingly, producers have strong economic incentives to increase canola production. However, given there is a limited amount of land available for crops, two strategies that commonly adopted by producers to achieve production goals are growing canola more frequently or increasing yields on the same field by adopting technologies (as developed) that improve seeding rates or disease resistance (Smith et al., 2013; Harker et al., 2015). Many producers have opted to grow canola more frequently in rotations, due to high economic returns especially in the short-term (Smith et al., 2013). This is likely contributing to reduced diversification in Prairie cropping rotations.

Risk is an important characteristic of crop production in Western Canada and the various sources of risk are almost unavoidable to agricultural producers. Risk is uncertain outcomes and in particular defined as possible exposure to unfavorable consequences (Hardaker et al., 2004). Business risk in agriculture is composed of uncertainties arising from four aspects: production, price, government policy and people[1]. Business risk exerts great influence on the farm profitability at the aggregate level. Individual crop producers universally encounter farm-level business risk in the form of price and production risk. Production risk is mainly derived from the natural growing stages of crops. Factors that potentially affect the quantity and quality of commercial crop production are weather, plant diseases and pests.

A significant contributing factor to production risk in cropping is disease. Concerns of diseases problem such as blackleg (*Leptospaeria maculans*) and clubroot (*Plasmodiophora brassicae*) are

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[1] People are a source of risk for the farm business as a result of major life crises such as death, serious injuries due to mishandling machinery or divorce of the farm owner (Hardaker et al., 2004).

at least partly attributed to the intensification of canola production (Connor et al. 2013). Evidence from previous studies indicated that increased levels of both disease severity and incidence are associated with shortened rotation intervals for canola. In the long-term, yield performance and profitability of canola will be significantly affected as consequences of increased disease occurrences and associated production costs (Harker et al., 2015; Smith et al., 2013; Johnston et al., 2005; Kutcher et al., 2013). Producers may employ a variety of risk management strategies to cope with the agricultural risk such as diversifying crops and rotations, or adjusting production inputs that alter the probability of risk occurrences. Other more direct risk management tools that require engagement in contractual positions are forward sales, futures and options (Hardaker et al., 2004). Besides private tools, governments play an essential role in promoting risk assessments as well as launching public business risk management (BRM) programs that aim to mitigate all risks for domestic agricultural producers (OECD, 2019). Previous literature suggested that participation in BRM programs has assisted producers in mitigating agricultural risks to a significant extent (Jeffrey et al., 2017; Liu et al., 2018). Examples of current Canadian public BRM programs are crop insurance (AgriInsurance), stabilization (AgriStability and AgriInvest), and disaster relief (AgriRecovery) which were recently renewed and updated in early 2018 (AAFC, 2018).

1.2 Economic Problem

Previous literature has suggested that less intensified canola rotations and adoption of diversified cropping systems are advantageous since these practices maintain the long-term productivity and profitability of crop production from an agronomic standpoint (Smith et al., 2013). Nonetheless, the annual crop data from 2016 Census of Agriculture showed a completely different story with more canola being grown over the past few decades (Statistics Canada, 2016). This, combined with patterns for other field crops, suggests that crop rotations are trending towards less diversification. This inconsistency could possibly be explained by the following: 1) producers are making irrational decisions due to failure of factoring risk in production; 2) long-term agronomic implications are ignored as producers only consider maximizing profit in the short-run instead of long-run; 3) effects of participation in public BRM programs are “masking” the impacts of risk which in turn influences resulting crop management practices; or 4) the benefits of growing more canola in rotations outweigh the costs, although more diversified rotations are optimal for producers in the long-term.

It is usually assumed that producers act as rational decision makers who maximize wealth or profit or minimize costs subject to a set of constraints when faced with multiple choices. However, the realistic decision-making process is very complicated when lack of perfect information or more factors are involved. In this specific study, the decisions to choose certain cropping system and allocation of scarce resources to the agreed upon land uses are interdependent with producers' behavior in terms of individual economic optimization or in other words, wealth maximization in the long-term. Based on the above three statements, therefore, another important economic insight we need to explore from the optimization is whether producers are better-off from respective decisions and policies both in the short-run and long-run.

The study examines the economic trade-offs of adopting alternative cropping system through evaluation of both the net returns and the variability of net returns in crop production. This is done through simulation and risk assessment methods, accounting for stochastic components relevant to agricultural practices.

1.3 Research Problem and Objectives

The main objective of this study is to quantify and evaluate economic performance for representative farms, under different crop production systems in Black and Dark Grey soil zones in Alberta and Saskatchewan. Specifically, the study examines the economics of differing degrees of diversification in crop rotations. The following research objectives are examined in detail:

- quantify the risk-return trade-offs and assess risk efficiency for rotations that differ in terms of length and degree of diversification;
- quantify the marginal cost associated with adoption of rotations that are more or less diversified, taking into account negative productivity factors and risk, and

- assess the effects of participation in public business risk management programs on the level and variability of net returns and optimal diversification in rotations.[2]

Results drawn from this study address the list of objectives and may provide useful information for different stakeholders who are potentially involved in and affected by decisions related to farming operations. This study estimates farm-level net benefits and costs associated with adoption of alternative cropping systems which will provide economic insights for producers.

This study also evaluates alternative BRM programs in terms of variability of net returns for producers. Results of the assessment will be useful to producers in identifying economically viable and risk efficient cropping options. In addition, policy makers will find the analysis helpful in developing appropriate policy instruments that incentivize producers to adopt BRM programs.

1.4 Organization of the Thesis

The thesis consists of six chapters. Chapter 2 provides an overview of the literature on issues and research objectives that tend to be addressed in the study. Chapter 3 outlines the methodology and modeling approach employed to address the objectives of the study. Chapter 4 provides detailed information of the study area, which is the region of representative farms located, the relevant data used, and the empirical models. Results and discussion are presented in Chapter 5. Chapter 6 summarizes the findings and concludes with limitations and recommendations for future research.

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[2] The extent to which participation in these business risk management programs changes (i.e., reduces) the optimal level of diversification in crop rotation decisions represents a form of moral hazard. The issue of moral hazard effects for AgriStability has been examined by Rude and Ker (2013), for example.

CHAPTER 2: Background and Literature Review

This chapter provides background information on agricultural crop production in the Canadian Prairie region. The main objective is to review previous studies that examine agronomic and economic concerns of adopting traditional cropping systems or that identify alternative crop rotations and/or production management strategies to tackle the relevant issues. This chapter introduces factors that potentially affect crop production, including crop diversification, crop diseases and weeds. Moreover, strategies used in addressing problems associated with canola are discussed specifically. An overview of previous economic studies of cropping systems in relevant study areas is provided at the end of the chapter.

2.1 Impacts of Cropping System Diversification

The choice of crops to be grown by producers tends to be highly responsive to market trends. As a consequence, producers' decisions in terms of crop rotations are driven by demand in the form of relative commodity prices (Johnston et al., 2005). The use of fallow periods (i.e., non-crop growing season) was introduced in the Canadian Prairies to maintain soil quality after harvesting seasons. Since the late 1980s, the use of this practice has been gradually replaced by growing oilseeds and legume crops. According to the Census of Agriculture, the area of summer fallow area decreased from 20.5 million to 2.2 million acres in the Canadian Prairie provinces over the period 1986 to 2016 (Statistics Canada, 2016). The reduction of fallow area has been accompanied by a significant growth in the area seeded to canola. The same pattern was observed in area grown for other field crops including barley, wheat and field peas, but not as much as canola (Statistics Canada, 2017).

Canola production continues to expand with 21.3 million tonnes produced in Canada in 2017. Total production has more than tripled in the last two decades (Statistics Canada, 2018). The area seeded to canola almost doubled from 1997 to 2007, going from approximately 12 million to 23 million acres, with 95% of this area located in the three Canadian Prairie provinces (Statistics Canada, 2018). The expansion of canola represented a producer strategy to diversify rotations in response to declines in wheat prices (Maaz et al., 2018). The increase in canola production has resulted in canola-intensive rotations (i.e., higher frequency in rotations) despite advice from crop experts suggesting the best canola rotational period is once in every four years due to increased disease pressure from intensified rotations (Cook, 2006; Kutcher et al., 2013; Smith et al., 2013). Thus, the agronomic impacts of diversified cropping systems and more specifically the canola intensive rotations are introduced in the following sections.

2.1.1 Yield

There is a wide range of agronomic studies from western Canada that demonstrate the potential of crop diversification in enhancing yields and cropping system stability (e.g., Guo et al., 2005; Kutcher et al., 2013; Harker et al., 2015; Liu et al., 2019). However, wheat and canola are still the dominant crops in rotations grown in the Canadian Prairies based on both the 2011 and 2016 Census of Agriculture (Luce et al., 2015; Statistics Canada, 2016). The high-frequency canola rotation practice is mainly attributable to the increasing demand for canola products and market access globally (Maaz et al., 2018). Some notable events that have facilitated the maturing of the market for canola are the formation of the Canola Council of Canada in 1980 (Brewin and Malla, 2013); the implementation of provincial levy programs in 1990, and increasing national demand for canola cooking oil (Casseus, 2009). The suitability of canola for production in different soil zones, the increasing market access, and the economic importance have made canola intensification possible on the production side in Western Canada (Zentner et al., 2002; Maaz et al., 2018). The increasingly specialized production systems (i.e., wheat and canola) have raised great concerns for the sustainability of agricultural development in Western Canada (Luce et al., 2015). There is evidence of significant yield losses shown in cases of crops seeded on their own stubble (Beckie and Brandt, 1997; Kutcher et al., 2013). The negative impact on yield is reinforced particularly in cropping systems involving intensive canola.

Canola following a previous canola crop usually results in lower yield performance (O'Donovan et al., 2014). Kutcher et al. (2013) found that increased plant pathogen to be the major cause of yield losses as canola frequency increased in rotations. Another study by Harker et al. (2012) reported an 8% decrease in yield when three years of continuous canola was grown relative to one year of wheat in between two canola crops. Similar results are reported in studies by Johnston et al. (2005), Dosdall et al. (2012) and Kutcher et al. (2013). The practice of short intervals between canola crops or even continuous canola prevented infected plant residues from fully decomposing, instead providing the same perfect host crop for pathogens to be transmitted.

It is argued that root damage caused by root maggot (*Delia* spp.) larvae might have contributed to canola yield reduction as well (Dosdall et al., 2012). Another factor, identified by Bruce et al. (2005), was that allelopathy[3] from residues of wheat or canola might cause yield losses in canola. Harker et al. (2015) stated that higher canola yields were achieved by increasing rotation diversity, specifically including wheat or field peas followed by barley in rotations. The improved canola yields from rotation diversification may be associated with decreasing crop disease incidence and severity, especially Blackleg (Harker et al., 2015).

The rotational benefits of legume crops (e.g., field peas, beans) are examined by many studies. Harker et al. (2015) found that oilseed and cereal yields always respond positively to the addition of field peas in the crop sequence. Legumes are essential in diversifying cropping sequences because they require less water and nutrients than wheat and canola and thus are capable of leaving more resources in the soil for following crops (Liu et al., 2011). Moreover, the accumulation of N in soils is made possible by atmospheric nitrogen fixation by legumes. Because of these benefits associated with legume crops, Smith et al. (2013) characterized legumes as a yield booster for subsequent oilseed and cereal crops. An example of nitrogen benefits is in a study by Stevenson and Van Kessel (1996a), in which the authors found the nitrogen content derived from wheat after field peas was five times greater than wheat after another wheat.

Non-nitrogen benefits associated with growing legumes have also been recorded (Johnston et al., 2005; Williams et al., 2014; Luce et al., 2015). These include reduced weed populations, reduced incidence of leaf and root diseases for subsequent crops and improved availability of S, P and K (Stevenson and Van Kessel, 1996a). A similar study by Stevenson and Van Kessel (1996b) for six sites in Saskatchewan indicated a 43% increase in wheat yields when following field peas, relative to following another cereal crop in rotations. In addition, O'Donovan et al. (2014) found the average canola yield after field peas increased about 10% at seven sites in Western Canada compared to the case where wheat was the preceding crop. An instance of decreased canola yield when following field peas was reported by Johnston et al. (2005) in 2001. However, this was due

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[3] This is the carryover of beneficial or harmful effects of one plant on another. Examples are plant residues or release of biochemicals.

to unusual drought conditions on field pea stubble that caused canola yields to be even lower than when seeded on its own stubble.

The benefits of increasing diversification in rotations are also well documented. Yield improvements resulting from longer rotations are attributed to factors including reduction of nitrogen use, interruption of pathogen pest cycles as well as reduced weed densities (Cathcart et al., 2006; Young et al., 1996). For example, a significant linear increase in canola yield as rotation interval increases from zero to two years was found at five western Canadian study sites and was consistent over time (Harker et al., 2015). Cathcart et al. (2006) also reported significant canola yield gain at a study site in the Edmonton area by varying rotation intervals from 1-in-2 to 1-in-4-years. In the same study, the 1-in-3-year diversified canola rotation was found to be the least risky rotation. Similar studies conducted on the Black and Dark Gray soils in northern Alberta reported a 19% increase in yield with a 2-year break, compared to only a 6% increase with a 1-year break between continuous canola (Cathcart et al., 2006). Another study investigated yields resulting from planting different canola cultivars and found universally low yields as the interval between canola crops decreased, regardless of canola variety. As noted earlier, crops planted after the same crop resulted in lower yields than when planted after other crops. The difference in yield is suggested to be caused by disease pathogens that may ultimately lead to impairment of field productivity (Johnston et al., 2005; Kutcher et al., 2013). The impact of crop rotation adoption on the likelihood of crop diseases and pests is discussed next.

2.1.2 Crop Diseases

Besides the direct yield impact from adopting less diversified cropping systems, many important diseases are found to impede the growth of major cash crops in Western Canada. The increasing likelihood of crop diseases and pests are usually considered to be related to the intensive production of a single crop or reduced intervals between crops in a rotation (Krupinsky et al. 2002; Cook, 2006; Kutcher et al., 2013). A typical example in the current study is the increasing practice of high-frequency canola in rotations. Two canola-associated diseases, Clubroot and Blackleg, are common to the Canadian Prairie provinces, and these diseases have caused significant impacts on canola production in this region.

2.1.2.1 Clubroot

Clubroot, caused by *Plasmodiophora brassicae Woronin*, is a common soilborne disease of plants in the family *Brassicae* (Dixon, 2009). In Western Canada, the first Clubroot case was identified near Edmonton in Central Alberta in 2003 and has continued to spread into the neighboring provinces of Saskatchewan and Manitoba (Tewari et al., 2005). It was estimated that there is a 30% to 100% yield loss in severely infected canola fields across the Prairies (Hwang et al., 2011). Clubroot is very difficult to control since each infected plant can potentially produce and leave up to 8×10^8 resting spores in soils (Hwang et al., 2012). Resting spores are also extremely long-lived and can stay viable in soils for over 15 years (Wallenhammar, 1996). The field adjacent to infected fields is under greater exposure to Clubroot outbreak since spores can be carried along with machines during farming activities (Strelkov, 2020).

It is of great significance to reduce the frequency of canola rotation so that disease occurrences are controlled and managed properly. Strelkov et al. (2006) found that fields with canola seeded every year or one in every two years are identified with the highest level of disease severity in Alberta. In addition, Strelkov (2020) indicated that the Clubroot incidence in rotations with canola grown once in every two years is much greater than that for once in every three years although no specific statistics are available. This is due to the accumulation of pathogen inoculum[4] that results from canola intensification. Concerning the inoculum level, it is suggested that a two-year break from canola can considerably reduce the pathogen population compared to a one-year break (Peng et al., 2014). In the same Peng et al. (2014) study, canola grown once in four years was recommended as the optimal rotation system to mitigate the disease impact on canola, even in heavily infested areas.

Strelkov (2020) also mentioned other cultural strategies available for producers to manage Clubroot. Management practices include growing genetic resistant canola, sanitation, soil amendments using chemicals, and regulatory intervention. Regulatory management would involve requiring producers in areas under high risk of infection to strictly follow the rotation recommendation of canola once every four years, using the Clubroot resistant varieties (AAF,

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[4] Inoculum is a portion of the pathogen that initiates infection in plants, and may include spores, sclerotia or parts of fungi (Abdulkhair and Alghuthaymi, 2016).

2019). Moreover, a break longer than four years would be required in areas identified with Clubroot and the local governments authorized to issue a Notice to Control to enforce the action (AAF, 2019).

Not all of the potential strategies are feasible to adopt due to time and/or financial constraints. For example, it is costly and time-consuming to practice sanitation. Regulatory management would also not be favored by producers due to significant potential economic costs. Of all the disease management tools, growing Clubroot resistant canola varieties is a primary option for crop farmers in Western Canada (Strelkov, 2020). It is an affordable strategy since the costs of growing resistant canola are usually included as part of the seed cost, although this practice does not eliminate the disease event due to the breakdown of genetic resistance over time. It is worth noting that the effectiveness of resistant cultivars is reinforced by jointly extending the rotation intervals. In particular, a 25% yield increase results from planting resistant canola cultivars with the integration of a 3-year break relative to continuous canola (Peng et al., 2014). The risk of Clubroot generally decreases with increasing rotation lengths. However, no explicit statistics of yield impact are available since local governments only report the presence of disease without quantifying the yield losses (Strelkov, 2020; Rempel et al., 2014).

2.1.2.2 Blackleg

Blackleg is another economically important disease of canola in Western Canada. Blackleg was initially identified in Saskatchewan in 1975 but did not spread to the rest of the Prairies until the early 1980s (Gugel and Petrie, 1992). The disease is caused by two fungi species, *Leptosphaeria maculans* and *Leptosphaeria biglobosa*. The pathogen is residue-borne and can spread to other plants through air transmission (Strelkov, 2020). Serious economic and yield losses in canola crops are mainly caused by the first of the two fungi species, as it is highly virulent. The infected plant will primarily show reductions in seed yield and will eventually be killed (AAF, 2019). The probability of an outbreak in fields adjacent to infected areas is higher in the case of Blackleg due to the air transmission of spores for up to 8 km (Strelkov, 2020).

This disease is characterized by incidence (percentage of infected plants) and severity (amount of infected plant tissue) (Xi et al., 1990). Both Blackleg incidence and severity increase with increased canola frequency in rotations (Guo et al., 2005; Kutcher et al., 2013). A rapid increase in disease incidence and severity is noticed when canola is rotated more frequently than once every three years (Harker et al., 2015). A similar result was obtained by Kutcher et al. (2013) where increased inoculum level and pathogen population for future crops was attributed to shorter rotations (i.e., less than once in four years), causing increased infected canola residue in soils. Hwang et al. (2016) described the Blackleg severity and canola yield loss to be linearly correlated by developing a yield loss model. Regression results showed a 17.2% canola yield reduction and 13% pod losses per plant for an incremental change in Blackleg severity in the Edmonton area of Alberta.

Crop rotation is an efficient and cost-effective tool available to producers to control Blackleg (Gugel and Petrie, 1992). It breaks the chain between crops that causes disease events and allows infected canola residues to naturally decompose over a sufficient time (Gugel and Petrie, 1992). The rotational effects in response to Blackleg as reflected in yield are also presented in several studies. Johnston et al. (2005) found the lowest canola yield and greater Blackleg incidence resulted from seeding canola after canola was grown in the previous year. In comparison, higher canola yield is achieved by planting canola after flax, cereals (e.g., wheat) or peas (Guo et al., 2005). A similar finding is observed by Zentner et al. (2002) in that increasing crop diversity in rotations helps break disease cycles through the degradation of infected residues. A slightly different conclusion is drawn by Bailey et al. (2000) who found minimal effect of crop diversity on disease severity in three 4-year rotations. This is partly due to a longer time (beyond four years) required for rotation treatments to take effect in reducing inoculum levels. Continuous or shorter canola rotations provide no flexibility for the decomposition of host-crop residues, leading to replication and perpetuation of the fungi. Thus, the benefit of employing crop rotation to combat Blackleg is heavily dependent on the rotation length (Kutcher et al., 2013).

Some studies also examined and compared yield response of susceptible and Blackleg-resistant canola cultivars. Results showed that the yield performance of Blackleg resistant cultivars is consistently better than for susceptible cultivars, with yield increasing by approximately 60% regardless of rotation sequence (Kutcher et al., 2013). Another more recent study in Alberta found that compared to susceptible cultivars, Blackleg severity was lower in disease-resistant cultivars and the canola seed yield increased dramatically by up to 120% to 128% (Hwang et al., 2016).

Kutcher et al. (2013) reported a similar amount of yield losses between two cultivars as Blackleg severity increased. As mentioned earlier about the inverse relationship between rotation frequency and disease probability, there is likely erosion of genetic resistance in cultivars that led to more serious yield reduction from shorter canola rotations (Smith et al., 2013). Although Strelkov (2020) mentioned that the Blackleg-resistant cultivars suffered less from resistance loss than Clubroot-resistant cultivars, it is still advantageous to lengthen rotations for disease-resistant canola to prevent new virulent races of Blackleg (Smith et al., 2013). The preventative management strategies for Blackleg are the same as for Clubroot, with a couple of exceptions. First, sanitation practice is not feasible in Blackleg control because of airborne spores. Second, fungicides can effectively reduce the Blackleg incidence and severity with a minor impact on canola yield (Strelkov, 2020). A downside of fungicide application is that it can only control Blackleg in short-interval canola rotations (Smith et al., 2013).

2.1.2.3 Diseases of Cereal Crops

Yields and resulting economic performance of cropping farms and the degree of crop diseases are affected by the choice of rotation. Therefore, one of the interests of the current study is to explore knowledge of a variety of crop diseases that are relevant to the crops commonly grown in rotations by farmers in Western Canada.

For example, leaf diseases of cereal crops have been studied extensively by crop scientists (e.g., Krupinsky et al., 2004; Turkington et al., 2012; Conner et al., 2013). In particular, a fungal disease Fusarium head blight (FHB) has been found to cause serious damage to cereal crops such as wheat, barley, and oats (AAF, 2020). Among all fungi species that potentially cause FHB, the most devastating impact on crops is associated with *Fusarium graminearum*. Haidukowski et al. (2005) found extreme yield losses along with detrimental impacts on grain quality under a serious FHB outbreak. Kutcher et al. (2013) also observed yield losses and increasing leaf spot severity under intensification of cereal crops (i.e., two consecutive years of barley). This is due to the increased risk of seed and seedling diseases for cereals following another cereal

(Turkington et al., 2012). However, evidence from previous literature on adoption of the rotational strategy in disease management is mixed.

Lafond et al. (2006) determined that the probability of foliar and root diseases in spring wheat was reduced by including field peas, flax or fallow as part of the crop sequence. Spring wheat yield was higher when seeded after field peas had been grown or after fallow in comparison to seeding on wheat stubble, mainly because of higher soil moisture level from these alternative rotation sequences. Bailey et al. (2001) also found consistently higher yields by planting wheat after summer fallow or field peas. In particular, fungal populations in wheat leaves and roots were reduced by increasing crop diversity. Nonetheless, Beres et al. (2018) claimed limited effects from rotations on wheat disease severity and the spread of fungal species. The mechanism of rotation in mitigating diseases is to break the chain of transmission using non-host crops, while a limited number of non-host crops are currently available. With a real situation that occurred on an Alberta farm, Beres et al. (2018) concluded yellow mustard to be the only true non-host crop for controlling FHB, where oilseeds and legumes were falsely treated as non-host crops by producers. Relatively speaking, environmental factors such as precipitation and temperature exert bigger impacts on disease severity for most crops than does choice of rotation. Rotation effects on yields are more detectable only if cereal crops are grown intensively (Bailey et al., 2001; Krupinsky et al., 2004; Beres et al., 2018).

2.1.2.4 Weeds

Weed species found on the Canadian Prairies can be introduced through intensification of crop production and weeds are considered to be the most significant yield-limiting factor in crop production in Canada. Weed densities increase with intensity of crops in rotations and further cause serious competition for resources (i.e., water, nutrients and sunlight) between crops and weed species (Asaduzzaman et al., 2014). Economically important crops such as cereals and oilseeds are exposed to increasing weed pressure due to more intensive (i.e., less diversified) rotations in the Prairies. A common weed in Western Canada is volunteer canola[5]. This

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[5] Volunteer canola is an annual weed species reproduced by seeds of canola crops, and contributes negatively to yield by competing with crops for water, sunlight and nutrients (MARD, 2020).

contributes negatively to yields by introducing seedling disease and increasing pest pressure. Volunteer canola is capable of providing hosts for Clubroot and Blackleg even during seasons without canola and leads to loss of efficacy for crop rotation strategies in controlling diseases (Canola Council of Canada, 2020). Since weed invasions have seriously impacted crop yield and quality, more than $500 million is spent by Canadian producers each year on herbicide inputs in field crops (Beckie et al., 2008).

Crop yield differences between weedy and weed-free conditions are reported in Central Alberta. An empirical study by Neil (2001) reported the average yield reduction from a weed-free to a weedy circumstance is 40% for canola, 27% for barley, and the highest 67% for field peas. More severe yield losses are found in field peas relative to barley since a strong negative correlation was found between weed density and pea yield.

Zand and Beckie (2002) claimed that within canola varieties, hybrid canola cultivars appear to be twice as competitive as open-pollinated cultivars when indicators of high weed interference are presented (i.e. high plant density and strong growth of wild oats[6]). Cathcart et al. (2006) found the highest weed population to occur in continuous canola relative to less intensive rotations (i.e., growing once every three or four years). The reduction of weed densities by adopting more diverse or three-year rotations relative to continuous canola was 35% and 25%, respectively. Surprisingly, a minimal effect of 14% was found with a four-year rotation, which is attributed to a higher proportion of annual broadleaf weeds[7] in the sequence (Cathcart et al., 2006). Another study by Harker et al. (2012) observed lower weed biomass in wheat-canola-canola and wheat-wheat-canola rotations in comparison with continuous canola. This finding is explained by potential differences in herbicide regimes, canola cultivars, crop types, and again crop weed competition.

Regarding weed management, Harker et al. (2015) argued that the effect of weed control from herbicide applications overlays that of crop rotation since both conventional and hybrid canola

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[6] Wild oats is an important annual grass weed due to its contribution to yield losses across the Prairie region.

[7] These are annual weed species that are easy to spot in fields due to the leafy structure.

cultivars are treated with glyphosate or glufosinate before seeding. In this case, a more challenging issue raised from excessive use of herbicides is the increasing weed pressure caused by herbicide resistance (Harker et al., 2012). In consequence, producers are encouraged to shift focus to integrated methods of weed control. Of all techniques of integrated weed management (IWM), diversified rotation is the most important although it is often ignored in real practices in favor of short-term profitability (Harker et al., 2003; Harker et al., 2015). Other available cultural practices of IWM investigated by Harker et al. (2016) are crop species, crop life cycles, seeding rates and dates, harvesting dates, and herbicide rates. The authors suggested that under a proper combination of these practices, a similar effect of weed control can be achieved as if a full herbicide treatment was used for the same wheat-canola rotation. Thus, IWM practices are important replacement strategies for herbicides that are no longer effective or to preserve herbicide efficacy for a longer time (Harker et al., 2016).

2.2 Literature on Economics Analysis of Diversified Cropping Systems

From a systematic review of the literature, it appears that there is relatively limited research that has been conducted specifically relating to the economic analysis of alternative cropping systems in Western Canada. For example, there has been an economic analysis done from an agronomic study of crop diversification on the Black and Dark Gray Soil zones of Saskatchewan (Zentner et al., 2002). A more recent study by Smith et al. (2013) examined the profitability of short-duration canola rotations in Western Canada. The net returns of a range of pre-defined crops and crop rotations were compared to determine rotations with the greatest economic feasibility. However, these studies were primarily focused on the agronomic benefits for producers who adopt diversified cropping system versus more specialized cropping system. They were not conducted with a focus on farm-level economics of crop production.

In both Western Canada and the Upper Midwest of the US where similarities are found in agricultural landscapes (i.e. soil types) and crops grown, many researchers have looked at the economics of alternative and conventional cropping systems. The term “system” here refers to management practices related to cropland such as tillage, zero-tillage, reduced inputs and organic farming (DeVuyst et al., 2006 and Zentner et al., 2011). However, the major crops and rotations in these studies are often different from what have been considered in the present study. Other studies of Davis et al. (2012), Xie (2014) and Bruce (2017) conducted economic analyses of integrated crop-livestock systems in the US and Western Canada, in which more complicated relationships between crop and livestock operations are investigated.

Although previous literature concluded that farm profitability increased with crop diversity in rotations, less effort has been put on evaluation of economic performances for alternative cropping decisions. The current study intends to explore insights into alternative cropping systems from the economic perspective.

2.3 Chapter Summary

Great attention has been drawn in Western Canada about choosing the appropriate cropping system to maintain the long-term sustainability of commercial crop production. Producers are encouraged to shift from high-frequency canola to more diversified cropping systems. However, few are changing production decisions as there are incentives to exploit the short-term profit of growing canola (Blackshaw et al., 2008). However, less diversified cropping systems contribute to creating an environment conducive to increased incidence of plant disease, weed pressure from herbicide resistance, with a resulting negative impact on crop yields.

The major crop diseases involved in intensive canola production are Clubroot and Blackleg. The increasing likelihood of crop diseases will not only cause serious instant yield reductions but also adversely affect the productivity and profitability of crop production in the long-term. These consequences have led producers to rethink the importance of crop diversification in rotations (Davis et al., 2012).

Many studies have examined the impacts of diversified cropping systems with a few of them focused on quantitative analyses. Almost all studies have concluded that rotations with greater crop diversity would benefit cropping activities both economically and agronomically in the long-term relative to more specialized rotations that are dominated by high-value canola crops. This study aims to fill an information gap in this area by employing a representative farm approach. Combining statistical data and expert opinion, the study models three representative crop farms using Monte Carlo simulation. The economic trade-offs between different cropping systems are determined by using the Net Present Value (NPV) analysis method. Moreover, the variability of returns is also considered and evaluated using risk efficiency analysis tools.

CHAPTER 3: Theoretical Model

Producer decisions regarding cropping management, including choice of rotation, result in important financial and agronomic impacts on crop production businesses over time. This chapter discusses the employment of risk efficiency analysis techniques to evaluate and determine the optimal cropping decision for producers who desire to maximize expected utility from farm operations while under risky conditions. The theory of expected utility is derived based on wealth as the outcome measure of interest. In this study net present value (NPV) is used to proxy wealth and represent the farm-level performance in the study. The approach of modeling agricultural systems and the structure of the representative farm model are also discussed later in the chapter.

3.1 Expected Utility

Utility is the degree of satisfaction received from consumption of goods and services. In this study, it is defined with respect to monetary measure such as income or wealth obtained from cropping activities. The expected utility is the utility (crop production returns) under uncertain conditions. It is the weighted average utility of all possible outcomes of a decision[8] under uncertainty (Hardaker et al., 2004). According to Hardaker et al. (2004), each decision maker has a utility function and individual risk preferences are influenced by the shape of utility function. For example, Figure 3.1 shows an example of a concave utility function, where x_1 and x_2 are outcomes of a particular action, and x_{bar} is the expected outcomes. $U(x_{bar})$ is the utility of the expected outcome and E[U(x)] represents the expected utility of the outcomes. The concavity of the utility function implies decreasing marginal utility as outcome increases. Given a set of assumptions about the nature of preferences, producers are assumed to make decisions that maximize their expected utility (Hardaker et al., 2004).

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[8] For the current study this specifically refers to cropping decisions in regards to choice of rotation.

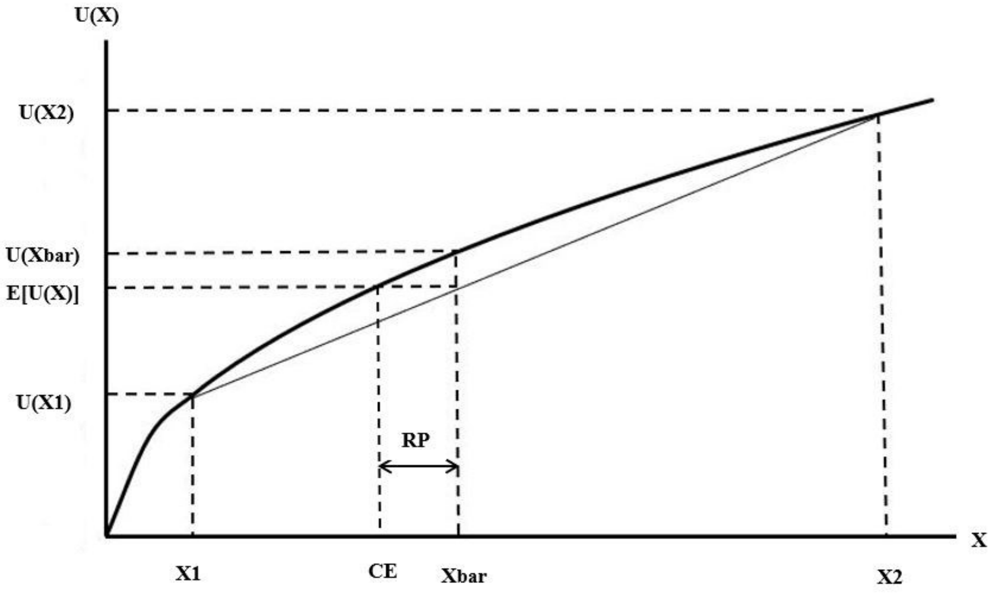

Figure 3. 1 Concave Utility Function

3.1.1 Producer Attitudes Towards Risk

The concavity presented in Figure 3.1 means that the decision maker would prefer the expected outcome over the risky action itself. This is illustrated through the concept of a certainty equivalent (CE). In Figure 3.1, the CE represents the amount, received with certainty, that is equivalent in expected utility terms to the risky action (Hardaker et al., 2004). For a concave utility function, the CE is less than the expected outcome. Although not shown in Figure 3.1, a risky alternative with greater expected utility would also have a greater CE value. The consistency between expected utility and CE is described by an equation $U(CE_x) = E[U(x)]$, where x is the risky action. If the CE of one rotation is higher than the other regardless of risk attitude, then that rotation is always going to maximize the expected utility for producers.

In Figure 3.1, the horizontal distance between the CE and the expected outcome x_{bar} is defined as the risk premium (RP), which is the amount a decision maker would be willing to pay to eliminate risk. RP can be considered as a measure of risk aversion (i.e., a more risk averse individual would be willing to pay more to eliminate a given amount of risk) and thus affected by the curvature of the utility function. Specifically, the more concave the utility curve, the greater the RP for a given risky action and the greater the degree of risk aversion for the decision maker. Similar discussion can be provided for decision makers with convex or linear utility functions and these decision makers are characterized as risk loving and risk neutral, respectively (Hagen and Wenstøp, 1984). Producers in this empirical study are assumed to be risk averse when making their cropping decisions since it is usually how individuals would behave in the agricultural businesses that are vulnerable to risk.

3.1.2 Measuring Risk Aversion

Recall that the degree of risk aversion is measured by the curvature of the utility function. Two alternative measures for quantifying the level of risk aversion are absolute risk aversion and relative risk aversion. The absolute risk aversion is a measure of decision maker's reaction to uncertainty relating to dollar value changes in the current wealth. The absolute risk aversion function from Hardaker et al. (2004) is presented as follow:

$$\mathrm{r_a(w)} = -\mathrm{U''(w)/U'(w)} \tag{3.1}$$

Where $U'(\mathrm{w})$ and $U''(\mathrm{w})$ represent the first and second derivative of the utility function $\mathrm{U(w)}$. The second derivative implies three possible attitudes toward risk reflected by signs of positive, negative or zero. Three types of risk attitudes that characterized by second derivatives of utility function are expressed as follow:

$$\begin{gathered} U''(\mathrm{w}) < 0, \text{risk averse} \\ U''(\mathrm{w}) = 0, \text{risk neutral} \\ U''(\mathrm{w}) > 0, \text{risk loving} \end{gathered} \tag{3.2}$$

A limitation associated with $\mathrm{r_a}$ is that the values are affected by units and scale for the relevant outcome measures, which in this case is wealth. This creates challenges in identifying the appropriate ranges of absolute risk aversion to consider for the empirical analysis (Hardaker et al., 2004). The issue, however, is addressed by using a related measure, relative risk aversion $\mathrm{r_r(w)}$.

The relative risk aversion $\mathrm{r_r(w)}$ is a measure of decision maker's behavior to uncertainty relating to percentage changes in the current wealth. Equation (3.3) is the function of relative risk aversion (Hardaker et al., 2004):

$$\mathrm{r_r(w)} = -\frac{\mathrm{U''(w)}}{\mathrm{U'(w)}} = \mathrm{wr_a(w)} \tag{3.3}$$

The equation is the same as the absolute risk aversion function but the term *w* is multiplied to the second derivative of the utility function, which represents measure of the percentage change in wealth. A range of relative risk aversion coefficients proposed by Anderson and Dillon (1992) were used to solve the currency issue of absolute risk aversion mentioned above:

$\mathrm{r_r}(w) = 0.5$, hardly risk averse at all
$\mathrm{r_r(w)} = 1.0$, somewhat risk averse
$\mathrm{r_r(w)} = 2.0$, rather risk averse
$\mathrm{r_r(w)} = 3.0$, very risk averse
$\mathrm{r_r(w)} = 4.0$, extremely risk averse

These relative risk aversion coefficient values may be converted to absolute risk aversion coefficients to use in the risk efficiency analysis by rearranging (3.3) to $\mathrm{r_a(w)} = \mathrm{r_r(w)/w}$; that is, divide the wealth with coefficients of relative risk aversion listed above.

3.2 Risk Efficiency Analysis

The direct implementation of expected utility in empirical analysis is often complicated as specification of a utility function is problematic. To address this problem, a set of tools are developed based on assumptions about the nature of preferences. Many of these use pair-wise comparisons of risky actions to identify a set of "risk efficient" actions. A risk efficient action is defined as an action that maximizes expected utility for a decision maker, given the feasible set of possible actions and the level of risk aversion. Different risky alternatives are further divided into two groups after applying a risk efficiency criterion: the efficient set and the inefficient set[9]. The risk efficient set contains alternatives which will be potentially risk efficient for at least one of the relevant decision makers. Conversely, the inefficient set has those alternatives which no relevant decision maker will choose. Typically, more than one alternative will be included in the efficient set based on the risk efficiency criteria and the nature of trade-offs in terms of errors in

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[9] Risk efficiency criteria are procedures used to compare alternative actions with respect to the risk efficiency.

judgement[10]. An appropriate tool is required to examine the risk efficiency to identify the risk efficient set. Risk efficiency analysis can be conceptually done using the following techniques: mean-variance (EV) analysis, stochastic dominance, and SERF analysis.

3.2.1 Mean-Variance Analysis

The first risk efficiency tool is the mean-variance (EV) criterion. This criterion assumes that decision makers are risk averse (Hardaker et al., 2004). The decision rule is based on a pair-wise comparison of expected values and variances between possible alternatives. The EV criterion rule states that if alternative A is compared with a second alternative B, A is preferred by all risk averse decision-makers if its expected value is at least as great as the expected value for B, and the variance for A is no greater than the variance for B, with at least one inequality being strict.

EV analysis is relatively straightforward to implement as it requires information on the mean and the variance of outcomes for risky alternatives. However, besides the assumption of risk averse behavior, it does require additional restrictive assumptions that either the probability distributions of outcomes should be normal or the utility function is quadratic (Hardaker et al., 2004). The additional assumption is problematic since there is no guarantee that the outcome distributions will be normally distributed. As well, the assumption of quadratic utility implies an increasing absolute risk aversion with wealth. However, empirical evidence suggests that producer behavior does not typically exhibit this pattern (Guiso and Paiella, 2008).

3.2.2 Stochastic Dominance

Stochastic dominance criteria represent another set of risk efficiency criteria. Similar to the EV criterion, stochastic dominance criteria are also implemented through pair-wise comparisons of risky alternatives. The various stochastic dominance criteria differ in terms of assumptions made about decision maker risk preferences. Two examples of stochastic dominance criteria are first-degree stochastic dominance (FSD) and second-degree stochastic dominance (SSD) (Hadar and Russell, 1969; Hanoch and Levy, 1969).

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[10] This refers to Type I and Type II errors where the former means an action is eliminated when it is efficient and the latter means an action is considered efficient when it is in fact inefficient.

3.2.2.1 First Degree Stochastic Dominance

FSD assumes decision makers have positive marginal utility of wealth (more is preferred to less) (King and Robison, 1984). This implies absolute risk aversion between $-\infty < \mathrm{r_a(w)} < +\infty$. The use of FSD involves pair-wise comparison of risky alternatives, each of which is characterized by a probability distribution of outcomes defined by cumulative distribution functions (CDFs). Alternative A dominates alternative B by FSD if and only if the value of the CDF at every outcome (i.e., the probability of obtaining no more than that outcome) is no greater for A than for B, and strictly less for at least one outcome. Graphically, this means the CDF for A (i.e., the preferred alternative) is below the CDF for B (i.e., the dominated alternative); that is, the CDFs do not cross. If A dominates B, B is placed in the inefficient set and removed from consideration. Otherwise, both A and B remain in consideration.[11] After the process of pair-wise comparisons is complete, alternatives that are not dominated constitute the efficient set and represent alternatives that may be optimal for decision makers with positive marginal utility. Conversely, the alternatives in inefficient set would never be considered by relevant decision makers.

FSD is criticized with respect to the lack of discriminatory power; that is, the efficient sets are often large. Given the very broad assumption of positive marginal utility, the FSD efficient set is often large and may include alternatives that are not actually risk efficient. For example, neither of the alternatives in a pair-wise comparison is considered dominant when the two CDFs intersect on the graph, regardless of where that intersection occurs. Therefore, stronger assumptions regarding decision maker risk preferences are often deemed necessary to reduce the size of the efficient set.

3.2.2.2 Second Degree Stochastic Dominance (SSD)

The SSD also assumes a positive marginal utility of wealth but also assumes that decision makers are risk averse. In other words, SSD is more restrictive in terms of assumptions than is FSD. It implies absolute risk aversion between $0 < \mathrm{r_a(w)} < +\infty$. The same pair-wise comparison process is applied to SSD as was the case for FSD. The decision rule for the

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[11] The opposite will be true if the pair-wise comparison results in the CDF for B being always below the CDF for A; that is, B will dominate by FSD.

comparison is that alternative A dominates alternative B by SSD if and only if the area under CDF at every outcome is no greater for A than B, and is strictly less for at least one outcome. Graphically, for A to dominate B, the CDF for A must initially (for low outcome levels) be at or below B, so that B "accumulates" area faster than A. Unlike FSD, A may still dominate B if the CDFs cross, but the accumulated area under the CDF for A must always be no greater than that for B. If A dominates B, B is placed in the inefficient set and removed from consideration.

Because of more restrictive assumptions about individual risk preferences, SSD generally generates a smaller efficient set than for FSD and is in fact a subset of the FSD efficient set. However, the use of SSD may still result in larger efficient sets. At least partly due to the potential for larger efficient sets resulting from the use of stochastic dominance criteria, an alternative approach has been developed, called stochastic efficiency with respect to a function (SERF) (Hardaker et al., 2004).

3.2.3 Stochastic Efficiency with Respect to a Function (SERF)

SERF is implemented through comparisons of risky alternatives with respect to CE values. Recall that greater expected utility is associated with greater values of CE in the context of expected utility maximization. The associated CE value can be calculated if a particular form for the utility function is assumed for decision makers.

Assuming a functional form for utility is chosen such that the level of absolute risk aversion can be expressed as a function of the parameters for the utility function, CEs are calculated for each risky alternative over a relevant range of absolute risk aversion levels. Patterns of CEs for the risky alternatives may be evaluated either numerically or graphically. The general rule of SERF analysis given the assumptions is that only those risky alternatives that have the greatest CE for at least one value of absolute risk aversion in the relevant range would make up the efficient set. If the CEs obtained are plotted against the coefficients of risk aversion for each alternative, alternative A will be included in the risk efficient set if the CE curve for A is above the CE curve for all other alternatives for at least one relevant risk aversion level.

SERF has stronger discriminatory power than conventional stochastic dominance in that it generally results in a smaller efficient set without confining to pair-wise comparisons. The efficient set is identified by comparing all alternatives over the range of risk aversion simultaneously. Moreover, SERF method can be implemented in a straightforward manner using a spreadsheet where alternatives can be compared through computation of CE values from an inverse utility function. SERF also provides the cardinal ranking of all alternatives at each risk aversion by estimating and comparing the utility-weighted risk premiums; that is, the vertical distance between CEs. The efficient set can be further reduced to a smaller number of alternatives or possibly only one, if more is known about decision maker's risk preferences; that is, if the range of risk aversion for decision makers can be narrowed (Hardaker et al., 2004). More details of SERF implementation are discussed in chapter 4.

3.3 Net Present Value (NPV) Analysis

The entire process involved in the risk efficiency analysis is explained in the context of wealth being the relevant economic performance measure. The empirical measure used in the current analysis as a proxy for wealth is net present value (NPV), which is a capital budgeting measure. NPV is usually used in investment analysis to help decision-makers determine whether a project is sufficiently profitable. Ross and Jordan (2008) defined NPV as the present value of future cash flows (inflows and outflows) minus the present value of costs for an investment project. A positive NPV indicates profits generated by an investment are at least as great as the required rate of return (i.e., the opportunity cost of investment) and the investment is therefore financially acceptable. Conversely, a negative NPV indicates that the investment is not sufficiently profitable and should not be undertaken.

Another interpretation of NPV is that it represents the net amount that an investment will add to the current wealth valued today. In other words, higher NPV values are associated with greater wealth accumulation from the investment. In the context of the current study, which assumes that the farm as an ongoing business, the NPV for a particular crop rotation will proxy the amount that the rotation adds to wealth. The proxy for farm wealth is obtained when time horizon is extended into perpetuity. Therefore, NPV can be used as a proxy of wealth in this empirical study.

To calculate NPV in the current study, each cash flow is discounted to its present value and summed over the relevant time periods. NPV analysis considers all cash flows of the farm operations and it also factors in the time value of money for farm businesses that potentially extend in the long-term. The formula for calculating NPV is expressed as follows (Copeland and Weston, 2005):

$$\mathrm{NPV} = \sum_{t=1}^{N} \frac{\mathrm{CF}_t}{(1+r)^t} \quad (3.4)$$

where CF_t is the net cash flow in time t, N is the time of the project lasts in years, and r is the discount rate.

3.3.1 Choice of Appropriate Discount Rate

The discount rate is the rate of return used to discount future cash flows back to present values. It reflects the market-determined opportunity cost of capital decision makers, assuming an objective of wealth maximization (Copeland and Weston, 2005). The discount rate is not a random value since the NPV can be potentially affected by different choices of discount rates for any long-term projects. Copeland and Weston (2005) also stated the capability of a discount rate to inform risk in investment decisions when cash flows are uncertain. In this situation, the discount rate is the sum of a risk-free rate and a risk premium where the latter reflects the level of risk and risk preferences.

An investment is considered financially acceptable only if the expected return is high enough to cover the risk entailed in the decision (Ross and Jordan, 2008). It further means that the discount rate may vary among investments depending on the relative riskiness of projects. Based on the information provided above, choosing an appropriate discount rate is an important consideration. One method that can be used to determine the discount rate is the Capital Market Line (CML). The CML approach involves using market information (expected returns and volatility of returns), a risk-free return, and information about the volatility of returns for the proposed investment. This information is combined to calculate an expected portfolio return for the proposed investment that is then used as the discount rate. The CML calculation proposed by Sharpe et al. (2000) is shown in equation (3.5):

$$\mathrm{R_p} = \mathrm{r_f} + \frac{\mathrm{R_T} - \mathrm{r_f}}{\sigma_\mathrm{T}} \sigma_\mathrm{p} \tag{3.5}$$

where $\mathrm{R_p}$ is the expected portfolio return (discount rate), $\mathrm{r_f}$ is the risk-free rate of return, $\mathrm{R_T}$ is the expected market return, σ_T is the standard deviation of market return and σ_p is the standard deviation of portfolio return. In consequence, the discount rate $\mathrm{R_p}$ is defined jointly by factors expressed on the right-hand side of the equation above.

This approach was previously employed by Cortus (2005) to determine the discount rate for a farm-level economic analysis of wetland drainage decisions in the Canadian Prairie Pothole region. Cortus obtained a maximum discount rate of 13.9% by using the CML method that aligned with similar studies dealing with farm-level analysis. However, the previous studies had involved a mix of crop and livestock farming operations, and it was suggested that the discount rate applied to a crop farm (as was the case in Cortus' study) would normally lower than on a livestock farm due to the lower risk associated with cropping operations. Thus, the final discount rate used in the NPV analysis for grain production is determined to be 10%. A 10% discount rate is also used by Koeckhoven (2008) in a similar economic study of Best Management Practices (BMP) adoptions on a mixed cow-calf and cropping operations in southern Alberta. Later, Trautman (2012) also adapted work from Cortus to use a 10% discount rate in studying the economics of BMP adoptions on crop farms in Alberta.

3.4 Modeling Agricultural Systems – Simulation Analysis

The study uses cash flow NPV analysis to evaluate the economic performances of alternative cropping systems in Alberta and Southern Saskatchewan. In consequence, an appropriate modeling technique is required to generate cash flows for the production system in the representative farm. The agricultural system is complex due to its dynamic nature and stochasticity in economic and biological parameters such as prices and yields. Given these complexities, it is appropriate to model the agricultural systems in the current study using simulation analysis.

Shannon (1992) defined simulation as the process of constructing a model that mimics a real system, and conducting experiments in the model to understand the system behavior or assist decision-making on various strategies involved in the operation. According to Maria (1997), simulation models are either dynamic or static, depending on whether variables in the model are time-varying or based on a specific point of time. Moreover, the model could either be deterministic or stochastic. A model is stochastic if it includes at least one random variable, while none of the variables are random in a deterministic model. The simulation model is also called the “input-output model” with each output yielded for a given input (Shannon, 1992).

The typical structure of a simulation model is provided in Figure 3.2. To further explain the model structure, a cropping operation is assumed and decision-makers are concerned about returns from the operation. Decision variables include the choice of crops, and production inputs including seeds, chemicals, and fertilizers. Environmental variables are crop prices and yields, and input prices. The simulation model could include probability distributions from which values of the environmental variables are drawn stochastically. The simulated outputs may include net return or profit, which is calculated from the values of the input variables; for example, crop prices multiplied by crop yields from which input costs are subtracted. The measure of performance is the net return from crop production. This could be a single value or, if multiple values of the environmental input variables are drawn, the simulation could generate a distribution of output variables. The model of each cropping system is built upon a structure like this and the results could be used to determine the best cropping system from a set of decisions by comparing the outputs.

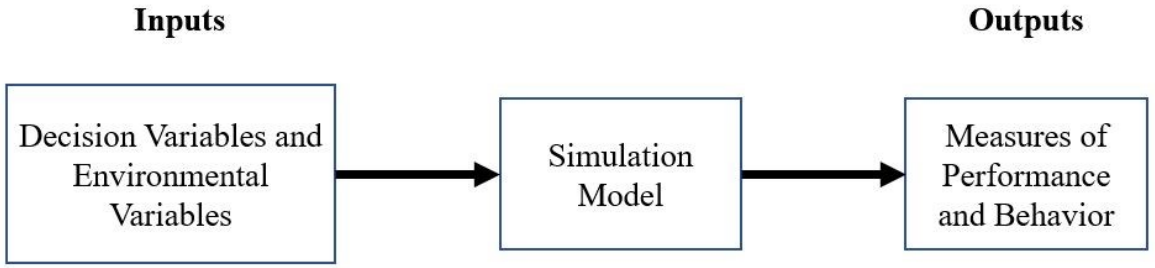

Figure 3.2 Structure of Simulation Model

Source: Evans and Olson (2002)

Simulation analysis has advantages for modeling agricultural systems due to its flexibility and ability to incorporate risk. It provides a range of possible outcomes for a decision instead of necessarily solving for a single optimal solution. Uncertainty of variables can be incorporated into the model and estimated with probability distributions. Simulation also allows evaluating the impacts of changes to the model by varying assumptions associated with the environmental variables. Thus, "previews" of effects that may occur in the real agricultural system are presented without imposing extra costs or risks to the action. Furthermore, simulation analysis allows modeling of complex relationships between input variables. Because of these advantages, simulation models are extensively developed and applied in the context of agriculture in testing hypotheses, exploring policies, and evaluating alternative management decisions of agricultural systems (Bechini and Stockle, 2007).

3.5 Representative Farm Model Framework

Monte Carlo simulation is selected to model the crop production system in this study because of the ability to incorporate risk associated with crop prices and yields. Monte Carlo simulation allows for flexibility in modeling stochastic components including crop prices, crop yields, and yield adjustment effects. It also enables modeling relationships of the production system and adoptions of public business risk management (BRM) programs for the representative farm. This study utilizes a Microsoft Excel add-in software package @RISK (Palisade Corporation, 2010) to construct and run a Monte Carlo simulation model. This platform is chosen because it is intuitive and relatively simple to implement. Moreover, the time required to run the resulting model and generate results is reasonably short even with a large number of iterations.

As indicated above, crop prices, crop yields, and yield adjustment effects are modeled stochastically. Thus, each of these variables is defined as a probability distribution in @RISK. The NPV resulting from each cropping system is the measure of economic performance and the difference between NPVs represents the economic trade-off associated with adoption of alternative crop rotations by the representative farm. Given the stochastic nature of the simulation, a distribution of NPVs is generated and evaluated for each alternative crop rotation.

A working simulation model is built to analyze the economic performance of a cropping system in the representative farm. The first step is defining characteristics of a representative farm including location, farm size, crops, and crop rotations. Next, production costs for seed, fertilizer, chemicals, repairs, transportation, and machinery replacements are incorporated into the model depending on specific crops in rotations. Parameters with uncertainty including crop prices, crop yields, and yield adjustment effects from previous crops are further incorporated and modeled stochastically in the simulation model. The economic impacts of BRM programs including AgriStability and AgriInsurance are incorporated as part of the cash flow NPV analysis in the baseline farm model. It is also noted that some variables are interconnected in the model. For example, crop yield is directly affected by the yield adjustment effect and BRM payments are interdependent with crop prices and yields. The time value of money is accounted for by the discount rate in the NPV analysis.

Each representative farm has multiple rotations and NPV analysis is conducted for each rotation in the simulation model. Intuitively, the rotation generating the greatest NPV would be selected by producers. However, the stochastic nature of crop production complicated this question and so additional risk efficiency analysis is undertaken. Figure 3.3 presents a schematic diagram of the representative farm model. White boxes represent major decision variables of the agricultural model, green boxes represent stochastic variables, blue boxes represent variables involved in cash flow relationships, and orange boxes represent model outputs. The double-ended arrow between Crop Yields and Yield Adjustments indicates that these variables are mutually affected.

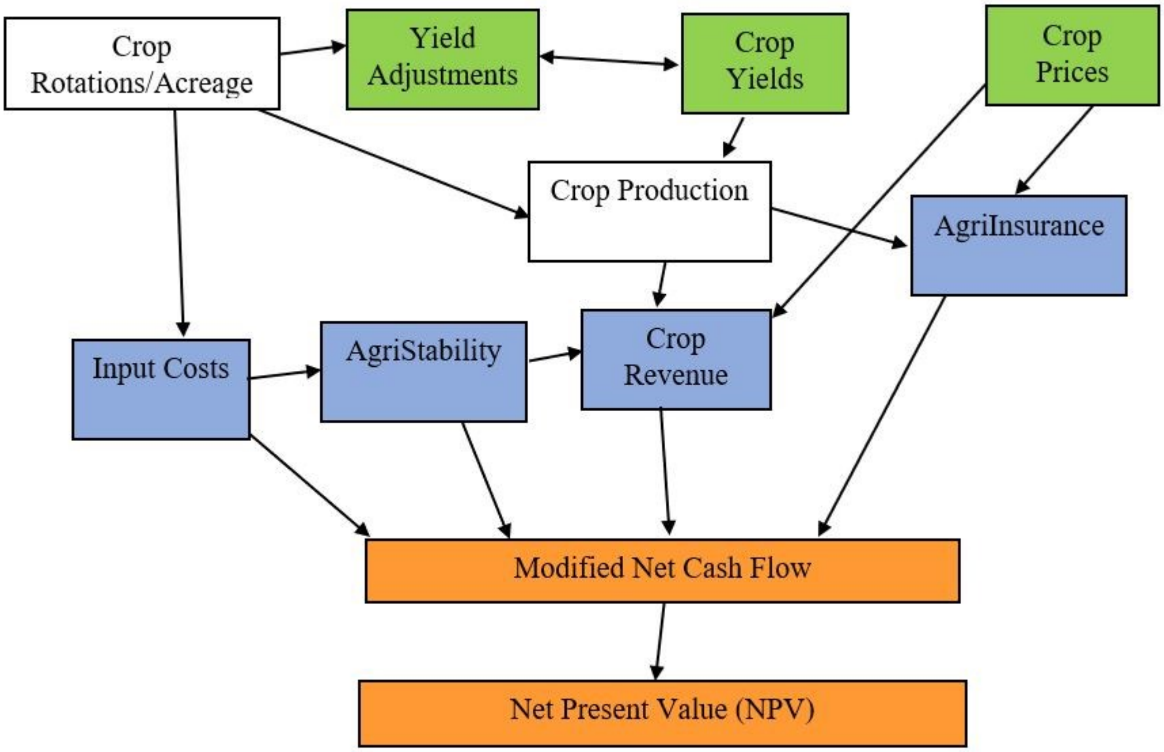

Figure 3.3 Representative Farm Model Structure

3.6 Chapter Summary

This chapter first discusses the central economic objective of expected utility maximization in the study and how it relates to the decision analysis under risky conditions. Different techniques of evaluating the risk efficiency for alternative cropping systems are also discussed. The SERF analysis is a suitable method to determine whether or not a crop rotation is risk efficient to producers who have different risk preferences when facing uncertainties.

The capital budgeting method NPV analysis is used to evaluate the economic performance of the crop farm business. The Monte Carlo simulation analysis is chosen to model the agricultural system and generates distribution of NPVs that are used in SERF analysis as a proxy of wealth. The SERF model is implemented in the Microsoft Excel spreadsheet and the complete representative farm model is built in Microsoft Excel using @RISK software.

CHAPTER 4: The Representative Farm and Empirical Simulation Model

This chapter discusses the procedures used to identify the representative farm characteristics and establishment of stochastic variables in the farm models, including crop prices, crop yields, production costs, etc. All aspects of models are incorporated into the @Risk program for Monte Carlo simulation analysis. It also outlines methods for evaluating economic benefits and costs associated with farm production, as well as participation in business risk management programs. Finally, the process for implementing the stochastic efficiency with respect to a function (SERF) analysis is presented. SERF is used to assess potential producer adoption of cropping systems considering risk, returns, and risk preferences.

4.1 Representative Farm Characteristics

This section describes procedures of identifying and calculating characteristics that are specific to representative farms analyzed in the study. Farm location, size and crop production are essential elements for setting up the structure for Monte Carlo simulation model discussed later in this chapter.

4.1.1 Location

The initial consideration in defining representative farms is location. In this regard, there are alternative criteria that could be used to identify locations included soil zone, crop insurance risk areas and ecoregions[12]. A final decision was made to use soil zones in locating and defining representative farms because a) it is consistent with previous studies, b) crop budgets available for crops are based on soil zone, and c) soil zones are generally consistent with ecoregions.

It was decided to locate the study in both the Black and the Dark Gray Soil zones of Alberta, and the Black Soil zone of Southern Saskatchewan[13]. The study excludes the Dark Gray Soil zone of Saskatchewan as the area for this specific soil zone within the agriculturally productive part of the province is small and thus not representative of crop production for the province. It was further decided that within each soil zone one representative county or rural municipality (RM)

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[12] Ecoregions are areas that have similar geography, environmental conditions and climate.

[13] This research is done as a part of a larger crop diversification project, and analysis for Dark Brown and Brown soil zones was done by other members of the research team.

would be used as the location for each farm. The reason to define a Black Soil zone farm in each of Alberta and Saskatchewan is that there are differences in growing conditions and crops between the two provinces. For example, 2016 Census of Agriculture has reported flax, lentils and soybeans to be crops uniquely grown in Saskatchewan (Statistics Canada, 2016).

Counties and RMs located in Alberta and Southern Saskatchewan, with soil zones overlaid, are presented in Figure 4.1 and Figure 4.2, respectively. The area of Black and Dark Gray soil zones extends over much of the province from north to south in Alberta and the same is true for the Black soil zone in southern Saskatchewan. Thus, counties within boundaries of the respective soil zones are further put into different sub-regions because of climatic differences. In Alberta, two subregions (North and South) are defined in the Black Soil zone, and three subregions (East, South Northwest) are defined in the Dark Gray Soil zone. In Saskatchewan, four subregions are defined in the Black Soil zone including East, Northeast, Southeast, and North and Northwest. However, counties in the Southeast subregion are excluded from consideration due to significant crop differences caused by climatic variations. According to the 2016 Census of Agriculture, soybean areas are reported specifically in counties of the southeast Black Soil subregion while zero acreage is reported in the other three subregions in the Saskatchewan Black Soil zone (Statistics Canada, 2016).

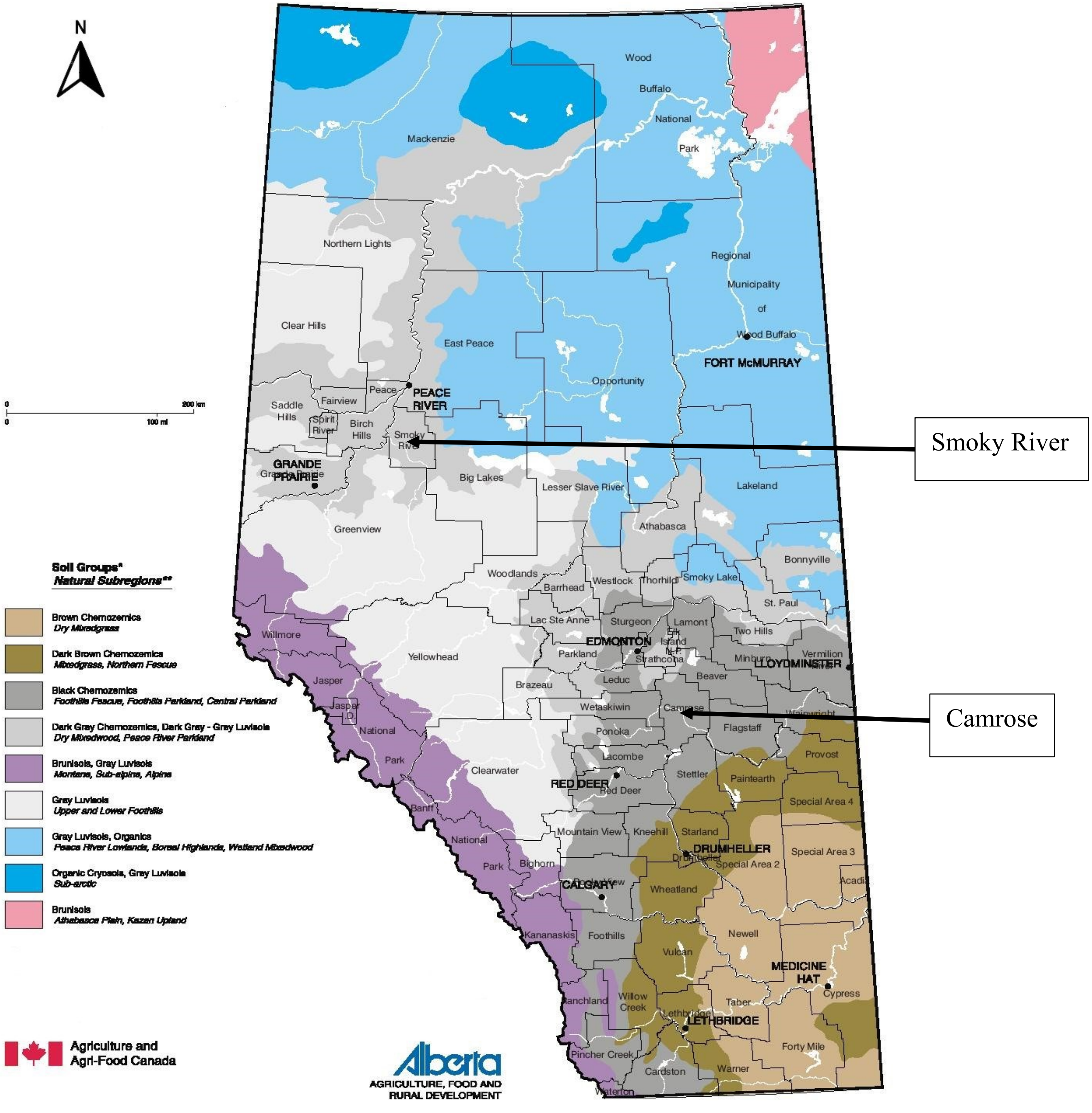
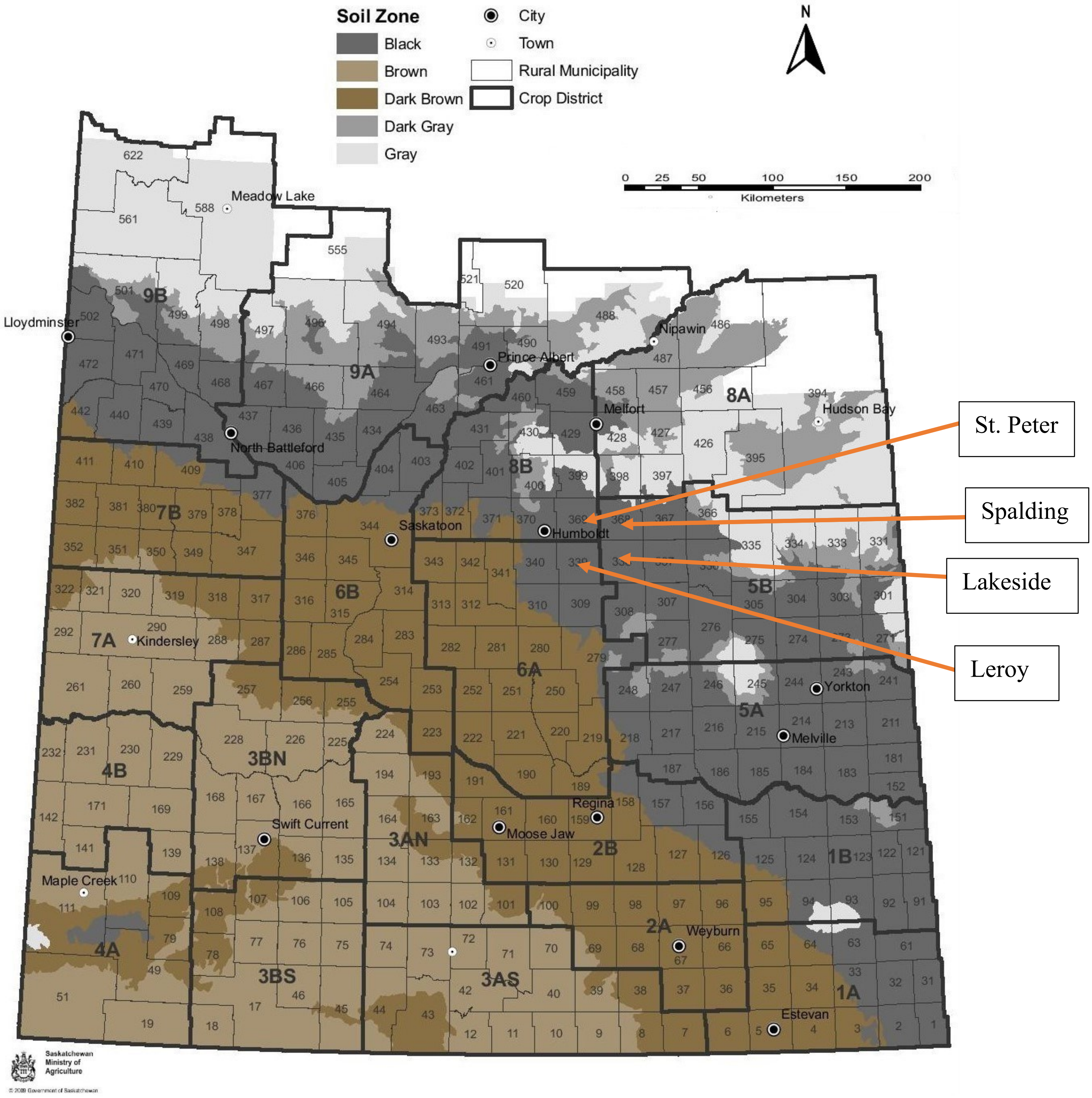


Figure 4.1 Alberta Soil Zone Map

Source: AAF (2015)



St. Peter

Spalding

Lakeside

Leroy

Figure 4.2 Southern Saskatchewan Soil Zone Map

Source: SAF (2019)

A soil coding process is used to determine which counties should be considered within each soil zone. The decision rule was that a county had to be covered by at least two thirds of a specific soil zone to be included in that zone. Counties that have approximately equal proportions of Black and Dark Gray soils are excluded from consideration since they are not sufficiently representative of either soil zone. It was also decided to exclude counties in close proximity to larger metropolitan areas. These counties would include significant non-agricultural areas which would not be representative of intensive cropping activities. A list of counties/RMs included in each of the two provinces after soil coding is provided in Appendix A.

The representative farm locations are selected from the remaining counties based on two agricultural statistics that measured the significance of crop production: 1) percentage of farms devoted to crop production and 2) the proportion of agricultural land allocated to crops. The data from 2016 Census of Agriculture provide the total number of farms that are considered to be engaged in production of crops, cattle, hog and poultry (Statistics Canada, 2016). Table 4.1 shows counties with the highest proportion of crop farms in the corresponding subregion of Black and Dark Gray Soil zones in Alberta, and in the Black Soil zone of Saskatchewan. Given that lower crop farm percentages are reported in South Black subregion (Lacombe) and South Dark Gray subregion (Parkland) in Alberta, they are excluded from further analysis. All counties in the Alberta Northern Black subregion are retained for consideration as higher proportions of crop farms are documented except for those already provided in Table 4.1. Specifically, most counties in the North Black Soil zone have approximately 50% crop farms. On the other hand, all counties located in the NE, and N and NW Saskatchewan subregions are also considered as many counties have at least 80% crop farms. Crop farm statistics of all counties are provided in Appendix B.

Table 4.1 Counties and rural municipalities with the highest percentage of crop farms in the respective soil zone subregions of Alberta and Saskatchewan, 2016[a]

	Soil Subregion[b]	County/ Municipal District	Total Farms	Crop Farms	Farms in (cattle, hog and poultry)
Alberta	Black (South)	Lacombe	1034	329 (31.8%)	390 (68.2%)
	Black (North)	Flagstaff	638	415 (65.1%)	139 (34.9%)
	Dark Gray (East)	Westlock	744	326 (43.8%)	240 (56.2%)
	Dark Gray (South)	Parkland	679	107 (15.8%)	227 (84.2%)
	Dark Gray (NW)	Smoky River	306	251 (82.0%)	18 (18%)
Saskatchewan	Black (East)	Abernethy	114	90 (79.0%)	14 (21%)
	Black (NE)	Leroy	108	92 (85.2%)	5 (14.8%)
	Black (NE)	Sliding Hills	108	92 (85.2)	2 (14.8)
	Black (N & NW)	Hoodoo	146	131 (89.7%)	9 (10.3%)

Source: Statistics Canada (2016)

[a] Percentages do not sum to 100% because other farm types, such as sheep and goat farming, and other crop farming, are not included in the analysis.

[b] Counties are grouped and defined into subregions on the Black and Dark Gray Soil zones, respectively. Directions (north, south, east, SE, NW, N and NW) represent relative positions of each subregion on the soil group map of Alberta and Saskatchewan.

To refine the choice of representative counties, data from the 2016 Census of Agriculture for total farm area, land allocated to pasture, natural, woodland or wetland, Christmas tree area, summer fallow and other uses are collected to calculate the proportion of land dedicated to crops (Statistics Canada, 2016). These measures are then used to evaluate the alternative counties. As mentioned above, counties in certain subregions with greater proportion of crop farms are considered. However, given the large number of eligible counties in southern Saskatchewan, the cut-off for consideration was increased. The reassessment was then conducted by using counties with at least 50% and 80% crop farms as threshold values for Alberta and Saskatchewan, respectively. The statistics of agricultural land devoted to crop production in the selected counties are presented in Table 4.2.

Table 4.2 Counties and area of farm land (in acres) included in choosing representative farms for each soil zone with significant cropping activities, 2016

	Soil Zone	County/ Municipal District	Area in crops	Area in (summer fallow, tame pasture and natural)	Area in (woodland, Christmas tree and other uses)
Alberta	Black	Flagstaff	694,020 (68.2%)	208,492 (20.5%)	114,509 (11.3%)
		Camrose	620,421 (74.9%)	149,568 (18.1%)	58,224 (7.0%)
		Minburn	496,297 (69.1%)	175,667 (24.4%)	47,060 (6.5%)
		Lamont	398,381 (65.4%)	147,518 (24.2%)	63,313 (10.4%)
	Dark Gray	Smoky River	545,973 (82.2%)	50,131 (7.6%)	67,953 (10.2%)
Saskatchewan	Black	Sliding Hills	119,907 (85.1%)	8474 (6.0%)	12,545 (8.9%)
		Buchanan	115,396 (81.7%)	9821 (7.0%)	15,936 (11.3%)
		Emerald	131,900 (71.8%)	13,141 (7.2%)	38,555 (21.0)
		Elfros	106,099 (72.7%)	13,955 (9.6%)	25,913 (17.7%)
		Leroy	198,541 (89.7%)	6512 (3.0%)	161,86 (7.3%)
		Lakeside	134,647 (86.9%)	9212 (5.9%)	11,154 (7.2%)
		Spalding	143,503 (77.7%)	20,923 (11.3%)	20,352 (11.0%)
		Hoodoo	159,235 (79.5%)	8674 (4.3%)	32,456 (16.2%)
		Flett's Springs	179,212 (81.7%)	11,693 (5.3%)	28,362 (13.0%)
		St. Louis	143,033 (85.0%)	6357 (3.8%)	18,919 (11.2%)
		St. Peter	193,833 (91.9%)	2964 (1.4%)	1445 (6.7%)
		Humboldt	166,955 (78.6%)	14,629 (6.9%)	30,779 (14.5%)

Source: Statistics Canada (2016)
Note: Values in parentheses are the percentages of total farm area for the respective type of land use.

In Alberta, it was decided to locate the representative farm for the Black soil zone in the County of Camrose. Although the County of Flagstaff had a higher proportion of crop farms (65.1%) than Camrose (52.4%), the latter was chosen because of the highest percentage of agricultural land (approximately 75%) devoted to crops. In the Dark Gray soil zone, the Municipal District of Smoky River was determined to be the location of representative farm. This county is dominant over all other counties in the Dark Gray soil zone, and has the largest proportion of crop farms as well as the agricultural land seeded in crops (both around 82%).

In the northeast Black soil zone of Saskatchewan, both RMs of Sliding Hills and Leroy had the highest proportion of crop farms at 85.2%. However, Leroy was chosen over Sliding Hills due to a higher proportion of crop land (89.7%) versus 85.1% in Sliding Hills. Among the north and northwest Black Soil zone counties, the RMs of Hoodoo and St. Peter had approximately 89.7%

and 84.7% crop farms, respectively. The RM of St. Peter was selected because of significant agricultural land allocated to crops (91.9%) compared to 79.5% in Hoodoo. However, a final decision was made to locate the representative farm in an area consisting of four adjacent counties. Crop experts (Brooks, 2019; Cutts, 2019; Whatley, 2019) suggested that since the size of an RM in Saskatchewan is smaller than a county in Alberta, the farm location should be expanded with adjacent RMs to be fully representative of crop production. By using four representative counties, the area of each crop would be sufficiently large and comparable to crop production in Alberta representative counties. Therefore, four RMs were included and used as the location of the representative farm in the Black soil zone of Saskatchewan; St. Peter, Leroy, Lakeside and Spalding. The percentage of land allocated to crops in two additional counties was high with approximately 86.9% in Lakeside and 77.7% in Spalding.

4.1.2 Farm Size

The size of the representative farms was determined based on the Census of Agriculture (2016) and expert opinion from AAF. It was important that the farms should be representative in terms of commercial operations in the relevant regions of Alberta and Saskatchewan. In a previous study by Trautman (2012), the minimum size of commercially viable farms was determined to be 1,600 acres. However, cropping experts (Blue, 2020; Manglai, 2020) suggested the minimum size of a commercially viable farm ranges from 2,000 to 3,000 acres.

In the Census of Agriculture, farms that are in the range of commercially viable farms defined in the previous paragraph are classified into the following categories in terms of area: 1600 to 2239 acres, 2240 to 2879 acres, 2880 to 3519 acres, and 3520 or higher (Statistics Canada, 2016). Table 4.3 shows that majority of commercial farms (80.5%) in the Camrose County fall between 1600 to 3519 acres. Thus, it is reasonable to set the size of representative farm at 2560 acres for the Camrose County as it conforms to advice from crop experts about minimum size and the statistics also indicated it as an appropriate size to use in the study. As well, 2560 acres is appropriate as it represents exactly four sections of land. In the Municipal District of Smoky River, the representative farm size is determined to be 1920 acres. This number lies within the range of 1600 to 3519 acres which 65.4% of commercial farms are belonged to this category.

This size is also greater than the minimum commercial farm size of 1600 acres used in the earlier study and represents exactly three sections of land.

Table 4.3 Distribution of farms by size, by county

	Number of Farms		
Farm Size (Acres)	Camrose	Smoky River	Saskatchewan[a]
Under 560	558	94	162
560-759	71	13	35
760-1119	89	33	48
1120-1599	80	36	47
1600 to 2239	60	44	46
2240 to 2879	47	25	24
2880 to 3519	25	16	18
3520 and over	32	45	55
Total Commercial Farms[b]	164	130	143
Total Farms	962	306	435
% of Commercial Farms sized from 1600 to 3519 aces	80.5%	65.4%	61.5%

Source: Statistics Canada (2016)

[a] Farm numbers in Saskatchewan are the sum of four representative counties: St. Peter, Leroy, Spalding and Lakeside.

[b] Commercial farms are at least 2000 acres.

The farm size defined in Camrose county at 2560 acres is also used for the representative farm in Saskatchewan. The decision is based on both agricultural statistics and expert opinion. First, a relatively large proportion of commercial farms (61.5%) in Saskatchewan are between 1600 to 3519 acres, as indicated in Table 4.3. Secondly, expert opinion (Manglai, 2020; Blue, 2020) suggested that using a consistent size for Black Soil zone representative farms in both Alberta and Saskatchewan is appropriate.

4.2 Crop and Rotations[14]

Identifying potential crops and the associated rotation sequences are fundamental to the construction of farm simulation model. Each representative farm has a group of potentially feasible crops that are determined separately due to climatic and other differences across soil zones, such as precipitation, temperature, and soil moisture. Crops considered in the study are determined based on relevant agricultural statistics (i.e., area grown) and recommendations from experts. Dominant crops of representative counties are determined based on seeded area (in acres) from the 2016 Census of Agriculture (Statistics Canada, 2016). Table 4.4 provides the top ten field crops grown in each representative county by area.

Table 4.4 Acreage of principal[a] crops grown in representative counties, 2016

	Camrose	**Smoky River**	**Saskatchewan[b]**
Crop		**Acres**	
Canola	216,301	259,729	294,762
Spring Wheat	183,430	189,092	54,694
Barley	103,574	16,940	122,871
Field Peas	43,284	48,672	23,845
Oats	9809	3734	40,839
Alfalfa	29,097	7689	4837
Tame Hay	15,646	4336	9163
Forage Seed	489	6784	2755
Mixed Grains	4196	N/A[c]	N/A
Lentils	N/A	2010	2024
Flaxseed	1957	1070[d]	6720
Corn	2018	580	92
Other Dry Beans	3371	N/A	N/A
Other Crops	2218	N/A	6481
Total	615,390	539,566	569,083

Source: Statistics Canada (2016)

[a] Top ten crops reported based on acreages grown in each representative county.

[b] Acres reported in Saskatchewan are the sum of four representative counties: St. Peter, Leroy, Spalding and Lakeside.

[c] N/A denotes values that are unavailable due to zero acreage or confidentiality (i.e., too few producers growing the crop).

[d] Flaxseed area in Smoky River is taken from 2011 census data since flax data are unavailable for Smoky River in 2016.

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[14] For simplicity in writing rotations, in sections 4.2.1 to 4.2.3 crops are abbreviated as follows: spring wheat (SW), canola (C), barley (B), oats (O), field peas (FP) and flax (F).

According to the 2016 Census of Agriculture, common crops grown in all representative counties are canola, spring wheat, barley and field peas. In Saskatchewan, canola, barley, spring wheat and oats are dominant crops with a slightly smaller area of field peas, based on the reported total acreages for the four representative counties. Other crops such as alfalfa and tame hay also represent significant areas, especially in the two representative Alberta counties. However, hay crops (alfalfa and tame hay) are excluded from rotation considerations since the study focuses on commercial crop production. Hay is often produced to support beef or dairy enterprises.

4.2.1 Base Rotation

Rotations developed in each farm varied from a two-year to an eight-year sequence, and included both specialized and diversified rotations. The base rotation is consistent for all three farms. It is a two-year cereal-oilseed rotation consisting of spring wheat and canola (SW-C). The reason for choosing SW-C as the base rotation is because spring wheat and canola are the two most common crops, in terms of area, in each representative county (Statistics Canada, 2016)[15]. Moreover, experts suggested wheat-canola was a commonly adopted rotation by producers in the Canadian Prairies (Brooks, 2019; Cutts, 2019; Whatley, 2019). The study also considers more specialized rotations with increased frequency of canola, along with more diversified rotations.

The decision was made to study canola intensive rotations because producers in western Canada have increased the frequency of canola in rotations due to higher short-term expected returns associated with growing canola (Smith et al., 2013). Regarding considerations of more diversified rotations in the study, Krupinsky et al. (2002); Johnston et al. (2005) and Kutcher et al. (2013) have listed a range of benefits from adopting diversified and longer rotations including the maintenance of long-term productivity and reduced likelihood of crop diseases and pest problems. The following sub-sections provide a discussion of alternative rotations developed for each representative farm.

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[15] This is true for the two Alberta counties, but not for the RMs in Saskatchewan used to define the representative farm characteristics. However, the decision was made to use SW-C as the base rotation for all three farms based on expert opinion and the desire for consistency across the three farms.

4.2.2 Alberta Black and Dark Gray Soil Zone Rotations

Alternative rotations in both Black and Dark Gray Soil zones were determined based on expert opinion using sound agronomics and real cropping activities adopted by producers. Statistical information from the 2016 Census of Agriculture was employed to further confirm decisions on crops included in the rotations. Spring wheat (SW) and canola (C) were the two crops present in all alternative rotations. Barley was included in several rotations it is the third largest crop in terms of seeded area, at least for the representative Alberta counties. Field peas were also included in some rotations because it is a common crop and is agronomically beneficial due to its ability to fix nitrogen and boost yields for subsequent crops (Smith et al., 2013). In addition, experts suggested field peas as a great annual crop to improve diversification as all three main crop families (cereal, oilseed and pulse annual legume) would then be included in the crop rotation (Brooks, 2019; Cutts, 2019; Whatley, 2019). Lastly, oats were included in some rotations as it is an alternative cereal crop for barley and is agronomically feasible to substitute for barley to further diversify the rotation.

Canola intensive rotations are also considered in the analysis. Increasing the frequency of canola has significant disadvantages such as increasing disease likelihood and breakdown of resistance of canola cultivars. However, canola intensive rotations are increasingly favored by producers due to higher economic value associated with canola. Thus, rotations of varying canola intensities are modeled in the study.

From this process, ten rotations are defined for the Camrose and Smoky River representative farms. The set of rotations are identical for both farms. Crop sequences are provided in Table 4.5 with canola-intensive rotations listed first, followed by the more diversified rotations at the bottom. For these farms as well as for the Saskatchewan farm, it is assumed that all crops in a particular rotation are grown in each year of the analysis with the area for each crop being based on the number of crops in the rotation and the length of the rotation. For example, the SW-C base rotation is modeled as spring wheat and canola each being grown on half the farm area each year. Conversely, the SW-C-C-B rotation is modeled as half the farm being allocated to canola while a quarter of the area is allocated to each of spring wheat and barley.

Table 4.5 Crop rotations defined in Black and Dark Gray Soil Zone Farms, Alberta

Rotation No.	Rotation Sequence
1 (base)	SW-C
2	SW-C-C
3	SW-C-C-C
4	SW-C-C-B
5	SW-C-C-O
6	SW-C-B
7	SW-C-B-SW-C-O
8	SW-C-B-FP
9	SW-C-O-FP
10	SW-C-B-FP-SW-C-O-FP

4.2.3 Saskatchewan Black Soil Zone Rotations

The same principles used for the Alberta representative farms were applied in defining rotations for the Saskatchewan representative farm. The one exception was that an additional oilseed crop, flax, was included as part of the diversified rotations. Although the allocation of land to flax is limited in the Alberta representative counties, its planting area ranked among the top ten crops in all four counties that were selected as the representative location in Saskatchewan. Therefore, flax is considered in defining rotations specific to that representative farm.

Defining the rotations that included flax was assisted by expert opinion and previous literature. According to expert opinion from AAF, growing flax in northern Alberta and Saskatchewan is risky, especially during wet years since it has a long growing season and highly vulnerable under frozen conditions (i.e., frost) (Brook, 2019; Cutts, 2019; Whatley, 2019). They also suggested that flax should be planted near the end of a cropping sequence to avoid competition for soil nutrients with other crops due to its strong absorptive ability.

In field experiments conducted by Kutcher et al. (2013) in the Saskatchewan Black soil zone, Melfort, a four-year rotation including flax was developed: C-SW-F-SW. This rotation was agronomically sound as it reduced blackleg incidence and severity in canola when rotating with wheat and flax. A similar four-year rotation C-SW-F-C was developed by Guo et al. (2005) in Carman, Manitoba. This rotation appeared to significantly lower the occurrence of disease. Another rotation included in the current analysis, SW-C-B-F, was developed based on earlier work of Cortus (2005) in the RM of Emerald. Emerald is also located on the Black Soil zone in

Saskatchewan, and is in close proximity to the representative farm location in this study. As a result, the rotation is considered to be agronomically feasible for the current analysis. Similar to rotations defined for the Alberta representative farms, SW-C-O-F and SW-C-B-F-SW-C-O-F are developed as alternative or extended rotations with oats substituted for barley from the rotation SW-C-B-F. Flax always follows cereal crops in alternating crop sequences. This is because flax sown on cereal stubble resulted in higher yield performances compared to oilseed and legume crops (Flax Council of Canada, 2019). There are fifteen rotations defined for the Saskatchewan representative farm, and the rotation sequences are provided in Table 4.6.

Table 4.6 Crop rotations defined in Black Soil Zone Farm, Saskatchewan

Rotation No.	Rotation Sequence
1 (base)	SW-C
2	SW-C-C
3	SW-C-C-C
4	SW-C-C-B
5	SW-C-C-O
6	SW-C-B
7	C-SW-F-SW
8	C-SW-F-C
9	SW-C-B-FP
10	SW-C-O-FP
11	SW-C-B-F
12	SW-C-O-F
13	SW-C-B-SW-C-O
14	SW-C-B-FP-SW-C-O-FP
15	SW-C-B-F-SW-C-O-F

4.3 Stochastic Simulation Model Parameters

This section provides an explanation of the methods used to establish stochastic parameters for simulation models in the study. Stochastic parameters include crop price, yield and associated yield adjustments. These parameters are estimated using historical data.

4.3.1 Crop Yield Models

The stochastic yield of each crop is drawn directly from the estimated yield distributions based on historical county-level yield data. The historical yield data from were obtained for Alberta (1987 to 2017) and Saskatchewan (1987 to 2018) from Agriculture Financial Services Corporation (AFSC, 2019) and Government of Saskatchewan (SAF, 2019), respectively.

Summary statistics of historical yield data prior to de-trending for representative counties are provided in Table 4.7.

Table 4.7 Summary yield statistics by farm (tonne /acre)

County	Crop	Observations	Mean	Standard Deviation	Minimum	Maximum
Camrose	Barley	31	1.364	0.309	0.215	1.953
	Canola	31	0.740	0.244	0.124	1.189
	Spring Wheat	31	1.199	0.293	0.265	1.790
	Oats	31	1.153	0.373	0.104	1.956
	Field Peas	24[a]	1.070	0.370	0.000	1.602
Smoky River	Barley	31	1.285	0.317	0.715	1.959
	Canola	31	0.650	0.179	0.310	0.966
	Spring Wheat	31	1.128	0.283	0.648	1.639
	Oats	31	1.213	0.450	0.000	2.008
	Field Peas	23[b]	0.992	0.260	0.566	1.425
Saskatchewan	Barley	127	1.244	0.344	0.481	2.053
	Canola	127	0.644	0.209	0.235	1.200
	Spring Wheat	127	1.191	1.830	0.285	1.483
	Oats	127	1.199	0.399	0.428	2.143
	Field Peas	106[c]	0.941	0.267	0.299	1.548
	Flax	112[d]	0.531	0.148	0.190	0.793

Source: AFSC (2019) and SAF (2019)

Note: Summary statistics are generated from raw yield data prior to de-trending.

[a] 24 observations for field peas in Camrose because yield data of 1987 to 1994 are not reported.

[b] 23 observations for field peas in Smoky River because yield data of 1987 to 1993 are not reported.

[c] 106 observations for field peas in Saskatchewan because five data points (1987 to 1991) are missing from St. Peter, Lakeside and Spalding respectively, and six data points (1987 to 1992) are missing from Leroy.

[d] 112 observations for flax in Saskatchewan because two data points are missing from St. Peter, three data points are missing from Lakeside and ten data points are missing from Spalding.

4.3.1.1 Crop Yield De-trending

Prior to estimating probability distribution, data are tested to examine whether yields show an upward trend; that is, whether yield variability is influenced by technical change over time (Ker and Coble, 2003). The de-trending process ensures variations in yields modeled were only attributed to random events such as weather and environmental factors rather than changes in technology.

A common method of testing for a time trend is to regress yield against time using Ordinary Least Squares (OLS) regression. The historical county-level yields (Y_t) are regressed as a function of time (t) as shown in equation (4.1). The null hypothesis (H_0: no time trend) is rejected if the time coefficient (β) is statistically significant. A significant positive time coefficient confirms the presence of technical change in the yield data. In that case, yield is then detrended using residuals from the regression, calculated by subtracting predicted yield from observed yield for each year. Residuals are then added to the predicted value of the base year yield to obtain a series of detrended yields. In this study, the most recent year 2019 was chosen as the base year.

$$\mathrm{Y_t} = \alpha + \beta \mathrm{t} + \varepsilon_\mathrm{t} \tag{4.1}$$

The yield trend regression results, including coefficient estimates and two-tailed p-value statistics, are provided in Table 4.8.

Table 4.8 Time trend regression results of pre-detrending yields

	County	Crop	Constant	Time Coefficient	t-stat	Two-tailed p-value
Alberta	Camrose, Black	Barley	-29.319	0.0153***	2.72	0.011
	Camrose, Black	Canola	-39.309	0.0200***	6.05	0.000
	Camrose, Black	Oats	-36.238	0.0187***	2.75	0.010
	Camrose, Black	Spring Wheat	-39.195	0.0202***	4.32	0.000
	Camrose, Black	Field Peas	-16.737	0.0089	0.947	0.354
	Smoky River, Dark Gray	Barley	-45.975	0.0236***	4.95	0.000
	Smoky River, Dark Gray	Canola	-30.696	0.0156***	7.09	0.000
	Smoky River, Dark Gray	Oats	-20.305	0.0107	1.20	0.241
	Smoky River, Dark Gray	Spring Wheat	-43.486	0.0223***	5.51	0.000
	Smoky River, Dark Gray	Field Peas	-43.281	0.022***	3.22	0.004
Saskatchewan	Black	Barley	-42.831	0.022***	8.26	0.000
		Canola	-34.051	0.0173***	13.46	0.000
		Oats	-63.904	0.0325***	12.84	0.000
		Spring Wheat	-56.310	0.0286***	13.48	0.000
		Field peas	-19.653	0.0103***	3.20	0.002
		Flax	-16.642	0.0086***	6.49	0.000

Note: *, **, and *** represent statistical significance at the 10%, 5%, and 1% level, respectively.

All six crops (i.e., barley, canola, spring wheat, oats, field peas and flax) for the Saskatchewan farm had statistically significant time coefficients. For Camrose County, barley, canola, spring wheat and oats (i.e., all but field peas) had significantly positive time trends. For Smoky River, barley, canola, spring wheat and field peas (i.e., all but oats) had significant positive time coefficients. Thus, all crop yields were de-trended, with the exceptions of field peas in Camrose County and oats in Smoky River. Summary statistics of de-trended crop yields are provided in Tables 4.9 to 4.11. The data and graphs of de-trended crop yields are presented in Appendix C.

Table 4.9 Statistical summary of de-trended crop yields (tonne/acre), Camrose

Crop	Mean	Standard Deviation	Maximum	Minimum
Barley	1.59	0.28	2.01	0.44
Canola	1.04	0.16	1.27	0.42
Spring Wheat	1.50	0.23	1.87	0.57
Oats	1.43	0.33	2.03	0.38
Field Peas	1.12	0.30	1.60	0.16

Table 4.10 Statistical summary of de-trended crop yields (tonne/acre), Smoky River

Crop	Mean	Standard Deviation	Maximum	Minimum
Barley	1.64	0.23	2.33	0.98
Canola	0.88	0.11	1.26	0.51
Spring Wheat	1.46	0.20	2.05	0.92
Oats	1.30	0.32	2.33	0.28
Field Peas	1.42	0.27	2.42	0.79

Table 4.11 Statistical summary of de-trended crop yields (tonne/acre), Saskatchewan

Crop	Mean	Standard Deviation	Maximum	Minimum
Barley	1.59	0.28	2.16	0.75
Canola	0.91	0.13	1.22	0.48
Spring Wheat	1.48	0.22	2.05	0.91
Oats	1.71	0.26	2.63	1.12
Field Peas	1.07	0.25	1.56	0.41
Flax	0.66	0.13	0.95	0.29

4.3.1.2 Yield Distribution Fitting

As noted earlier, stochastic yields used in the simulation are drawn from empirical distributions, based on the historical yields (de-trended if necessary). To determine the best distribution to use to model the historical yields, each detrended yield series was fitted to alternative distributions using the “Distribution Fitting” option in @RISK. The “Distribution Fitting” feature fitted historical yield data into available distributions and generated goodness-of-fit test statistics to determine the best fitting of the alternative distributions. While a large number of alternative distributions are available for use, the options to be considered were limited to the following distributions: Beta, Gamma, Weibull, Triangular, Lognormal, and Exponential. There are two reasons for limiting the choices to these six distributions. First, they had the property of being truncated at zero which eliminated the possibility of negative crop yields. Secondly, they were flexible in terms of being able to model skewness and kurtosis. Field crop yields have been shown to demonstrate these properties (Day, 1965; Gallagher, 1987; Nelson and Preckel, 1989; Moss and Shonkwiler, 1993).

The goodness of fit for the alternative yield distributions was measured using Kolmogorov-Smirnov (K-S) test statistics. The K-S statistic is a non-parametric measure of goodness of fit, which describes how well the historical data match with a pre-determined distribution. A smaller test statistic represents a better fit between a specific distribution and the actual data. K-S statistics indicated that the Weibull distribution was the best fitting distribution for all crop yields in Camrose County. Results were mixed in Smoky River and for the Saskatchewan farm. However, in each case the Weibull was the best fitting distribution for at least half of the crops and was the second or third best fitting distribution in all other cases. Based on the overall results, the Weibull distribution was selected to model all yields in each farm, to provide a consistent modeling framework for all crops. K-S test statistics are presented in Tables 4.12 to 4.14**.** In each case the smallest K-S statistic value is highlighted in bold.

Table 4.12 K-S Statistics of the best yield distribution fitting in Camrose

Distribution	Barley	Canola	Oats	Spring Wheat	Field Peas
Weibull	**0.1441**	**0.1693**	**0.1656**	**0.1139**	**0.1407**
Beta	0.1542	0.1900	0.1749	0.1428	0.1461
Gamma	0.2157	0.2736	0.2391	0.2054	0.2047
Triangle	0.4125	0.4572	0.3171	0.4248	0.2652
Lognormal	0.2387	0.2902	0.2592	0.2303	0.2515
Exponential	0.5019	0.5125	0.4379	0.5327	0.4546

Note: N/A denotes the inability of data to fit in certain distributions because parameters of the distribution do not convergent.

Table 4.13 K-S Statistics of the best yield distribution fitting in Smoky River

Distribution	Barley	Canola	Oats	Spring Wheat	Field Peas	Flax
Weibull	0.0975	**0.0902**	**0.0949**	0.1248	0.1699	**0.0901**
Beta	0.0983	0.1104	0.1133	**0.1151**	N/A	0.0915
Gamma	0.0941	0.1320	0.1263	0.1237	0.1158	N/A
Lognormal	**0.0913**	0.1398	0.1327	0.1250	**0.1043**	N/A
Triangle	0.3551	0.3926	0.2151	0.3655	0.3284	0.1084
Exponential	0.5223	0.5149	0.4623	0.5348	0.5231	0.3422

Note: N/A denotes the inability of data to fit in certain distributions because parameters of the distribution do not convergent.

Table 4.14 K-S Statistics of the best yield distribution fitting in Saskatchewan counties

Distribution	Barley	Canola	Oats	Spring Wheat	Field Peas	Flax
Weibull	**0.0776**	**0.0705**	0.0656	0.0684	**0.1102**	**0.0719**
Beta	0.0893	0.0830	N/A	**0.0558**	0.1116	0.0749
Gamma	0.1459	0.1275	**0.0466**	0.0806	0.1770	0.1129
Lognormal	0.1584	0.1360	0.0564	0.0911	0.1932	0.1185
Triangle	0.2922	0.3414	0.3060	0.3354	0.2246	0.2410
Exponential	0.4422	0.4854	0.4823	0.4769	0.3939	0.4488

Note: N/A denotes the inability of data to fit in certain distributions because parameters of the distribution do not convergent.

The Weibull distribution probability density function is described below in (4.2):

$$f(x) = \frac{\alpha x^{\alpha-1}}{\beta{}^\wedge\alpha} e^{-\left(\frac{x}{\beta}\right)^{\alpha}} (\alpha > 0, \beta > 0) \tag{4.2}$$

where α and β are the continuous shape and scale parameters, respectively. Both α and β are non-zero values. The formula for the distribution mean is $\beta\Gamma(1+\frac{1}{\alpha})$ and the distribution variance is calculated as $\beta^2\left[\Gamma\left(1+\frac{2}{\alpha}\right)-\Gamma^2\left(1+\frac{1}{\alpha}\right)\right]$, where Γ is the Gamma function (Palisade Corporation, 2010). The initial estimated Weibull distribution parameters are provided in Table 4.15.

Table 4.15 Initial estimated Weibull distribution parameters, by county and crop

County	Crop	α	β
Camrose	Barley	8.30	1.69
	Canola	9.82	1.10
	Spring Wheat	9.11	1.58
	Oats	5.45	1.55
	Field Peas	4.59	1.21
Smoky River	Barley	8.08	1.74
	Canola	9.01	0.93
	Spring Wheat	8.36	1.55
	Oats	4.42	1.42
	Field Peas	5.31	1.53
Saskatchewan	Barley	7.24	1.70
	Canola	8.15	0.97
	Spring Wheat	7.46	1.58
	Oats	6.76	1.82
	Field Peas	5.28	1.17
	Flax	6.22	0.71

4.3.1.3 Marra-Schurle (M-S) Adjustment

The historical yield data for this study are available at the county level whereas the simulation is conducted at the farm level. Marra and Schurle (1994) suggested that using aggregated data to represent farm-level data is problematic since it usually results in farm-specific variability being underestimated. Hence, yield variability needed to be adjusted to remove biases that arose from the process of data aggregation (Marra and Schurle, 1994). An approach proposed by Marra and Schurle (1994) suggests that the variability of county-level yields should be adjusted upward by 0.1% for every percentage difference between county acreage and farm acreage within the county in order to approximate the degree of variability at the farm level. This yield correcting process has been adopted in previous simulation analyses such as Trautman (2012), Xie (2014) and Bruce (2017).

Based on the Marra-Schurle approach, the standard deviations of each detrended crop yield series were adjusted. In accordance with adjustment procedures developed by Marra and Schurle (1994), the farm acreage and the county acreage grown for each crop are used to represent the total farm acreage and total county acreage, respectively. The total acreage of each crop in the actual farm production ranges from 320 to 1280 acres in Camrose with a farm size of 2560 acres.

To maintain consistency, an average area of 853 acres[16] was used in the adjustment; that is, the farm equally divided between crops in a three-year rotation. A similar principle was applied to the other two farms. The percentage difference between farm and county acreage was obtained by using the following formula:

$$\% \text{ Difference} = (|\text{County Area} - \text{Farm Area}|) / [(\text{County Area} + \text{Farm Area}) /2] *100 \tag{4.3}$$

The resulting M-S adjustments of standard deviations for the representative farms are provided in Tables 4.16 to 4.18.

Table 4.16 Marra-Schurle adjustment of standard deviations for crop yields in the County of Camrose

	Barley	Canola	Spring Wheat	Oats	Field Peas
Farm Acreage	853	853	853	853	853
County Acreage[a] (2016)	103,574	216,301	183,430	9,809	43,284
% Difference	196.73	198.43	198.15	167.99	192.27
Marra-Schurle Adjustment Coefficient	0.10%	0.10%	0.10%	0.10%	0.10%
% Std. Dev. Change	19.67%	19.84%	19.81%	16.80%	19.23%
Actual Std. Dev.	0.28	0.16	0.23	0.33	0.30
Increase in Std. Dev.	0.05	0.03	0.04	0.06	0.06
Adjusted Std. Dev.	0.33	0.19	0.27	0.39	0.36

Source: Statistics Canada (2016)

[a] Total acreage of each crop in the actual farm production ranges from 320 to 1280 acres. To keep consistency, the average area 853, divided equally for a three-year rotation (SW-C-B) is used.

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[16] Technically, separate adjustments should be done for each rotation given that the area devoted to each crop will vary across rotations. However, it was decided not to do that in order to avoid unnecessary complexity in modeling. As well, it was determined that the difference between the adjusted standard deviation of crop yields from applying a consistent area for all crops in all rotations versus using rotation-specific crop acreages was numerically insignificant.

Table 4.17 Marra-Schurle adjustment of standard deviations for crop yields in the M.D. of Smoky River

	Barley	Canola	Spring Wheat	Oats	Field Peas
Farm Acreage	640	640	640	640	640
County Acreage[a] (2016)	16,940	259,729	189,092	3,734	48,672
% Difference	185.44	199.02	198.65	141.47	194.81
Marra-Schurle Adjustment Coefficient	0.10%	0.10%	0.10%	0.10%	0.10%
% Std. Dev. Change	18.54%	19.90%	19.87%	14.15%	19.48%
Actual Std. Dev.	0.23	0.11	0.20	0.32	0.27
Increase in Std. Dev.	0.05	0.02	0.04	0.05	0.05
Adjusted Std. Dev.	0.28	0.13	0.24	0.37	0.32

Source: Statistics Canada (2016)

[a] Total acreage of each crop in the actual farm production ranges from 240 to 960 acres. To keep consistency, the average area 640, divided equally for a three-year rotation (SW-C-B) is used.

Table 4.18 Marra-Schurle adjustment of standard deviations for crop yields in Saskatchewan farm

	Barley	Canola	Spring Wheat	Oats	Field Peas	Flax
Farm Acreage	853	853	853	853	853	853
County Acreage (2016)	30718	73691	36372	10210	5961	1680
% Difference	189.19	195.42	190.83	169.15	149.91	65.26
Marra-Schurle Adjustment Coefficient	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
% Std. Dev. Change	18.92%	19.54%	19.08%	16.91%	14.99%	6.53%
Actual Std. Dev.	0.28	0.13	0.22	0.27	0.25	0.12
Increase in Std. Dev.	0.05	0.03	0.04	0.04	0.04	0.01
Adjusted Std. Dev.	0.33	0.16	0.26	0.31	0.29	0.13

Source: Statistics Canada (2016)

[a] Total acreage of each crop in the actual farm production ranges from 320 to 1280 acres. To keep consistency, the average area 853, divided equally for a three-year rotation (SW-C-B) is used.

Using barley for the Camrose farm as an example, the county-level area in 2016 was 103,574 acres, while the farm-level area used in the calculation was 853 acres. The percentage difference was then calculated to be (|103,574 - 853|) / [(103,574 + 853)/2] *100 = 196.7%. The percentage change in standard deviation for barley was calculated by multiplying the percentage difference between the farm and county acreages by the M-S adjustment coefficient and dividing by one hundred: (196.7*0.1)/100 = 19.67%. The increase in standard deviation was obtained by multiplying the percentage difference by the initial county-level standard deviation (0.28), or 19.67% * 0.28 = 0.05. The post-adjusted standard deviation is the sum of actual and the increased amount of standard deviation: 0.28 + 0.05 = 0.33.

After the yield standard deviations were adjusted by the Marra-Schurle procedure, the continuous shape (α) and scale (β) parameters of Weibull distribution were adjusted accordingly to match the revised standard deviation without changing the mean yield. The α and β parameters were recalculated by solving the equations for mean and variance of the Weibull distribution. Specifically, the equations were set equal to the original mean yield and adjusted variance values and these were "solved" for the resulting shape and scale parameters. The adjusted Weibull distribution parameters for each crop are presented in Table 4.19.

Table 4.19 Adjusted Weibull distribution parameters, by county and crop

County	Crop	Adjusted α	Adjusted β
Camrose	Barley	5.59	1.73
	Canola	6.27	1.12
	Spring Wheat	6.43	1.61
	Oats	4.16	1.58
	Field Peas	3.42	1.23
Smoky River	Barley	6.87	1.75
	Canola	8.38	0.94
	Spring Wheat	7.24	1.56
	Oats	3.99	1.43
	Field Peas	5.10	1.54
Saskatchewan	Barley	5.57	1.72
	Canola	6.69	0.98
	Spring Wheat	6.58	1.59
	Oats	6.48	1.82
	Field Peas	4.16	1.19
	Flax	5.69	0.71

4.3.1.4 Maximum Crop Yield Restrictions

As noted earlier, Weibull distributions are truncated at zero, so there is no potential for negative crop yields. However, simulated yields drawn from the estimated yield distributions have the potential of being unrealistically (i.e., infinitely) high. To correct for this possibility, a maximum yield restriction was needed. In this study, the maximum yield restrictions were set by adding one standard deviation to the corresponding maximum crop yield observed in the detrended historical yield data. By adding one standard deviation, yields were prevented from reaching extremes that are unrealistically high. This rule is consistent with earlier studies by Trautman (2012) and Xie (2014). The maximum crop yield limits are given in Table 4.20.

Table 4.20 Maximum Crop Yield Restrictions by county and crop (tonne /acre)

County	Crop	Maximum Yield Restrictions
Camrose	Barley	2.29
	Canola	1.43
	Spring Wheat	2.19
	Oats	2.36
	Field Peas	1.90
Smoky River	Barley	2.57
	Canola	1.37
	Spring Wheat	2.25
	Oats	2.65
	Field Peas	2.68
	Flax	0.71
Saskatchewan	Barley	2.44
	Canola	1.35
	Spring Wheat	2.27
	Oats	2.89
	Field Peas	1.81
	Flax	1.08

4.3.1.5 Validation

Before finalizing the estimated crop yield distributions, they are validated against historical yields. Validation of crop yield models is performed by comparing means of detrended historical yields and the simulated yields from year 20 of the analysis. The purpose was to ascertain whether simulated yields were consistent with the historical yields.

Tables 4.21 to 4.23 provide historical mean yields and year 20 simulated mean yields for each crop and each representative farm. The percentage differences between the historical mean and the simulated mean were less than 2% for a majority of the crops. An unpaired t-test, assuming unequal variances, was also conducted for each crop. The resulted two-tailed p-values were all greater than or equal to 0.46, indicating no significant statistical difference between historical simulated mean yields for any of the crops.

Table 4.21 Mean historical and simulated truncated yield in year 20, Camrose County

Crop	Historical Mean (tonne/acre)	Simulated Mean (tonne/acre)	% Difference between means	Two-tailed p-value
Barley	1.594	1.593	-0.063%	0.92
Canola	1.040	1.040	0.00%	0.92
Spring Wheat	1.501	1.499	-0.13%	0.89
Oats	1.433	1.428	-0.35%	0.93
Field Peas	1.117	1.105	-1.07%	0.85

Table 4.22 Mean historical and simulated truncated yield in year-20, M.D. of Smoky River

Crop	Historical Mean (tonne/acre)	Simulated Mean (tonne/acre)	% Difference between means	Two-tailed p-value
Barley	1.638	1.637	-0.07%	0.93
Canola	0.885	0.890	0.54%	0.99
Spring Wheat	1.462	1.456	-0.40%	0.94
Oats	1.297	1.299	0.18%	0.96
Field Peas	1.423	1.413	-0.70%	0.81

Table 4.23 Mean historical and simulated truncated yield in year-20, Saskatchewan

Crop	Historical Mean (tonne/acre)	Simulated Mean (tonne/acre)	% Difference between means	Two-tailed p-value
Barley	1.589	1.590	0.00%	0.95
Canola	0.914	0.910	0.00%	0.46
Spring Wheat	1.483	1.480	0.00%	0.71
Oats	1.705	1.700	-0.31%	0.95
Field Peas	1.074	1.080	0.56%	0.70
Flax	0.658	0.659	0.22%	0.99

4.3.1.6 Yield Effect of Preceding Crops

The main objective of this study is to investigate the economic impacts of differing degrees of diversification in crop rotations. Thus, an important aspect to consider is the effect of the previous crop on current crop yield. It was suggested by Johnston et al. (2005) that yield performance of subsequent crops can be affected by previous crop stubble on which it is planted, and the degree of impact varied by crops. The yield reduction from monoculture or less diverse cropping systems is often considered to be caused by increasing pest infestation and reduced soil productivity. For example, canola seeded after canola resulted in an average of 10% to 15% yield reduction and the potential reason was that disease pathogens (e.g., blackleg) left on the crop stubble carried over to the next perfect host crop over the winter season (MASC, 2014).

In the current study, the effect of the previous crop is modeled by adjusting the stochastic yield drawn from the empirical distribution for a particular crop by a yield adjustment ratio. The calculation is shown in (4.4), where $\mathrm{Y}_{\mathrm{t,crop}}^{\mathrm{adj}}$ is the adjusted yield for a particular crop in year t, $\mathrm{Y}_{\mathrm{t,crop}}$ is the original pre-adjusted yield of the same crop, and $\mathrm{YAR}\ _{\mathrm{t,crop}}^{\mathrm{preceding\ crop}}$ is the yield adjustment ratio for the current crop, based on the preceding crop. A yield adjustment ratio value greater than one indicates a positive effect of the previous crop on the current crop yield, and a ratio less than indicates a negative effect of the previous crop.

$$\mathrm{Y}_{\mathrm{t,crop}}^{\mathrm{adj}} = \mathrm{Y}_{\mathrm{t,crop}} * \mathrm{YAR}\ _{\mathrm{t,crop}}^{\mathrm{preceding\ crop}} \tag{4.4}$$

The effect of preceding crops (i.e., the YAR ratio) is modeled as a stochastic element; that is, the yield adjustment ratio for a particular year for a particular crop combination is drawn from an empirically estimated distribution. A yield adjustment ratio distribution is specified for each combination of current and preceding crop within a rotation. For example, the SW-C-B rotation requires yield adjustment ratios for wheat following barley, canola following barley, and barley following canola.

County-level data from 2000 to 2018 for risk areas[17] 12 (which includes Camrose County) and 19 (which includes the Municipal District of Smoky River) are obtained from AFSC (2019c) for use in this analysis. The data provide annual risk area average yields for major crops, by preceding crop. For example, annual risk area average yields are provided separately for barley after barley, barley after wheat and barley after canola. These are used to calculate historical yield adjustment ratios for combinations of current and preceding crops based on rotations being modeled in representative farms. The equation for calculating the yield adjustment ratio is provided as follow:

$$\mathrm{YAR}_{\mathrm{t,crop}}^{\mathrm{preceding\ crop}} = \frac{\overline{\mathrm{Y}}_{\mathrm{t,crop}}^{\mathrm{preceding}}}{\overline{\mathrm{Y}}_{\mathrm{t,crop}}} \tag{4.5}$$

where the numerator represents the average yield for the crop in year t, taking the preceding crop into account and the denominator is the overall average yield in year t. Lastly, subscript t of the ratio itself indicates the annual yield adjustment ratio in year t. Based on the formula, the ratio indicates whether the effect of the previous crop on the current crop's yield is positive or negative relative to the overall yield for the crop in that year; that is whether the ratio is greater than or less than one, respectively. These ratios, although calculated by risk area, are assumed to be appropriate to represent the relative performance in the specific representative counties; that is, Camrose and Smoky River. Further, the ratios for risk area 12 are also assumed to be appropriate to use for the representative Saskatchewan farm (i.e., both are in the Black Soil Zone).

Yield adjustment ratios obtained for each year from the calculation in (4.5) are used to fit empirical distributions for use in the simulation. Summary statistics of raw yield adjustment ratios are provided in Appendix D. For example, the mean ratio for spring wheat following barley is 0.969, which indicates that the average wheat yield is reduced by approximately 3.1% if grown after barley, relative to the overall average wheat yield. Conversely, the mean ratio for spring wheat following canola is 1.023; that is, average wheat yield is increased by 2.3% relative to the overall average yield if grown after canola. Before fitting the calculated ratios to distributions, outlier values are removed.

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[17] Risk areas are regions in Alberta defined by AFSC for the purposes of crop insurance, specifically for calculations of insurance premiums.

The best-fit tool in @RISK was then employed to determine the appropriate distributions for use in the simulation modeling. Potential distributional forms were limited to those that have finite minimum and maximum values; that is, distributions that do not have infinite tails. This is done to avoid unrealistically low or high yield adjustments. Based on these principles and best-fit statistics, the two distributional options considered were Uniform and Triangular distributions. Based on the best fit analysis, a mixture of Uniform and the Triangular distributions are used in the simulation model.

Table 4.24 Fitted distributions and parameters for yield adjustment ratios, Camrose (Risk Area 12)

		Fitted Parameter		
Crop Combination	Fitted Distribution	Mode[a]	(Min, Max)	Mean
C-B	Triangular	1.027	(0.973, 1.098)	1.033
C-C	Uniform	--	(0.889, 1,043)	0.966
SW-C	Triangular	1.020	(0.938, 1.020)	0.965
B-SW	Triangular	1.020	(0.877, 1.020)	0.932
C-SW	Triangular	1.023	(0.988, 1.060)	1.024
O-SW	Triangular	0.880	(0.721, 1.033)	0.869
FP-SW	Triangular	1.017	(1.017, 1.184)	1.072
C-O	Triangular	1.197	(0.933, 1.197)	1.116
B-FP	Triangular	0.937	(0.937, 1.110)	0.995
O-FP	Triangular	0.776	(0.776, 1.166)	0.865

[a] Mode is a required parameter only when Triangular distribution is used and so it does not apply to crop combinations C-C and F-C where Uniform distribution is used to model yield adjustment ratios.

Table 4.25 Fitted distributions and parameters for yield adjustment ratios, Smoky River (Risk Area 19)

		Fitted Parameter		
Crop Combination	Fitted Distribution	Mode[a]	(Min, Max)	Mean
C-B	Triangular	0.997	(0.997, 1.125)	1.039
C-C	Triangular	1.041	(0.791, 1.041)	0.958
SW-C	Triangular	1.030	(0.971, 1.071)	1.024
B-SW	Uniform	--	(0.743, 1.118)	0.931
C-SW	Triangular	0.985	(0.985, 1.091)	1.021
O-SW	Uniform	--	(0.653,1.038)	0.845
FP-SW	Uniform	--	(0.827, 1.210)	1.019
C-O	Uniform	--	(0.977, 1.211)	1.094
B-FP	Triangular	0.911	(0.758, 1.239)	0.969
O-FP	Triangular	0.708	(0.708, 1.390)	0.936

[a] Mode is a required parameter only when Triangular distribution is used and so it does not apply to crop combinations C-C and F-C where Uniform distribution is used to model yield adjustment ratios.

For each fitted distribution, parameters required in modeling include minimum, maximum and mode for the Triangular distribution, and minimum and maximum values for the Uniform distribution. Summary statistics of original yield adjustment ratios and the fitted distribution statistics of each crop combination are provided above in Tables 4.24 and 4.25.

4.3.1.7 Crop Yield Correlations

The measure of correlation between crop yields is another crucial element for modeling yields in the simulation analysis. There is a greater probability for yields for crops grown on the same farm to be positively correlated since they are affected by environmental and climatic factors in a similar way. Correlation matrices used in the study were provided by AAF, and were developed from field level yield data for dryland crops produced in Black soil zones and Dark Gray soil zones from 2004 to 2006[18]. Tables 4.26 and 4.27 present yield correlation coefficients used for each representative farm.

Table 4.26 Correlation coefficients of crop yields in Risk Area 12, applied to Camrose and Saskatchewan

Crop	Barley	Canola	Spring Wheat	Oats	Field Peas	Flax
Barley	1					
Canola	0.6584	1				
Spring Wheat	0.7671	0.6553	1			
Oats	0.739	0.625	0.7671	1		
Field Peas	0.7566	0.6713	0.7671	0.7247	1	
Flax	0.6493	0.5974	0.6492	0.6331	0.7141	1

Table 4.27 Correlation coefficients of crop yields in Risk Area 19, applied to Smoky River

Crop	Barley	Canola	Spring Wheat	Oats	Field Peas
Barley	1				
Canola	0.4894	1			
Spring Wheat	0.5927	0.4449	1		
Oats	0.5695	0.447	0.5327	1	
Field Peas	0.4289	0.4197	0.4851	0.4808	1

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[18] The areas used to estimate the correlations in the matrices obtained from AAF don't match the Black and Dark Gray Soil zones exactly. However, the correlations used for the two Black Soil zone representative farms (Camrose and Saskatchewan) are based primarily on field level yields from Black Soil areas, and the same is true for the correlations used for the Dark Gray Soil zone representative farm (Smoky River).

4.3.1.8 Crop Residue Management

Crop residue is a by-product of harvesting annual grain crops and consists of the non-grain portion of the plant. In the production of cereal crops, this is referred to as straw. Crop residues from cereal crops (spring wheat, barley and oats) are incorporated as a part of the crop production and revenues are generated for farms by selling residues harvested in fields. Crop residue management decisions vary across locations and producers. For instance, one strategy is to retain crop residue in the field since it provides various benefits to the soil. This includes contributing to organic matter, assisting in maintaining soil moisture, and strengthening protection against erosion (SAF, 2019).

An alternative strategy in dealing with crop residue is to harvest straw for sale. The decision of whether to retain or sell the cereal crop residue depends on the value of contributions to soil quality relative to the market value. The frequency of residue harvest exerts significant impacts on soil quality. Thus, it is recommended that straw should be harvested every year on the Black and Dark Gray Soil zone for cereal crops (SAF, 2019). The rest of the crops in the study are excluded from residue management consideration because field peas and flax are low-residue crops which produce only half of residues of cereals. Residue of canola is not included due to its rapid decomposition in field (SAF, 2019).

If crop residue is removed, the total amount of straw to be baled after harvesting is determined by a grain to straw ratio that represents the proportion of straw generated per tonne of grain yield. Ratios for crops grown on Black/Dark Gray soils are obtained from SAF (2019); the ratios are 1.042 for barley, 1.471 for oats, and 1.666 for wheat. For example, the straw yield produced (tonnes per acre) for barley is calculated by multiplying the stochastic barley yield by 1.042. The selling price of straw is assumed to be $25 per 544 kg bale (AAF, 2016) and costs of baling and removing straw are based on custom rates from SAF (2008), updated to 2019 values, at $11.30 and $7.89 per 544 kg bale, respectively.

4.3.2 Crop Price Models

Similar to crop yields, crop prices were also modeled as being stochastic. However, a different approach was used in estimating the price models, and that approach is described in this section. Annual provincial crop prices for Alberta and Saskatchewan from 1987 to 2017 were used to estimate crop price models. In Alberta, prices of barley, canola, oats, field peas and flax were obtained from the Agriculture Statistics Yearbook (AAF, 2017). Spring wheat (No. 1 grade with 13.5% protein) prices were collected from two sources, each providing a partial time series. First, annual wheat prices[19] of 1987 to 2014 adjusted to Edmonton prices were obtained from Shooshtarian (AAF, 2019). Weekly spring wheat prices for 2015 to 2017 were obtained from the Alberta Wheat Commission (2019), with annual wheat prices calculated as the average of weekly prices. Saskatchewan weekly prices of 1987 to 2014 (inclusive) for barley, canola, spring wheat (excluding durum), oats, field peas and flax were collected (SAF, 2019). More recent prices of these crops (2015 to 2017) were collected from the Alberta Wheat Commission (2019). Saskatchewan annual crop prices were obtained by calculating the average of weekly prices. Summary statistics for the historical nominal price data are provided in Tables 4.28 and 4.29.

Table 4.28 Statistical summary of nominal prices ($/tonne), Alberta (1987 to 2017)

Crop	Obs.	Mean	Std. Dev.	Minimum	Maximum
Barley	31	138.50	50.13	66.60	249.86
Canola	31	365.96	98.76	238.10	570.11
Spring Wheat	31	191.16	52.88	116.50	321.39
Oats	31	137.05	41.00	67.44	210.09
Field Peas	31	205.45	62.04	113.00	331.92

Source: AAF (2017), Alberta Wheat Commission (2019) and CWB (2012)

Table 4.29 Statistical summary of nominal prices ($/tonne), Saskatchewan (1987 to 2017)

Crop	Obs.	Mean	Std. Dev.	Minimum	Maximum
Barley	33	118.58	40.16	62.05	200.92
Canola	33	367.16	97.09	217.78	581.82
Spring Wheat	33	201.94	92.39	108.87	490.40
Oats	33	128.04	38.21	65.00	195.85
Field Peas	28	219.39	66.44	131.55	382.98
Flax	33	355.09	122.99	161.43	580.09

Source: (SAF, 2019) and Alberta Wheat Commission (2019)

Before proceeding with further analysis, price data were adjusted for inflation by using the Consumer Price Index (CPI) for all items (Statistics Canada, 2019), with 2019 as the base year.

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[19] The annual wheat prices of 1987 to 2014 were based on Vancouver and adjusted to Edmonton prices for use in the study.

Summary statistics for the inflation-corrected crop prices in each province are provided in Tables 4.30 and 4.31. The data and graphs of inflation-corrected price series are provided in Appendix E.

Table 4.30 Statistical summary of inflation corrected prices ($/tonne), Alberta (1987 to 2017)

Crop	Mean	Standard Deviation	Minimum	Maximum
Barley	177.56	68.65	119.59	276.51
Canola	443.25	163.39	332.65	636.63
Spring Wheat	235.08	88.16	187.00	382.79
Oats	182.78	38.79	116.89	266.12
Field Peas	245.57	100.20	160.55	383.65

Source: AAF (2017), Alberta Wheat Commission (2019) and CWB (2012)

Table 4.31 Statistical summary of inflation corrected prices ($/tonne), Saskatchewan (1987 to 2017)

Crop	Mean	Standard Deviation	Minimum	Maximum
Barley	154.46	34.23	90.55	224.36
Canola	484.10	85.64	321.14	649.71
Spring Wheat	265.98	95.70	128.15	490.40
Oats	168.6	40.25	100.71	288.21
Field Peas	273.71	58.84	167.08	405.35
Flax	460.98	108.64	264.96	690.92

Source: (SAF, 2019) and Alberta Wheat Commission (2019)

4.3.2.1 Stationarity Test

Crop prices were tested for stationarity before using in further analysis. In modeling stochastic prices, the data were considered to be non-stationary if a unit root was present. Non-stationary prices should be modeled using a random walk process. Otherwise, if prices are stationary (i.e., no unit root), it is appropriate to model them as a time series model; that is, current price as a function of lagged prices. Stationarity of a stochastic process requires that the variances and autocovariances are finite and independent of time (Verbeek, 2008); that is, the mean and the variance of stationary price data should be the same in all time periods. The study adopted a commonly used test to examine stationarity for price data called Augmented Dickey Fuller (ADF) test (Stock and Watson, 2006). Specifically, the presence of unit root was tested using ADF for time series data.

A limitation of the ADF test is that it does not rule out non-stationarity for some price data. Most unit root tests have low power against stationarity, that is, stationarity is frequently rejected even if the data are actually stationary (Hobijn et al., 2004; Verbeek, 2008). In some cases, this may be due to a lack of sufficient information in the data to reject the null hypothesis of non-stationarity as opposed to the data truly being non-stationary. This is a known weakness of the ADF test (Verbeek, 2008). To resolve limitations in the ADF test, the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test was also used to examine stationarity for the price data. The KPSS test examines an opposite null hypothesis of ADF test; specifically, that the data are stationary. Both ADF and KPSS tests were employed in the study to ensure stationarity of price data is not falsely rejected.

4.3.2.1.1 Augmented Dicky Fuller (ADF) Test

Three versions of the ADF test were applied in STATA software, each with different assumptions. A baseline test was used, assuming no time trend and no drift. In addition, versions of the ADF test were run first assuming a drift[20] and then assuming a time trend[21]. According to test results reported in Tables 4.32 and 4.33, none of crops were stationary in the baseline case. When assuming a drift, all crop prices were stationary. However, the presence of a unit root was not rejected for prices of canola and field peas in Alberta and that of canola and spring wheat in Saskatchewan, when assuming a time trend.

Table 4.32 Augmented Dickey-Fuller (ADF) test results of Alberta crop prices

		Test Statistics	
Crop	Baseline	Drift	Trend
Barley	-0.374	-3.133***	-3.512**
Canola	-0.370	-2.439**	-2.437
Spring Wheat	-0.547	-3.974***	-3.903**
Oats	-0.649	-4.217***	-4.425***
Field Peas	-0.652	-2.642***	-2.619
Flax	-0.523	-3.156***	-3.346*
1% Crit. Value	-2.652	-2.467	-4.334
5 % Crit. Value	-1.950	-1.701	-3.580
10 % Crit. Value	-1.602	-1.313	-3.228

Note: ***, **, and * represent statistical significance at the 1%, 5%, and 10% level respectively.

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[20] Drift is a linear trend added to the random walk process, either upward or downward.

[21] Time trend in a random walk process could be a drift or a non-linear trend.

Table 4.33 Augmented Dickey-Fuller (ADF) test results of Saskatchewan crop prices

		Test Statistics	
Crop	Baseline	Drift	Trend
Barley	-0.313	-3.348***	-3.491**
Canola	-0.474	-2.997***	-2.932
Spring Wheat	-0.509	-2.462**	-2.329
Oats	-0.826	-3.996***	-3.963***
Field Peas	-0.602	-3.179***	-3.221*
Flax	-0.456	-3.673***	-3.860**
1% Crit. Value	-2.649	-2.457	-4.316
5 % Crit. Value	-1.950	-1.697	-3.572
10 % Crit. Value	-1.603	-1.310	-3.223

Note: ***, **, and * represent statistical significance at the 1%, 5%, and 10% level respectively.

4.3.2.1.2 Kwiatkowski-Phillips-Schmidt-Shin (KPSS) Test

As mentioned earlier, the null hypothesis of KPSS test is that the prices are stationary. KPSS tests were also performed in STATA using options of automatic lag length selection and Quadratic spectral (QS) kernel. Results of the KPSS test are presented in Tables 4.34 and 4.35. The results suggested for all crops in Saskatchewan, the null hypothesis of stationarity was not rejected. In Alberta, the null hypothesis of stationary was not rejected except for field pea prices. However, for the purpose of modeling prices in this study, field peas were still treated as being stationary because a) the null hypothesis was not rejected at 10% significance level, and b) it allowed for a consistent modeling approach to be used for all crop prices. Thus, crop prices in Alberta and Saskatchewan were all considered to be stationary and were modeled using time series modeling.

Table 4.34 KPSS test results of Alberta crop prices

Crop	Test Statistics
Barley	0.0657
Canola	0.101
Spring Wheat	0.0496
Oats	0.0353
Field Peas	0.205**
Flax	0.100
1% Crit. Value	0.216
5% Crit. Value	0.146
10% Crit. Value	0.119

Note: ***, **, and * represent statistical significance at the 1%, 5%, and 10% level respectively.

Table 4.35 KPSS test results of Saskatchewan crop prices

Crop	Test Statistics
Barley	0.0571
Canola	0.0798
Spring Wheat	0.0989
Oats	0.0676
Field Peas	0.0847
Flax	0.0717
1% Crit. Value	0.216
5% Crit. Value	0.146
10% Crit. Value	0.119

Note: ***, **, and * represent statistical significance at the 1%, 5%, and 10% level respectively.

4.3.2.2 Price Model Estimation

4.3.2.2.1 Optimal Lag Length Selection

Before formally estimating the time series price equations, it was necessary to determine the appropriate lag length to use for each crop. The Akaike Information Criterion (AIC) and Schwarz Bayesian Information Criterion (SBIC) were used to identify the optimal number of lags for each estimated price equation (Stock and Watson, 2006). A maximum of four lags was recommended by the test results and the smallest value for the AIC or SBIC statistic determined the optimal lag length. OLS regression was used to estimate each crop price equation individually, with prices lagged from one to four. In cases where different optimal lag lengths were suggested by AIC and SBIC for a certain equation, results were compared and the lag number with the smallest statistic was chosen regardless of the criterion used.

The AIC and SBIC results in Table 4.36 suggest the optimal lag length in Alberta for barley, canola, spring wheat and field peas is two years and the optimal lag length for oats is one year. Similar results are presented for crops in Saskatchewan in Table 4.37, except that an optimal lag of one year is suggested for flax, and a two-year lag is assigned to oats.

Table 4.36 Lag length test statistics for price equations (AIC & SBIC), Alberta

	Lags	0	1	2	3	4
Barley	AIC	10.431	10.0693	10.0583*	10.1204	10.1766
	SBIC	10.479	10.1653*	10.2023	10.3124	10.4166
Canola	AIC	11.837	11.3226	11.1613*	11.2348	11.2627
	SBIC	11.8849	11.4186	11.3053*	11.4268	11.5027
Spring Wheat	AIC	10.746	10.7203	10.6808*	10.7549	10.7703
	SBIC	10.794*	10.8163	10.8248	10.9469	11.0103
Oats	AIC	10.0745	10.0643*	10.1226	10.1705	10.2422
	SBIC	10.1224*	10.1603	10.2666	10.3625	10.4822
Field Peas	AIC	10.9981	10.6337	10.5618*	10.5691	10.6386
	SBIC	10.4822	10.7296	10.7058*	10.7611	10.8786
Flax	AIC	12.2266	11.8792*	11.8994	11.9306	11.9887
	SBIC	12.2746	11.9752*	12.0434	12.1226	12.2286

Note: * denotes the minimum AIC and SBIC values.

Table 4.37 Lag length test statistics for price equations (AIC & SBIC), Saskatchewan

	Lags	0	1	2	3	4
Barley	AIC	10.0151	9.8259	9.6268*	9.6811	9.7425
	SBIC	10.0622	9.9202	9.7683*	9.8697	9.9782
Canola	AIC	11.8323	11.4747	11.3523*	11.4158	11.4584
	SBIC	11.8794	11.569	11.4937*	11.6044	11.6941
Spring Wheat	AIC	12.0111	11.7768	11.7311*	11.764	11.8126
	SBIC	12.0582	11.8711*	11.8725	11.9526	12.0483
Oats	AIC	9.9250	9.8625	9.7369*	9.7755	9.8378
	SBIC	9.9721	9.9568	9.8784*	9.9641	10.0735
Field Peas	AIC	11.1551	11.0332	10.8737*	10.8756	10.9421
	SBIC	11.2042	11.1314	11.0209*	11.0719	11.1876
Flax	AIC	12.2182	12.0801*	12.1114	12.1373	12.2027
	SBIC	12.2654	12.1744*	12.2528	12.3259	12.4384

Note: * represents the minimum AIC and SBIC values.

The price equations for the five crops in Alberta are provided from (4.6) to (4.10):

$$\mathrm{P}_t^B = \beta_0^B + \beta_1^B \mathrm{P}_{t-1}^B + \beta_2^B \mathrm{P}_{t-2}^B + \varepsilon_t^B \tag{4.6}$$

$$\mathrm{P}_t^C = \beta_0^C + \beta_1^C \mathrm{P}_{t-1}^C + \beta_2^C \mathrm{P}_{t-2}^C + \varepsilon_t^C \tag{4.7}$$

$$\mathrm{P}_t^{SW} = \beta_0^{SW} + \beta_1^{SW} \mathrm{P}_{t-1}^{SW} + \beta_2^{SW} \mathrm{P}_{t-2}^{SW} + \varepsilon_t^{SW} \tag{4.8}$$

$$\mathrm{P}_t^{FP} = \beta_0^{FP} + \beta_1^{FP} \mathrm{P}_{t-1}^{FP} + \beta_2^{FP} \mathrm{P}_{t-2}^{FP} + \varepsilon_t^{FP} \tag{4.9}$$

$$\mathrm{P}_t^O = \beta_0^O + \beta_1^O \mathrm{P}_{t-1}^O + \varepsilon_t^O \tag{4.10}$$

The same set of price equations as above are applied to barley, canola, spring wheat and field peas in Saskatchewan. However, equations are presented distinctly for oats and flax (4.11 and 4.12) because a different lag length is suggested for oats and flax only in Saskatchewan.

$$P_t^O = \beta_0^O + \beta_1^O P_{t-1}^O + \beta_2^O P_{t-2}^O + \varepsilon_t^O \tag{4.11}$$

$$P_t^F = \beta_0^F + \beta_1^F P_{t-1}^F + \varepsilon_t^F \tag{4.12}$$

In equations (4.6) to (4.12), $P^B, P^C, P^{SW}, P^O, P^{FP}, and\ P^F$ represent prices of barley, canola, spring wheat, oats, field peas and flax, respectively, P_{t-n}^i is the price of i^{th} crop in time period t-n, and β_0^i to β_n^i are the estimated coefficients for the corresponding lagged price variables.

4.3.2.2.2 Crop Price Model Results and Modeling of Stochastic Prices

Estimating the system of price equations using OLS regression would result in error terms being correlated across equations. In order to recognize and correct for the possibility of serial correlation, the two systems of price equations (i.e., for Alberta and Saskatchewan) were estimated using Seemingly Unrelated Regressions (SUR) in STATA. SUR results are provided in Tables 4.38 and 4.39. All constants were statistically significant at the 1% level. Estimated coefficients for prices lagged one year were statistically significant at the 1% level except for oats. For Alberta, half of the coefficient estimates of crop prices lagged two years were significant at a 5% level. A majority of price coefficients in Saskatchewan were highly significant for both one-year and two-year lags. Goodness of fit for the individual equations, represented by the R^2 values, ranged from 0.0556 to 0.5175. Similarly, R^2 values for Saskatchewan price model were also relatively low and ranged from 0.1546 to 0.4335. However, the reported chi-squared value for the Breusch-Pagan test of independence was 126.075 with a p-value of 0.000 for Alberta, and 112.784 with a p-value of 0.000 for Saskatchewan. These test statistics indicated the existence of serial correlation. Thus, the SUR model was appropriate to estimate price equations if crop prices were assumed to be affected by the same exogenous variable.

Table 4.38 Seemingly Unrelated Regression (SUR) Model results of Alberta

	Estimated Coefficients				
Variable	Barley	Canola	Spring Wheat	Field Peas	Oats
Lag 1	0.5224*** (0.1074)	0.7476*** (0.1155)	0.5551*** (0.1295)	0.6164*** (0.1154)	0.1762 (0.1286)
Lag 2	-0.1280 (0.08817)	-0.2695** (0.1134)	-0.3716*** (0.1190)	-0.1631 (0.1137)	
Constant	110.1269*** (18.9988)	253.5198 *** (48.1205)	210.6881*** (39.8698)	146.3544*** (27.5261)	148.3024 *** (24.4116)
Std. Error (RMSE)	32.4652	55.9965	46.1095	40.6122	34.6007
R^2	0.3545	0.5175	0.1374	0.4300	0.0556

Note: *, **, and *** represent statistical significance at the 10%, 5%, and 1% level, respectively. Standard errors are in brackets.

Table 4.39 Seemingly Unrelated Regression (SUR) Model results of Saskatchewan

	Estimated Coefficients					
Variable	Barley	Canola	Spring Wheat	Field Peas	Oats	Flax
Lag 1	0.5643*** (0.1090)	0.6792*** (0.1071)	0.6244*** (0.1615)	0.5260*** (0.1169)	0.3453*** (0.1280)	0.4493*** (0.1328)
Lag 2	-0.3615*** (0.1099)	-0.3456*** (0.1058)	-0.2826 (0.1922)	-0.3849*** (0.1162)	-0.4034*** (0.1277)	
Constant	125.8382*** (19.0890)	323.328*** (50.6390)	170.024*** (52.5986)	237.4014*** (36.2962)	176.967*** (26.3359)	263.4709*** (64.3602)
Std. Error (RMSE)	27.3232	67.2330	80.8948	48.2011	29.5245	87.1263
R^2	0.3755	0.4335	0.3351	0.3347	0.2703	0.1546

Note: *, **, and *** represent statistical significance at the 10%, 5%, and 1% level, respectively. Standard errors are in brackets.

Expected annual crop prices used in simulation were obtained from the SUR estimation, that is, the expected price in the current period was a function of own lagged prices, ignoring the random stochastic error term. The stochastic component was introduced and estimated through error terms for each price equation in the system. Error terms of crop price equations were assumed to be distributed with a standard normal distribution N(0,1). As noted earlier, error terms were likely to be correlated, as the dependent variables were likely affected by exogenous variables in a similar way. Therefore, errors needed to be adjusted and scaled by the standard deviation (Hull, 2003). The formulas for calculating error correlations are provided below (Hull, 2003):

$$\varepsilon_{\mathrm{m}} = \sum_{\mathrm{k=1}}^{\mathrm{k=m}} \delta_{\mathrm{mk}}\, \mathrm{x}_{\mathrm{k}}$$

$$\sum_{\mathrm{k}} \delta_{\mathrm{mk}}^{2} = 1 \tag{4.13}$$

$$\sum\nolimits_{\mathrm{k}} \delta_{\mathrm{mk}}\, \delta_{\mathrm{jk}} = \rho_{\mathrm{m,j}}$$

where ε_m represents the correlated error term for price of crop m, x_k is the error term draw scaled to the standard deviation for the corresponding crop price, $\rho_{m,j}$ is the correlation between errors for crop prices m and j, and δ_{mk} are terms solved from this system of equations (4.13).

Trautman (2012) and Xie (2014) determined that the correlated error equations would become extremely complicated to manipulate and solve using the above equations if more than four crops were involved in the process. In their analyses, this complexity is addressed by dividing the crops into subgroups and treating them separately in the analysis. Given that there are five crop prices for Alberta and six for Saskatchewan, a similar process was used in the current analysis. To proceed with this approach, the error correlations resulting from the SUR model were used to determine crop errors to be correlated with each other. The magnitude and the sign of correlation coefficients served as good indicators. In particular, a strong positive correlation coefficient meant that the errors of two specified crop prices were highly correlated and should be grouped together. The estimated correlation coefficients are shown in Tables 4.40 and 4.41.

Table 4.40 SUR-estimated error correlations for price equations, Alberta

	ε^{B}	ε^{C}	$\varepsilon^{\mathrm{SW}}$	ε^{O}	$\varepsilon^{\mathrm{FP}}$
ε^{B}	1.000				
ε^{C}	0.6416	1.000			
$\varepsilon^{\mathrm{SW}}$	0.2220	0.4077	1.000		
ε^{O}	0.7502	0.3754	0.1824	1.000	
$\varepsilon^{\mathrm{FP}}$	0.6540	0.7716	0.4637	0.3846	1.000

Table 4.41 SUR-estimated error correlations for price equations, Saskatchewan

	ε^{B}	ε^{C}	ε^{SW}	ε^{O}	ε^{FP}	ε^{F}
ε^{B}	1.000					
ε^{C}	0.7128	1.000				
ε^{SW}	0.0481	-0.3755	1.000			
ε^{O}	0.6812	0.5756	-0.0467	1.000		
ε^{FP}	0.6665	0.7984	-0.2440	0.5608	1.000	
ε^{F}	0.5771	0.6215	-0.1792	0.6156	0.5502	1.000

Prices of canola, field peas and flax were put into one subgroup. Prices for barley, spring wheat and oats were grouped together although the correlation coefficient between barley and spring wheat was relatively low. The purpose of dividing crops in such a manner was to ensure groupings made sense in both statistical and logical aspects since one grouping contained all cereal crops and the other contained pulse and oilseed crops. Based on resulted sub-groupings of crop price, equations for the correlated error terms are as follows:

$$\varepsilon_{B} = x_{B} \tag{4.14}$$

$$\varepsilon_{O} = \rho_{B,O}\, x_{B} + \left(\sqrt{1-\rho_{B,O}^{2}}\right) x_{O} \tag{4.15}$$

$$\varepsilon_{SW} = \rho_{B,SW} x_{B} + \left(\frac{\rho_{O,SW} - \rho_{B,O}\rho_{B,SW}}{\sqrt{1-\rho_{B,O}^{2}}}\right) x_{O} + \left(\sqrt{1-\rho_{B,SW}^{2} - \left(\frac{\rho_{O,SW} - \rho_{B,O}\rho_{B,SW}}{\sqrt{1-\rho_{B,O}^{2}}}\right)^{2}}\right) x_{SW} \tag{4.16}$$

$$\varepsilon_{C} = x_{C} \tag{4.17}$$

$$\varepsilon_{FP} = \rho_{C,FP} x_{C} + \left(\sqrt{1-\rho_{C,FP}^{2}}\right) x_{FP} \tag{4.18}$$

$$\varepsilon_{F} = \rho_{C,F}x_{C} + \left(\frac{\rho_{FP,F} - \rho_{C,FP}\rho_{C,F}}{\sqrt{1-\rho_{C,FP}^{2}}}\right)x_{FP} + \left(\sqrt{1-\rho_{C,F}^{2} - \left(\frac{\rho_{FP,F} - \rho_{C,FP}\rho_{C,F}}{1-\rho_{C,FP}^{2}}\right)^{2}}\right)x_{F} \tag{4.19}$$

The subscripts B, C, SW, O, FP, and F represent barley, canola, spring wheat, oats, field peas, and flax respectively, and all other notation is defined as above.

4.3.2.3 Adjustments and Validation of Crop Price Models

To test whether the simulated prices are modeled accurately over time and to validate the crop price models, means of inflation-adjusted historical prices and means of simulated prices in year 20 were compared using an unpaired t-test assuming unequal variances. The price models were simulated 5000 times to generate the distributions of year 20 simulated prices. Statistical results are provided in Tables 4.42 and 4.43. The resulting two-tailed p-values were at least 0.27 (or greater) for all prices across the two provinces. Therefore, the null hypothesis of equal means was not rejected. It was therefore concluded that crop prices were accurately represented through the estimated price model equations.

Table 4.42 Mean of historical prices, simulated prices in year-20 and t-test statistics, Alberta

Crop	Historical Mean ($/tonne)	Simulated Mean ($/tonne)	Two-tailed p-value
Barley	182.713	182.350	0.96
Canola	490.867	488.28	0.87
Spring Wheat	256.907	257.28	0.97
Oats	182.784	180.86	0.78
Field Peas	276.125	271.56	0.68

Table 4.43 Mean of historical prices, simulated prices in year-20 and t-test statistics, Saskatchewan

Crop	Historical Mean ($/tonne)	Simulated Mean ($/tonne)	Two-tailed p-value
Barley	154.46	157.20	0.65
Canola	484.10	485.50	0.93
Spring Wheat	265.98	260.23	0.73
Oats	168.60	162.72	0.41
Field Peas	273.71	261.12	0.27
Flax	460.98	470.59	0.62

4.4 Economic Relationships

This section provides information about how revenues and expenses associated with the farm-level crop production were determined in the model. This section also addresses the incorporation of business risk management programs (i.e. AgriStability and AgriInsurance). The connections explored between these variables are essential in calculating cash flows for representative farms.

4.4.1 Revenues

The majority of production revenue was from sales of crops. In the simulation model this was calculated by multiplying the simulated crop price and crop yield for each crop to obtain revenue per acre. This was then multiplied by the corresponding acreage for each crop and summed across the crops in the rotation to obtain total annual crop revenue. Other sources of revenue for the representative farms arise from the following two channels: sales of crop residues and payments from business risk management (BRM) programs. More details about the BRM programs are provided later in the section.

4.4.2 Input Cost

Total production cost consisted of multiple elements, including expenses for seed, fertilizer, chemicals, trucking and marketing, fuel, oil and lube, machinery repairs, building repairs, and utilities and miscellaneous costs. Input costs for Alberta were obtained from 2019 Production Costs and Returns reported by AgriProfit$ Cropping Alternatives for the Black and Grey-Wooded (Peace Region) Soil Zones (AAF, 2019b). Input costs for Saskatchewan were obtained from 2019 Crop Planning Guide for Black Soils (SAF, 2019). There were no trucking and marketing costs included in the budgets for Saskatchewan, and so the costs for the Black soil zone cost data in Alberta were adapted for use on the Saskatchewan farm.

The total chemical cost in Saskatchewan was recalculated to exclude costs of fungicides, insecticides and/or pre-harvest/desiccation applications for all crops except for spring wheat and field peas. This was done for the purposes of consistency, as no equivalent expenses were reported for the Black Soil zone farm in Alberta. A detailed breakdown of production costs for each farm is provided in Tables 4.44 to 4.46.

Table 4.44 Production Costs for Alberta Black soil farm ($/acre)

	Barley	Canola	Spring Wheat	Oats	Field Peas
Seed	27.78	72.88	37.13	26.13	45.01
Fertilizer	70.5	100	70.5	60.5	27
Chemical	18.99	33.24	48.6	14.74	39.91
Trucking and Marketing	23.9	16.19	21.11	19.45	19.7
Fuel, Oil and Lube	18.67	20.27	19.74	20.8	25.6
Machinery Repairs	14.06	15.89	17.97	14.06	18.49
Building Repairs	2.08	2.34	2.08	2.86	4.69
Utilities and Miscellaneous	10.34	12.59	10.34	10.34	12.59
Total Input Cost	186.32	273.40	227.47	168.88	192.99

Source: AAF (2019)

Table 4.45 Production Costs for Alberta Dark Gray soil farm ($/acre)

	Barley	Canola	Spring Wheat	Oats	Field Peas
Seed	20.2	53	27	19	38.09
Fertilizer	59.5	84.5	59.5	51.5	21
Chemical	19.1	27.19	42.79	14.83	40.15
Trucking and Marketing	21.88	11.64	19.7	20.06	17.59
Fuel, Oil and Lube	30.23	35.99	28.61	25.34	36.07
Machinery Repairs	11.46	13.02	12.5	13.02	13.54
Building Repairs	2.08	4.43	3.91	2.6	3.13
Utilities and Miscellaneous	10.34	12.59	10.34	10.34	8.96
Total Input Cost	174.79	242.36	204.35	156.69	178.53

Source: AAF (2019)

Table 4.46 Production Costs for Saskatchewan Black soil farm ($/acre)

	Barley	Canola	Spring Wheat	Oats	Field Peas	Flax
Seed	28.86	66.19	31.36	33.92	59.955	18.23
Fertilizer	81.02	105.07	85.68	79.92	30.31	62.96
Chemical	28.32	49.99	78.68	23.70	95.47	58.34
Trucking and Marketing	23.9	16.19	21.11	19.45	19.7	16.19
Fuel, Oil and Lube	25.5	23.13	24.34	25.21	19.8	22.08
Machinery Repairs	10.9	10.9	10.9	10.9	10.9	10.9
Building Repairs	0.85	0.85	0.85	0.85	0.85	0.85
Utilities and Miscellaneous	4.9	4.9	4.9	4.9	4.9	4.9
Total Input Cost	204.25	277.22	257.82	198.85	241.89	194.45

Source: SAF (2019)

A pattern of decreasing total production costs per acre (by crop) is noticed in moving from Saskatchewan to Camrose and finally Smoky River. The difference in total input cost across farms is attributed to the chemical cost, which is the highest in Saskatchewan and the lowest in Smoky River for all crops, even after the adjustment discussed above.

Regarding input costs, it is assumed in this analysis that the per acre cost for each crop is not affected by the specific rotation being modeled. In practice, the choice of rotation may have an effect on producer decisions concerning inputs. For example, in the case of more canola-intensive rotations producers may make use of additional herbicides/fungicides in order to minimize the potential for disease and weed problems. Given the limited data available for production costs, it is not feasible to incorporate this into the analysis.

4.4.3 Machinery Complement

It was assumed that each representative farm has a complement of machinery used in completing required operations associated with crop production. Employment of machinery contributes to farm cash outflows through fuel consumption, repair and maintenance. Machinery also needs to be replaced periodically, resulting in large cash outflows. The time interval for machinery replacement will vary significantly between producers. Timing of machinery replacement depends on factors such as economic feasibility and amount of annual use. The resulting diversity in decisions of machinery replacement lead to modeling challenges. However, the cashflow implications of machinery replacement should not be neglected in the analysis.

Previous representative farm studies (e.g., Cortus 2005; Koechoven 2008; Trautman 2012) used a consistent approach to obtain relevant cash flows by developing explicit machinery complements and modeling replacement separately from input costs for each farm. The general procedure used by these studies was to estimate a constant annual cash expenditure and use it as a proxy for machinery replacement expenditures. This constant annual amount is in theory the value required to maintain the initial book value of the machinery complement.

For example, Trautman (2012) developed a machinery complement for representative farms in the Black and Dark Gray Soil zones to estimate the value of machinery replacement. To determine types of machinery implemented, assumptions were made in terms of time constraints to complete cropping operations such as seeding, spraying and harvesting. The size of machinery required to complete these tasks was then determined based on information from AAF Machinery Cost Calculator and Farm Machinery Custom and Rental Rate Guide (SAF). Decisions were made specifically about time allocated to each cropping activity mentioned above. The initial book value of machinery complement was calculated based on machinery characteristics (i.e., type and size) and age[22] as of the starting period for simulation. A constant annual cash flow was then generated to represent expenditures for machinery replacement. This cash flow was defined as the expenditure required to maintain the machinery replacement at its initial book value. Essentially this expenditure was equal to total annual machinery depreciation.

This study used machinery replacement costs estimated by Trautman (2012), adjusted for inflation, in the net cash flow calculations. The representative farms modeled by Trautman (2012) were the same size as those defined for the current study (both Black and Dark Gray Soil zones). Thus, it was decided that using estimates from Trautman (2012) as the starting values for calculating machinery replacement cost in this study was a reasonable approach.

The annual machinery replacement expenditures for Trautman's representative farms located in Black and Dark Gray soil zones were \$21.86 and \$25.64 per acre, respectively, with a base year of 2008. These values were then adjusted for inflation using the Machinery Price Index from

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[22] The average age of machinery was assumed to be five years. This was consistent with similar previous studies (e.g., Cortus 2005; Koechoven 2008).

Statistics Canada with a base year of 2019. The resulting adjusted machinery replacement expenditures were \$28.04 per acre for the Black Soil zone farms and \$32.89 per acre for the Dark Gray Soil zone farm.

4.4.4 Business Risk Management Programs

It was assumed that the representative farms in this study participate in business risk management program (BRM) programs. These BRM programs are provided publicly by federal and provincial governments through the Canadian Agricultural Partnership initiative and are designed to assist producers in managing significant risk and economic losses in crop production (AFSC, 2019). The specific risk management tools included in the suite of BRM programs are AgriStability, AgriInsurance, AgriInvest, and AgriRecovery. In Alberta and Saskatchewan, these programs are administered by provincial crown corporations: Agricultural Financial Services Corporation (AFSC) and Saskatchewan Crop Insurance Corporation (SCIC), respectively.

In this study, representative farms are assumed to participate in the AgriStability and AgriInsurance programs. These two programs are incorporated in the simulation analysis. The selected coverage rates and insurance options are consistent with those applicable to Alberta and Saskatchewan (AFSC, 2019; SCIC, 2019).

4.4.4.1 AgriInsurance

AgriInsurance, or crop insurance, assists producers in reducing production and financial losses due to occurrence of designated natural perils such as drought, flood, snow and plant disease (AFSC, 2019b). It also provides a degree of price protection through options described in this section[23].

The basic decision for producers within the crop insurance program is the choice of coverage level for each crop. This is expressed as a percentage of the producer's historical average yield, and represents the critical yield at which a crop insurance payment would be triggered, or the

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[23] The discussion in this section uses terminology consistent with the version of crop insurance implemented in Alberta by AFSC. However, the structure and options for crop insurance in Saskatchewan is very similar, and so the modeling of crop insurance for the Saskatchewan representative farm is the same as for the two Alberta farms.

insured yield. Producers are allowed to choose coverage at 50%, 60%, 70% and 80% of their average yields for most insurable crops (AFSC, 2019b)[24]. In this study, an 80% coverage level was selected for all crops, which was consistent with previous representative farm cropping studies (e.g., Trautman 2012; Xie 2014; Bruce 2017). The production coverage per acre for an individual crop was then calculated as insured yield multiplied by the spring insurance price (SIP). The insured yield is the historical average yield (referred to as risk area average yield) multiplied by the selected 80% coverage rate.

SIP is a prediction of the fall market price made in spring. In reality, the specific value chosen for the SIP is based on analysis of historical and current prices and information/expectations regarding trends in future prices. In this study, the deterministic portion of the price equation estimated from SUR model is assumed to be the expected price or SIP for the current year. In other words, it is calculated using the price equation of lagged prices, without including the error term. The fall market price (FMP) is the actual price of insured crops after harvesting. In this study, FMP was set equal to the stochastic crop price generated from the simulation; that is, the price after the stochastic elements (error terms) were included.

In this study, a crop insurance payment was triggered when the actual stochastic yield of a crop fell below the insured yield in a particular year. The actual yield was the simulated yield drawn from historical yield distribution (adjusted for previous crop). As noted above, the insured yield is a function of the risk area average yield. In the simulation analysis the risk area average yield for each crop in the first year of the simulation was set equal to the historical average yield obtained from the detrended yield series. For subsequent years, the risk area average yield was calculated as the average of the actual simulated yield in the current period and the risk area average yield generated in the previous year of the simulation. The basic insurance payout (4.20) was calculated as the yield shortfall multiplied by the SIP (AFSC, 2019b).

Basic Insurance Payout =

$$(\text{Risk Area Average Yield} * \text{Coverage Level} - \text{Actual Yield}) * \text{SIP} \tag{4.20}$$

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[24] For example, if the producer chooses 80% coverage, a payment would be triggered if the actual yield is below 80% of the historical average.

The variable price benefit (VPB) is another form of support that is automatically included in the crop insurance program. In the event of a yield shortfall (i.e., a regular crop insurance payment is triggered), the VPB insures against the case of the market price increasing during the growing season; that is, the FMP being greater than the SIP. The support provided by the VPB payment is limited to between a 10% to 50% increase of FMP above the SIP. In the current study the VPB payment per acre for a particular crop was calculated as:

$$\text{VPB} = \begin{cases} 0, & \text{if actual yield} > \text{insured yield} \\ (\text{insured yield} - \text{actual yield}) * (\text{FMP} - \text{SIP}), & \text{if actual yield} < \text{insured yield and SIP} < \text{FMP} \leq 1.5\text{SIP} \\ (\text{insured yield} - \text{actual yield}) * (1.5 * \text{SIP} - \text{SIP}), & \text{if actual yield} < \text{insured yield and } 1.1\text{SIP} < \text{FMP} \leq 1.5\text{SIP} \end{cases} \tag{4.21}$$

The spring price endorsement (SPE) is an optional “add in” that provides additional protection against price volatility in the event that the fall market price is at least 10% lower than the SIP. The SPE payment covers up to a 50% price decline within a program year. The SPE addresses price risk rather than production risk and there does not have to be a regular crop insurance payout in order to qualify for an SPE payout. For the purposes of the simulation analysis in the current study, it was assumed that the representative farms opt in for SPE. The SPE payment per acre for a particular crop was calculated as:

$$\text{SPE} = \begin{cases} 0, \text{if FMP } \geq 0.9\text{SIP} \\ \min(\text{actual yield}, \text{insured yield}) * (\text{SIP} - \text{FMP}), \text{if } 0.9\text{SIP } > \text{FMP } > 0.5\text{SIP} \\ \min(\text{actual yield}, \text{insured yield}) * (\text{SIP} - 0.5\text{SIP}), \text{if FMP } \leq 0.5\text{SIP} \end{cases} \tag{4.22}$$

The total insurance premium cost for a particular crop was calculated as the dollar value of production coverage multiplied by the premium rate for that crop. Premium rates are determined annually and can be varied by crops and risk area. Table 4.47 shows premium rates for three common crops in Alberta. All of the percentages are close to 10% (AFSC, 2017). For simplicity in calculation, a consistent premium rate of 10% was applied to all crops for all three representative farms[25].

Table 4.47 Premium rates per acre by crop ($/acre)

Crop	Premium Rate
Spring Wheat	10.82
Barley	10.76
Canola	13.95

Source: AFSC (2017)

AgriInsurance is a cost sharing program and therefore the premium cost is split between three parties: the federal government, the provincial government and producers, with a ratio of 24:36:40, respectively (AFSC, 2019b). Given this ratio, 40% of the total premium cost was assumed to be paid by the representative producers, and was calculated as the product of the monetary value of the total premium for the chosen production coverage and the producers' share of premium cost.

4.4.4.2 AgriStability

AgriStability is another program in the suite of business risk management programs. This program plays a role in protecting against large income declines (AFSC, 2019a). When AgriStability was initiated it was administered under the Growing Forward and Growing Forward 2 policy frameworks. Currently the program is administered by the Canadian Agricultural Partnership Agreement (AFSC, 2019a).

AgriStability provides protection against declines in production margin; that is, revenue net of eligible expenses. Program benefits are calculated by comparing current production margin (PM) with a historical average production margin, referred to as the reference margin (REF). A payment is offered to producers if the PM is less than 70% of the REF. As noted earlier, the PM is a proxy for the margin between revenue and eligible operating expenses. It is calculated as the difference between Allowable Income and Allowable Expenses (AFSC, 2019a). In general, allowable income for cropping operations includes revenues from sale of crops and crop residues,

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[25] The impact on NPV by using different canola premium rates (10% versus 13.95%) was examined and no significant qualitative effects were found on the study results.

plus crop insurance payments. Allowable expenses are input costs directly associated with crop production, excluding machinery replacement cost (AFSC, 2019a). REF[26] is equal to the average of the five most recent PMs, excluding the highest and the lowest PM values over that five-year period. This three-year average is referred to as an "Olympic Average" (AFSC, 2019a).

If an AgriStability payment is triggered, it is equal to 70% of the difference between the "trigger point" value (i.e., 70% of the RM) and the PM for the program years. The AgriStability calculation used in the simulation models was as follows (AFSC, 2019a):

AgriStability Payment =

$$\begin{array}{c} 0, \quad \text{if PM} \geq 70\%\ \text{RM} \\ 70\% * (70\%\ \text{RM} - \text{PM}), \text{if PM} < 70\%\ \text{RM} \end{array} \tag{4.23}$$

The annual fee associated with participating in the AgriStability program is 0.45% of the contribution reference margin, multiplied by 70% (ASFC, 2019a). In other words, \$0.0045 is paid by the producer for each dollar of contribution reference margin. A minimum program fee is \$45 is charged. Besides the program fee, an additional \$55 Administrative Cost Share is also paid annually by participants (AFSC, 2019a).

4.5 Simulation and Cash Flows for Alternative Cropping System Adoption Analysis

This section provides an explanation of the cash flow analysis incorporated into the simulation model to examine economics of adoption of alternative crop rotations. The annual farm-level performance measured by annual cash flow was obtained for each rotation in the baseline scenario and converted into Net Present Values (NPV). The simulated NPV results of each rotation were compared within and across representative farms. The NPV difference represented the economic impacts of choosing one rotation over another for the representative farm.

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[26] The applied reference margin is the minimum of the Olympic average and the average eligible expenses calculated using the same three years.

4.5.1 Net Cash Flow

The net present value (NPV) was calculated from a stream of net cash flows resulting from farm operations. The approach used to calculate net cash flow was slightly different from what would normally be done in an accounting exercise. Specifically, the net cash flow explicitly included revenues and expenses associated with farm production. Cash flows associated with machinery replacement and participation in business risk management (BRM) programs were also included. The expenditures associated with debt servicing, conversely, were excluded from the net cash flow calculation. This was done because the study focused on production management rather than financial management of the representative farms. In particular, the asset and debt structure associated with the farms was not specified and so debt servicing was not considered. Given this deviation from the usual net cash flow calculation, the term "Modified Net Cash Flow" (MNCF) was used to denote the net cash flows.

4.5.2 Net Present Value Calculations

The NPV for each iteration in the simulation was calculated using the formula provided in equation (4.24) and a distribution of NPV was generated through the repetitive iterative process for each crop rotation. The simulation analysis was conducted over a twenty-year time horizon, but cash flows were assumed to continue indefinitely beyond year 20 because farm businesses were assumed to continue to operate past the end of the simulated time horizon. As a consequence, these future farm returns were reflected by calculating an NPV in perpetuity; that is, the NPV was calculated using the following formula:

$$\mathrm{NPV}_{\mathrm{Perpetuity}} = \sum_{\mathrm{t}=1}^{20} \frac{\mathrm{MNCF}_{\mathrm{t}}}{(1+\mathrm{r})^{\mathrm{t}}} + \frac{\mathrm{MNCF}_{20}}{\mathrm{r}} \times \frac{1}{(1+\mathrm{r})^{20}} \tag{4.24}$$

where $MNCF_t$ was the modified net cash flow in time *t* (*t* = 1 to 20) and *r* was the discount rate. The first term in equation represented the sum of discounted MNCFs over the 20-year simulation period. The second term represented the present value of the MNCF for year n, assumed to extend in perpetuity. Economic performance of alternative crop rotations for each farm was evaluated by comparing simulated NPVs. Differences between expected NPVs indicated economic trade-offs associated with selecting specific crop rotations. Rotations with higher expected NPV contributed more to expected wealth of the farm. In contrast, adopting rotations with lower expected NPV would make the crop production less profitable than the baseline rotation scenario.

4.5.3 Discount Rate

The discount rate used in the Monte Carlo simulation varies depending on the type of business being analyzed. The Canadian Treasury Board recommended a 10% discount rate in 1976, calculated as the weighted average from three sources: the marginal cost of foreign capital inflows, the interest rate of domestic savings and the interest rate of postponed investments (Treasury Board of Canada Secretariat, 2007). Recent work by Trautman (2012) and Bruce (2017) used the same 10% discount rate to assess the economics of BMP adoptions by agricultural producers in Alberta. Therefore, 10% was selected as the appropriate discount rate in this study. Sensitivity analysis on the discount rate was also performed and the results are discussed later in Chapter 5.

4.5.4 Time Horizon

A 20-year time horizon was chosen for the simulation analysis in this study. The base rotation and intensive canola rotations mostly ranged from two to four years in length. However, the rotational periods for more diversified rotations in the study were longer, from six years to a maximum of eight years in length. Thus, a 20-year study period was deemed sufficient to support analyses with complete rotation cycles in each representative farm. In addition to the 20-year time horizon used in the simulation model, an extra five years (year -4 to year 0) was added to the beginning of the simulation period, prior to the beginning of year one. The five “non-positive” years were included to set up cash flow calculations for the BRM programs. It was assumed that the representative farms were ongoing businesses; that is, they existed prior to the beginning of the 20-year period modeled in this analysis. According to AFSC and SCIC (2019), program margins (AgriStability) and insurance coverage levels (AgriInsurance) are calculated based on a minimum five-year historical information for ongoing farm businesses. In this case, participants are required to submit five years of yield records to be eligible in the new program year. The effect of different time horizons on simulation results was tested through a sensitivity analysis. The results are discussed in the next chapter.

4.5.5 Simulation Model Iteration

The Monte Carlo simulation was conducted using the @RISK add-in program for Excel, through an iterative process. Each crop rotation was simulated over multiple iterations, with @RISK being used to draw different random values from the specified probability distributions in every iteration. Each iteration started anew, with NPVs being recalculated using new draws from the distributions. In this way, distributions of outcomes were generated in the model.

The @RISK program allows flexibility with respect to the choice of number of iterations for each simulation scenario. There are trade-offs associated with different choices. A smaller number of iterations (e.g., 1000) allows completion of simulation in a shorter time, while a larger number of iterations (e.g., 5000, 10,000 or more) generates more accurate distributions that are closer to reality, but accordingly requires more time and computing power.

Sensitivity analysis was conducted in the current study to compare results obtained using different numbers of iterations; specifically results for 1000, 2500, 5000 and 10,000 iterations were compared. A two-sample Kolmogorov-Smirnov (K-S) test was performed in STATA to compare the resulting distributions of NPV for the four different scenarios, assuming a null hypothesis of zero statistical difference between NPV distributions; 5000 iterations was treated as the control group. The purpose of conducting these tests was to examine whether there was a statistically significant difference between the empirical NPV distributions generated with alternative numbers of iterations. The impact of iteration choices was tested using the wheat-canola (SW-C) rotation for Camrose representative farm.

The resulting K-S statistics were statistically insignificant at the 5% significance level, as shown in Table 4.48. This was interpreted to mean that none of the null hypotheses were rejected in the analysis and there was no significant effect associated with the choice of iteration number. As a result, 5000 iterations were used in the simulation of all crop rotation scenarios for all three farms.

Table 4.48 K-S statistics of mean NPVs of base rotation SW-C with 5000 and alternative 1000, 2500 and 10,000 iterations in Camrose

Iterations	Mean NPV ($/farm)	Test Statistics		
		K-S statistics[a]	Difference[b]	Two -tailed P-value[c]
5000	5,925,722.97			
1000	5,916,784.99	0.383	0.024	0.723
2500	5,919,745.88	0.629	0.012	0.974
10,000	5,116,691.03	0.232	0.015	0.459

[a] K-S statistics resulted from testing for significant difference between mean NPVs of simulations with the default 5000 iteration and each of three iterations 1000, 2500 and 10,000.

[b] Combined statistical difference of pairwise comparisons between each alternative iteration and the default 5000 iterations.

[c] Combined p-value of pairwise comparisons between each alternative iteration and the default 5000 iterations.

4.6 Stochastic Risk Efficiency Analysis

The SERF analysis is implemented in the study to evaluate the risk efficiency of the alternative rotations for each representative farm. The outcomes compared for different rotations are the probability distributions of wealth; that is, distributions of NPVs resulted from the Monte Carlo simulation analysis. The SERF analysis is implemented using Microsoft Excel.

As discussed in Chapter 3, the risky alternative with the greatest CE will have the greatest expected utility. In order to incorporate information about risk preferences of producers and calculate CE values, a particular form for the utility function should be specified (Hardaker et al., 2004). Based on Hardaker et al. (2004), three potential functional forms are considered for the SERF analysis: negative exponential, logarithmic and power. This study assumed a negative exponential utility function and the functional form is expressed as follows:

$$\mathrm{U} = 1 - \exp(-\mathrm{cw})\,, \mathrm{c} > 0 \tag{4.25}$$

where *U* represents utility, w represents wealth, and c is the sole function parameter. The negative exponential function implies a constant absolute risk aversion (CARA), where the absolute risk aversion coefficient is equal to the parameter “c”. The assumption of CARA is limiting in terms of representing potential producer behavior. However, it is empirically convenient in terms of the ability to derive an algebraic expression for CE. As well, by varying the value of c, it is possible to model a wide range of absolute risk aversion levels in the SERF analysis.

The use of SERF involves ordering alternatives with respect to their CE for a particular level of absolute risk aversion (Hardaker et al., 2004). The level of risk aversion may be varied to determine whether the most risk efficient alternative varies by risk preferences. To compute CE values, the inverse of negative exponential utility function is calculated as indicated in (4.26) by Hardaker et al. (2004):

$$\mathrm{CE}\big(\mathrm{NPV}, \mathrm{r_a}(\mathrm{NPV})\big) = \ln\left\{\left[\frac{1}{\mathrm{n}}\sum_{\mathrm{i}=1}^{\mathrm{n}} \exp\big(-\mathrm{r_a}(\mathrm{NPV})\mathrm{NPV_{ij}}\big)\right]^{-1/\mathrm{r_a}(\mathrm{NPV})}\right\} \tag{4.26}$$

where NPV_{ij} represents NPV for crop rotation *j,* and n is the number of observations in the NPV distribution for each rotation.

The implementation of SERF using the negative exponential utility function requires the specification of a range of absolute risk aversion levels that lie between an upper and lower bound. As discussed in Chapter 3, Anderson and Dillon (1992) argued that the relevant range of relative risk aversion is from 0.5 to 4. Given the relationship between relative and absolute risk aversion measures, this relative risk aversion range may be converted to an upper and lower bound for absolute risk aversion by dividing the relative risk aversion level by the level of wealth. In this instance, expected NPV for the base rotation in each farm will be used to represent wealth in the calculation. Table 4.49 provides the expected value for simulated NPV of the base rotation and resulting absolute risk aversion bounds for each farm.

Table 4.49 Mean NPV of base rotation ($) and defined upper and lower bounds for absolute risk aversion, by representative farm

Representative Farm	Base Rotation Mean NPV ($)	Lower Bound	Upper Bound
Camrose	5,916,811.89	0.0000001	0.0000007
Smoky River	3,797,273.37	0.0000001	0.000001
Saskatchewan	4,849,133.96	0.0000001	0.0000009

The CE calculations for SERF, using the formula in (4.26), can be done in an Excel spreadsheet. For a specific rotation, the distribution of simulated NPVs is exported from the @Risk simulation model and the CE is calculated for a specific absolute risk aversion coefficient value. The CEs[27] are calculated for specific values over a range of risk aversion coefficients between the two bounds provided in the table above at an increment of 10^{-7}, with the same process being used for all representative farms.

CE values for each alternative rotation over a finite range of absolute risk aversion coefficient are calculated and presented in tabular form. For simplicity of interpreting the SERF results, these CE values are plotted against the risk aversion over the range defined for each farm. All rotations are compared simultaneously in the resulting graph and ordered in terms of the rule; that is, only those have the greatest or equal CE values for some values in the absolute risk aversion range are risk efficient. Otherwise, alternatives are dominated under the SERF criterion (Hardaker et al., 2004). The efficient set identified from a set of rotations in each farm are also graphed for detailed comparisons. SERF results in the baseline and scenarios with modified assumptions are also discussed in the next chapter.

4.7 Chapter Summary

The chapter uses statistical data and expert opinion to build three representative commercial crop farms in Alberta and Southern Saskatchewan. The farm size and crop production characteristics are determined. Stochastic crop price, crop yield and yield effects from preceding crops are

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[27] Different CE calculation rules are applied to individuals who are risk neutral, risk loving or extremely risk averse (Hardaker et al., 2004). However, this is not relevant to the current study given the range of relative risk aversion levels used in the SERF analysis.

estimated based on historical data collected from Statistics Canada and AAF and AFSC. Production revenue, production costs and business risk management programs are modeled by incorporating the built stochastic parameters. Modified net cash flows are converted into net present values.

Models are built to be flexible in analyzing adoptions of cropping systems considered dynamics in crop yields and BRM participation for representative farms. The effect of yield adjustment and the adoption of BRM programs will cause changes to the economic performance of representative farms including production costs and revenue. NPV analysis is employed to evaluate adoption of alternative cropping systems for each farm. Sensitivity analysis is used to examine feasibility of adoption for alternative values of key parameters determined for the model. SERF analysis is also employed to assess risk associated with adoption of alternative cropping systems under baseline scenario as opposed to varying circumstances.

CHAPTER 5：Results and Discussion

This chapter presents and discusses the results of the simulation models outlined in Chapter 4. Differences in NPV are calculated for all rotations in the baseline scenario that are used for intra-farm comparisons. Sensitivity analyses on key model parameters and SERF analysis of cropping system adoptions with differing circumstances are also discussed. Interpretation of results is based on both tabular and graphical presentations. However, before getting into further discussion, model validation of the base rotation (SW-C) model is performed and discussed in section 5.1.

5.1 Validation of the Representative Farm Model

The validation process examines the degree to which an estimated model is an accurate representation of the real world from the perspective of the purpose for which it was built (Sornette et al., 2007). In the current study, validation is done by comparing the simulated net present value for the baseline operation to farmland values for the respective farm locations. Similar approaches have been employed to validate farm models in previous studies (e.g., Trautman, 2012; Xie, 2014; Bruce, 2017).

Land value is a measure of willingness to pay (WTP) for a piece of land where the transaction of land grants the buyer the right to earn returns on that land each year in perpetuity. As mentioned in Chapter 4, the net present value (NPV) of future returns is assumed to be based on the expected wealth generated by the land. The expected NPV for the base rotation (SW-C) is converted to a per acre basis and then compared with land values that are determined on the same basis. Farmland values shown in Table 5.1 are collected from Farm Credit Canada (2019) and AAF (2019c).

Table 5.1 Comparison of base rotation NPV to values of farmland and agricultural real estate transfers ($/acre)

Location	NPV per acre in perpetuity	2019 Farmland values[a]			2019 Average Agricultural Real Estate Transfer[b]
		Average	Min.	Max.	
Camrose	2314.74	4327	1400	8600	3951.07
Smoky River	1974.78	2141	1000	3300	2268.33
Saskatchewan	1896.28	1610	800	2500	N/A[c]

Source: FCC (2019a) and AAF (2019c)

[a] Farmland values are based on FCC data available for the particular regions. Camrose and Smoky River are represented by values from the Central and Peace regions of Alberta, respectively. The value for the Saskatchewan farm is obtained from the East Central region of Saskatchewan.

[b] Agricultural real estate transfers are county-level values rated by Canada Land Inventory (CLI) rating system. Class 2 is land with high agricultural suitability and capable of production of a wide range of crops.

[c] N/A denotes the equivalent agricultural real estate transfer data in Saskatchewan re not available.

The range of FCC land values for each farm is determined based on 90 percent of land sales data in the previous year from the Central Alberta (Camrose), Peace (Smoky River) and East Central Saskatchewan (Saskatchewan) regions (FCC, 2019a). The last column of Table 5.1 provides Agricultural Real Estate Transfer values from AAF (2019c) which are available for Alberta counties only. Thus, validation of the representative Saskatchewan farm model using equivalent data is not presented. The agricultural real estate transfer values are sorted by the Canada Land Inventory (C.L.I) rating system (class 1 to 7) which reflects the productive capability of land (AAF, 2019c). Land values for CLI 2 are used to compare with NPV per acre in the study. According to the definition provided by AAF, CLI2 indicates land with moderate limitations that restrict crop production or moderate conservation practices are required. Besides the underlining assumption that land quality is good in Camrose due to important crop production, acres of CLI2 land transferred in 2019 in Camrose represent the greatest number compared with other soil classes. Therefore, it is appropriate to use land transfer values in CLI2 for model validation.

Simulated per acre NPVs for the base rotation SW-C are relatively similar to farmland values in the M.D. of Smoky River and for the Saskatchewan farm. Thus, for these two farms, the expected NPVs represent a relatively good proxy for market land values reported by FCC (2019a) and AAF (2019c). However, NPV per acre in Camrose County deviates significantly from market values with an average difference of approximately one thousand dollars. The price gap is consistent when comparing to either estimate of market value; that is, FCC or AAF sources.

The difference between market land values and the per acre NPV in Camrose may be explained mainly by non-productivity factors. Real estate transfer values are higher due to competing demands for farmland that raise the bids to a level higher than what would be expected based on the agricultural productivity (FCC, 2019b). Another non-productivity factor that positively influenced market land values in Camrose is increased population density. According to census data, the population density for Camrose between the 2011 and 2016 census years increased by 8.6% (Statistics Canada, 2016). As noted by Bentley (2016), who investigated potential factors shaping the Alberta farmland values, population density is directly related to land values. Additionally, it may be the case that the productivity measures generating the NPV results (i.e., crop yields) may not be consistent with the agricultural suitability indicated by the CLI2 rating, which is the basis for the land value data.

5.2 Baseline Scenario Results

The baseline scenario model incorporates all aspects of the analysis including previous crop yield effect and participation in BRM programs. Alternative scenarios are discussed later that change some of these elements to examine the impact on the empirical results. Baseline results for the base rotation and alternative cropping systems in each representative farm are discussed first. The base rotation results (Table 5.2) served as the basis for analyzing changes in NPVs due to BRM program participation and yield effects from preceding crops.

Table 5.2 Expected total and per acre NPV of base rotation, by farm

Farm	Farm Size (acre)	Total NPV ($)	NPV ($/acre)
Camrose	2560	5,925,722.97	2314.74
Smoky River	1920	3,791,569.45	1974.78
Saskatchewan	2560	4,854,480.70	1896.28

5.2.1 Results of Base Rotation

Table 5.3 presents the mean NPV[28] and standard deviation for the base rotation for the representative farms. As discussed in the previous chapter, NPV calculations are based on modified net cash flows (MNCF) generated from crop production. Thus, NPV is measured as a proxy of wealth for farm operations; that is, greater NPV indicates a greater level of wealth. The resulting average NPVs are $5,925,722.97, $3,791,569.45 and $4,854,480.70 for farms located in the Alberta Black soil zone, Alberta Dark Gray soil zone, and Saskatchewan Black soil zone, respectively. The farm located in Central Alberta (Camrose County) has the greatest estimated wealth, followed by Saskatchewan farm and the lowest for the Dark Gray soil farm (Smoky River). A main contributing factor to the difference in wealth is the modeled canola yield. As indicated earlier in Chapter 4 mean de-trended canola yields for the three farms followed the same pattern as expected wealth: Camrose (1.04), Saskatchewan (0.91) and Smoky River (0.88). The difference in input costs per acre of individual crops also contributed to the wealth gap. The total production cost per acre of all crops in the three farms reported in Chapter 4 followed a reversed pattern as expected wealth: Saskatchewan (highest), followed by Camrose, and Smoky River.

Table 5.3 Expected NPVs, standard deviations and annual modified net cashflows of base rotation by representative farm

Farm Location	Soil Zone	Mean NPV	Standard Deviation	Mean Annual MNCF
Camrose	Black	$5,925,722.97	$584,233.67	$542,539.15
Smoky River	Dark Gray	$3,791,569.45	$339,026.29	$324,857.06
Saskatchewan	Black	$4,854,480.70	$617,366.42	$409,486.37

Results for the standard deviations are slightly surprising since they are somewhat inconsistent with the assumption of economic theory that in general, variance increases with expected returns. The unexpected pattern is found specifically for the Black Soil zone farm in Saskatchewan. This

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[28] The NPVs presented and discussed in this chapter are "in perpetuity"; that is, they are calculated using an infinite time horizon. The calculation of NPV with perpetuity is provided in Chapter 4, section 4.4.3.

farm has the second-highest mean NPV but the largest standard deviation. With the same assumptions of soil zone and rotations across two farms, the inconsistency between mean NPVs and variances is probably due to the higher level of yield risk incurred, specifically for canola and flax production, in Saskatchewan relative to Alberta.

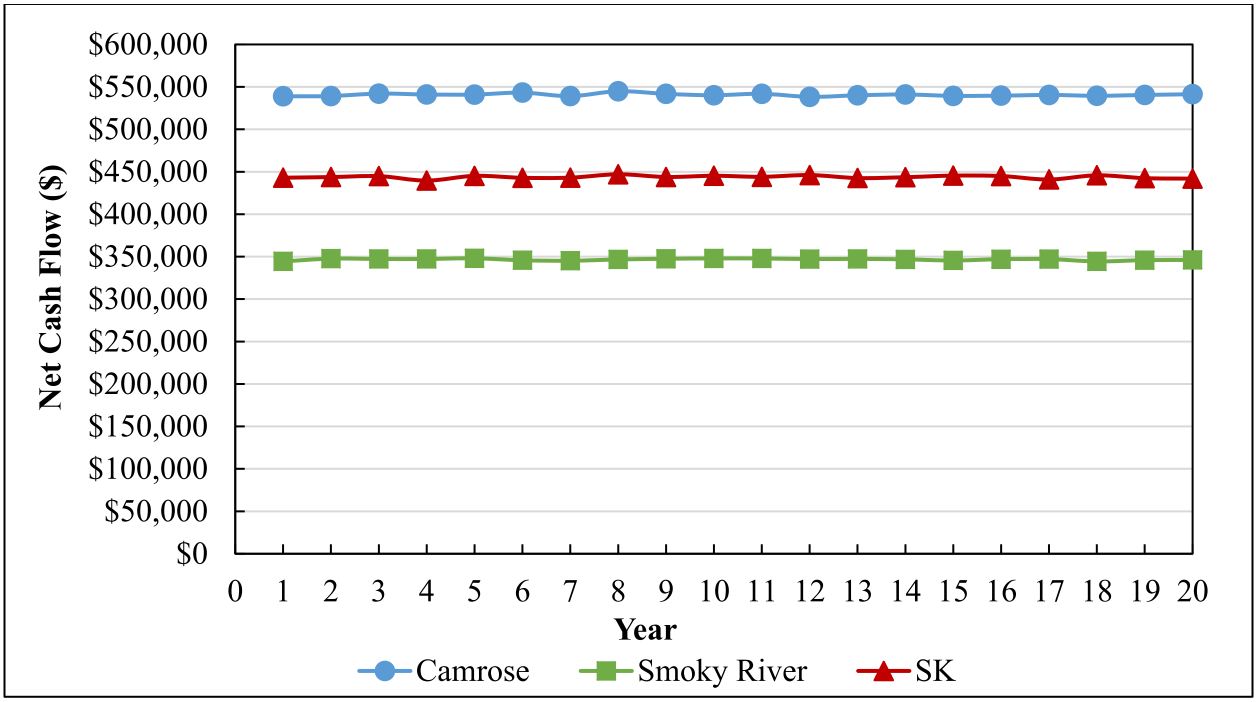

Figure 5.1 Mean annual modified net cash flows for the base rotation SW-C in representative farms over 20-year time period

Figure 5.1 shows annual average modified net cashflows for representatives over a twenty-year period. The net cashflows of base rotation in each farm are stable at the respective levels over time. Additionally, the pattern of annual average MNCFs, shown in Table 5.3, is consistent with the pattern of mean NPV in perpetuity between the farms.

5.2.2 Results of Alternative Rotations

The following sections discuss the results for alternative cropping rotations for each representative farm. Similar to the discussion for the base rotation, the economic impacts of alternative rotation adoptions are evaluated through differences in NPV. Inter-farm comparisons of baseline results for all rotations are performed to examine financial impacts in response to changes in crop sequences.

5.2.2.1 Camrose County

In the baseline scenario, average NPV results in Table 5.4 suggest rotations with greater canola intensity[29] generated higher expected wealth relative to more diversified rotations that included barley, oats and field peas. For example, the rotations with the greatest expected NPV for the Camrose farm are SW-C-C-C with $5.97 million and SW-C-C with $5.95 million. This result occurs because of the high value produced by canola in the crop sequence.

Results for diversified rotations are mixed but overall lower than that of canola-intensive rotations in Camrose County. The NPV pattern is plausible since the expected profitability tends to be higher in more specialized rotations relative to diversified rotations that include lower value crops. As outlined in Chapter 4, incorporating yield effect of preceding crops is likely to affect net cash flows with the degree of impact varying by crop. Recall in Table 4.24 that the mean yield adjustment ratios for barley and oats after canola are greater than 1 (1.033 and 1.116, respectively), which indicated positive yield response of growing barley and oats after canola. Therefore, expected returns of rotations SW-C-C-B and SW-C-C-O increased accordingly. Conversely, field pea yields were suppressed by growing after other crops. In particular, the mean yield adjustment ratios for B-FP and O-FP were less than one (0.995 and 0.865, respectively). These negative yield adjustment effects have resulted in lower expected returns for rotation SW-C-B-FP-SW-C-O-FP, SW-C-B-FP and SW-C-O-FP in Camrose.

Table 5.4 Expected NPV and standard deviations of alternative rotations, Camrose

Rotation	Mean NPV	Std. Dev.	Std. Dev. Ranking[a]
SW-C-C-C	$5,966,352.59	$635,988.40	7
SW-C-C	$5,948,061.86	$609,171.40	6
SW-C	$5,925,722.97	$584,233.67	5
SW-C-C-B	$5,073,310.22	$659,203.17	9
SW-C-C-O	$5,048,802.68	$550,720.62	1
SW-C-B	$4,788,947.91	$730,573.24	10
SW-C-B-SW-C-O	$4,740,001.69	$554,011.55	3
SW-C-O-FP	$4,710,822.11	$552,180.66	2
SW-C-B-FP-SW-C-O-FP	$4,689,902.03	$554,606.67	4
SW-C-B-FP	$4,673,173.00	$653,519.84	8

Note: Rotations are ranked by expected NPV in descending order.

[a] The last column provides rotation ranking based on standard deviations, ranked from 1 (lowest standard deviation) to 10 (highest standard deviation).

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[29] These are rotations with more than one year of canola in the crop sequence.

In general, it is expected that variance in returns increases with the level of expected return. In Camrose, the pattern of standard deviations does not comply with this pattern. An extreme case is SW-C-B that has the largest standard deviation of any rotation for that farm while the expected NPV is "in the middle" of the range for the modelled rotations. While there is no explicit evidence of naturally occurring factors leading to this result, the correlation coefficient between a combination of crops is suggested as a contributing factor. In general, a higher coefficient of correlation between crops would contribute to higher variability for the relevant rotation. According to the AARD correlation matrix, the coefficient for barley and spring wheat yields is the highest of all correlations at 0.77. The significant proportion of barley and wheat in rotation SW-C-B (two thirds), along with the positive high correlation contributes to a higher variance. A similar pattern is observed in other rotations with a higher proportion of wheat and barley. For example, the second and third highest variances are identified for SW-C-C-B and SW-C-B-FP, with wheat and barley together accounting for 50% of the crop sequence.

It was expected that variability in NPV would be greater for canola intensive rotations whereas lower variances would be found in diversified rotations. Variance measures the dispersion of expected returns of the portfolio from its mean and it informs the total risk of the portfolio. Considering each rotation as a portfolio with crops representing assets in a portfolio, the variance is dependent on the individual variances of the portfolio assets, their mutual correlations, and the relative proportions or weights for each asset in the portfolio. The portfolio variance formula for a three-asset portfolio variance is presented in equation (5.1):

$$\mathrm{w}_1^2\sigma_1^2 + \mathrm{w}_2^2\sigma_2^2 + \mathrm{w}_3^2\sigma_3^2 + 2\mathrm{w}_1\mathrm{w}_2\sigma_1\sigma_2\rho_{1,2} + 2\mathrm{w}_2\mathrm{w}_3\sigma_2\sigma_3\rho_{2,3} + 2\mathrm{w}_1\mathrm{w}_3\sigma_1\sigma_3\rho_{1,3} \qquad (5.1)$$

where subscripts 1, 2, and 3 represent crops 1, 2, and 3. w is the weight of crop in the portfolio; σ^2 is the squared standard deviation (variance) of a crop and ρ is the correlation coefficient between two crops. For example, the correlation between crop 1 and 2 is expressed as $\rho_{1,2.}$

Results for Camrose do not completely conform to this hypothesis because high-frequency canola rotations do not display higher variances. It is likely that variances of canola-intensive rotations were underestimated because the full impact of disease events was not captured. The top three highest standard deviations are identified for rotations SW-C-B, SW-C-C-B and SW-C-B-FP. These unusual NPV variances are due to high yield correlations between certain crops in the rotation. The correlation coefficient between barley and wheat (B-SW), as well as field peas and spring wheat (FP-SW) are among the larger values with values of 0.77 and 0.76, respectively. These coefficients are significantly higher than the yield correlation in the intensive canola rotations that equals 0.66 for spring wheat and canola (either SW-C or C-SW). The rest of diversified rotations have smaller variances which are consistent with the above hypothesis. Specifically, crop diversification allows higher returns from one crop to offset lower returns from another and risk is reduced through income stabilization.

An exception to this pattern is SW-C-C-O that has the smallest standard deviation. As stated earlier in the discussion, yield correlations have a significant impact on the variability of returns. Thus, lower variability in SW-C-C-O is explained by the yield correlation between canola and oats, which is also the smallest (0.63) among all crop combinations in the Camrose County.

5.2.2.2 M.D. of Smoky River

Expected NPVs in the Dark Gray soil farm shown in Table 5.5 have a different pattern than the Black soil farm. In the M.D. of Smoky River, canola intensive rotations do not dominate in terms of expected NPVs. The internal pattern of NPV for the three canola intensive rotations is reversed. Two factors contributed to the lower NPVs for canola-intensive rotations in Smoky River. These are a) lower relative expected crop yields[30] than for Camrose, and b) the previously mentioned yield adjustments. In particular, the relative expected yield for canola and other crops (i.e. barley, spring wheat, field peas) was the lowest among the three farms. Furthermore, the negative yield effect associated with growing canola after canola reinforces the reduction in expected returns for canola-intensive rotations. In consequence, the total expected return decreased instead with increased canola intensity.

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[30] Relative expected yield is calculated as a ratio between the mean detrended yield of two crops in the farm. The ratio indicates how productive a crop is in the farm relative to other crops, and also the relative productivity compared across farms.

Additionally, expected returns of more diversified rotations were higher than more specialized rotations, especially for those rotations that included field peas. This pattern is explained by a higher profitability for field peas in comparison to all other crops in the farm. The exceptionally high expected return for rotation SW-C-B-FP was due to a combination of positive previous yield adjustment effect and the greater profitability of field peas.

Table 5.5 Expected NPV and standard deviations of alternative rotations, Smoky River

Rotation	Mean NPV	Std. Dev.	Std. Dev. Ranking[b]
SW-C	\$3,791,569.45	\$339,026.29	9
SW-C-B-FP	\$3,611,352.57	\$319,200.25	6
SW-C-C	\$3,587,673.86	\$335,724.25	8
SW-C-C-C	\$3,496,852.93	\$345,753.32	10
SW-C-B-FP-SW-C-O-FP	\$3,451,962.52	\$315,349.73	5
SW-C-O-FP	\$3,404,593.21	\$335,654.44	7
SW-C-B	\$3,267,802.13	\$305,874.32	4
SW-C-C-B	\$3,242,159.04	\$299,713.97	2
SW-C-B-SW-C-O	\$3,034,723.61	\$292,953.85	1
SW-C-C-O	\$2,917,856.86	\$303,996.66	3

Note: Rotations are ranked by expected NPV in descending order.

[b] The last column provides rotation ranking based on standard deviations, ranked from 1 (lowest standard deviation) to 10 (highest standard deviation).

The pattern in standard deviations was not consistent with what would be expected given the pattern in expected returns for the Smoky River farm, but the observed trend makes sense from an agronomic perspective. The top three highest standard deviations are identified for rotations SW-C-C-C, SW-C and SW-C-C, in descending order. Higher risk is associated with increasing canola intensity due to negative yield effect of canola after canola, and the extremely high correlation between the same crops (correlation coefficient is 1 for C-C). Diversified rotations including barley and oats overall expressed consistency between variances and expected returns.

Another observation different from Camrose is that rotations with field peas have higher standard deviations relative to other diversified rotations. Given the pattern is not explained by correlations, it is suggested the higher variability in profit of field peas led to greater variance in relevant rotations in Smoky River. Table 5.6 provides the summary statistics of simulated margins in year-20 for each crop. Of all crops, field pea margin has the highest standard deviation meaning both field pea yield and price are reported with greater variability. Thus, adding field peas for diversification would increase the variance of expected return of that specific rotation compared to other crops (barley and oats).

Table 5.6 Simulated mean margins and standard deviations in yr-20 by crop ($/acre), Smoky River

Crop	Mean Margin	Standard Deviation
Barley	124.49	76.63
Canola	188.63	80.31
Spring Wheat	170.10	93.10
Field Peas	204.16	**106.75**
Oats	79.24	81.38

5.2.2.3 Saskatchewan Farm

According to the simulated results in Table 5.7, more variations were observed in the pattern of expected NPVs for rotations in the Saskatchewan farm.

Table 5.7 Expected NPV and standard deviations of alternative rotations, Saskatchewan

Rotation	Mean NPV	Std. Dev.	Std. Dev. Ranking[c]
SW-C	$4,854,480.70	$617,366.42	15
SW-C-C	$4,584,248.84	$573,209.72	13
C-SW-F-SW	$4,575,597.72	$588,120.15	14
SW-C-C-C	$4,471,244.89	$567,281.30	12
C-SW-F-C	$4,168,195.89	$520,777.19	11
SW-C-C-O	$3,891,173.44	$479,037.82	5
SW-C-O-F	$3,835,717.87	$452,907.50	1
SW-C-B-F-SW-C-O-F	$3,788,082.66	$456,623.88	2
SW-C-B-F	$3,748,663.35	$464,632.08	3
SW-C-C-B	$3,734,796.78	$486,810.81	6
SW-C-B-SW-C-O	$3,723,025.68	$478,886.99	4
SW-C-B	$3,628,125.32	$491,878.27	8
SW-C-O-FP	$3,626,096.03	$489,988.14	7
SW-C-B-FP-SW-C-O-FP	$3,504,174.16	$490,509.32	10
SW-C-B-FP	$3,382,796.99	$493,920.53	9

Note: Rotations are ranked by expected NPV in descending order.

[c] The last column provides rotation ranking based on standard deviations, ranked from 1 (lowest standard deviation) to 10 (highest standard deviation).

A pattern similar to Smoky River was observed where higher wealth resulted for canola-intensive rotations but in a reversed order in terms of canola intensity. Similar explanations may be applied to the Saskatchewan farm in that lower relative expected canola yield and previous yield adjustments have caused the reversed NPV pattern between the three canola-intensive rotations.

Higher expected returns were found in more diversified rotations that included flax, barley and oats than those with field peas. Higher expected price and yield for flax contributed to the higher expected returns for relevant rotations (i.e. C-SW-F-SW and C-SW-F-C). Specifically, the expected price of flax was high but its per acre cost was the lowest among all crops in Saskatchewan. The result also conformed to the finding of Manitoba Agriculture, Food and Rural Development (2019) which flax yielded higher when sown on cereal stubbles. In addition, the expected margin per acre calculated for flax is also higher, contributing to the higher expected NPV observed for the two flax rotations.

The pattern of standard deviations for rotations with intensive canola and flax is generally consistent with the expected returns. Variability of expected returns decreased as crop diversification gradually increased, especially for more diversified rotations with flax. Brooks (2019), Cutts (2019) and Whatley (2019) stated the risk of growing flax in the study area is greater, especially during years with high precipitation. In this study, higher variances in flax rotations are attributed to the greatest variability in the price simulated for flax relative to the other five crops in Saskatchewan. Table 5.8 shows summary statistics of simulated margins in year-20 for crops in Saskatchewan.

Table 5.8 Simulated mean margins and standard deviations of crop prices in year-20, Saskatchewan

Crop	Mean	Standard Deviation
Barley	157.20	27.28
Canola	485.50	67.02
Spring Wheat	260.23	81.1
Oats	261.12	46.27
Field Peas	162.72	26.23
Flax	470.59	**87.12**

5.3 Results of Sensitivity Analyses

Sensitivity analyses for three model variables: starting crop price, discount rate and time horizon are conducted for all rotations in Camrose County, to examine the potential impacts of changing assumed simulation parameters. The impacts on mean NPVs by varying assumptions of parameters in the model were examined for this representative farm and discussed in the following sections.

5.3.1 Starting Crop Prices

Different starting prices are likely to impact the simulated crop prices in simulation models because prices are estimated using a time series model in which current prices are based on previously simulated values. In the simulation model, the default starting prices were the historical average prices over the entire study period 1987 to 2017. Three alternative starting prices to be tested in the analysis are historical average prices calculating based on a 5-year average from 2013 to 2017), a 10-year average from 2008 to 2017, and the most recent 2017 price collected in data. Table 5.9 provides alternative price series used in the sensitivity analysis. For all crops, the 5-year average and 2017 price are both greater than the original historical average prices used as the starting values. The 10-year average is also greater than the original starting prices for all crops except for spring wheat. By comparing across columns, the 10-year average are the highest prices overall.

Table 5.9 Starting crop prices used in sensitivity analysis in Camrose ($/tonne)

Crop	Historical Average	10-year Average	5-year Average	2017
B	182.71	220.70	219.25	193.38
C	490.87	542.04	519.03	514.66
SW	256.91	279.93	250.92	267.44
FP	276.13	311.81	320.95	303.55
O	182.78	198.15	198.04	193.27
F	469.15	561.94	540.69	510.39

Sensitivity analysis results of starting prices are shown in Table 5.10. The resulting NPV pattern is consistent with prices in that the lowest expected NPV is generated from using the historical average prices over entire time period. Since current prices are a function of lagged prices in the simulation analysis, a lower starting price would certainly result in lower stochastic prices being simulated. Without changing other variables in the model, expected NPVs are moving the same way as starting prices. There are changes observed in NPV ranking for more diversified rotations (three with field peas and SW-C-B-SW-C-O), when different starting prices are used. Within these rotations, more similarities in terms of NPV ranking are found between models using the default and the 2017 prices, whereas the NPV of 5-yr and the 10-yr average prices have more similarities in rotation ranking. For example, the expected NPV of SW-C-B-SW-C-O is higher ($4,740,001.69) than SW-C-O-FP ($4,710,822.11) when assuming historical average prices, whereas the rotation ranking switched in case of using 2017 prices ($4,888,729.60 and $4,890,137.60 respectively). This is the only deviation found in rotation ranking between two starting price assumptions and more changes are detected in these rotations when compared the default with 5-yr and 10-yr averages. A likely cause of NPV changes between more diversified rotations is the price fluctuations, especially for field peas. In Table 5.10, the greatest level of change is found between the historical average and alternative starting prices for field peas, and the price gap ranges from $27 to $45 in comparisons with the 2017 price and the 5-year average respectively.

Table 5.10 Expected NPV resulted from using different starting prices ($/farm), Camrose

Rotation	Historical Ave. (default)	10-yr Ave.	5-yr Ave.	2017
SW-C	5,925,722.97	6,291,174.40	6,083,686.40	6,103,168.00
SW-C-C	5,948,061.86	6,386,227.20	6,162,304.00	6,159,820.80
SW-C-C-C	5,966,352.59	6,443,750.40	6,210,995.20	6,198,016.00
SW-C-C-B	5,073,310.22	5,528,934.40	5,359,923.20	5,267,507.20
SW-C-C-O	5,048,802.68	5,372,211.20	5,210,803.20	5,217,254.40
SW-C-B	4,788,947.91	5,189,978.12	5,029,676.89	4,928,588.11
SW-C-B-SW-C-O	4,740,001.69	5,078,144.00	4,941,952.00	4,888,729.60
SW-C-B-FP	4,673,173.00	5,082,163.20	5,001,958.40	4,870,451.20
SW-C-O-FP	4,710,822.11	5,014,937.60	4,935,091.20	4,890,137.60
SW-C-B-FP-SW-C-O-FP	4,689,902.03	5,040,256.00	4,954,470.40	4,871,833.60

The NPV standard deviations are provided below in Table 5.11. The pattern is consistent with expected NPVs where variance increase with expected returns. The highest standard deviations are obtained by using the 10-year averages for all rotations. Different from the pattern for expected NPVs, the internal ranking of rotations based on standard deviations stays exactly the same no matter which starting prices are used in the model.

Table 5.11 Standard deviations resulted from using different starting prices ($/farm), Camrose

Rotation	Historical Ave. (default)	10-yr Ave.	5-yr Ave.	2017
SW-C	584,233.67	596,710.40	587,059.20	588,492.80
SW-C-C	609,171.40	622,796.80	612,864.00	612,761.60
SW-C-C-C	635,988.40	648,832.00	638,873.60	637,798.40
SW-C-C-B	659,203.17	675,097.60	669,747.20	662,604.80
SW-C-C-O	550,720.62	557,004.80	550,092.80	549,990.40
SW-C-B	730,573.24	766,666.76	762,568.04	742,594.15
SW-C-B-SW-C-O	554,011.55	563,968.00	558,976.00	555,340.80
SW-C-B-FP	653,519.84	669,568.00	667,289.60	658,150.40
SW-C-O-FP	552,180.66	558,694.40	555,852.80	552,678.40
SW-C-B-FP-SW-C-O-FP	554,606.67	585,907.20	583,065.60	578,355.20

Overall, different assumptions of starting prices have a relatively small impact on expected NPVs in rotations for the Camrose representative farm. The percentage changes in NPV range from 2.9% to 9.0% (Table 5.12) when alternative starting prices are used in the simulation model relative to the default starting prices.

Table 5.12 Percentage change of mean NPVs (%) assuming different starting prices, Camrose

Rotation	10-yr	5-yr	2017
SW-C	6.17	2.67	2.99
SW-C-C	7.37	3.60	3.56
SW-C-C-C	8.00	4.10	3.88
SW-C-C-B	8.98	5.65	3.83
SW-C-C-O	6.41	3.21	3.34
SW-C-B	8.37	5.03	2.92
SW-C-B-SW-C-O	7.13	4.26	3.14
SW-C-B-FP	8.75	7.04	4.22
SW-C-O-FP	6.46	4.76	3.81
SW-C-B-FP-SW-C-O-FP	7.47	5.64	3.88

Note: percentages changes are calculated based on the default historical average prices over entire study period.

Although the largest NPV discrepancy resulted between the baseline and the 10-yr average prices and one of the rotations (SW-C-C-B) has the greatest numerical difference of $5,073,31022 and $5,528,934.40 respectively, it has a percentage change right below 10% (8.98%). Furthermore, a majority of rotations have small percentage changes in expected NPVs, ranging from 3% to 5% assuming any of three staring price series is tested. The degree of impact is similar across three representative farms.

5.3.2 Discount Rate

Sensitivity analysis on the discount rate is performed to investigate the effect on mean NPVs in the model. In the baseline models, a 10% discount rate is used in calculations. This is consistent with the rate adopted by earlier studies (Trautman, 2012; Xie, 2014 and Bruce, 2017). To conduct sensitivity analysis, additional discount rates of 8% and 12% are considered. Results of simulated mean NPVs using the different discount rates are provided in Table 5.13. As expected, the relative positions of all rotations remain the same in the ranking regarding the mean NPVs, regardless of the discount rate. Compared to the baseline scenario, a higher discount rate (12%) decreases NPVs whereas a smaller discount rate (8%) increases NPVs. This is because the higher (lower) discount rate penalizes future cash flows to a greater (lesser) degree. The reverse relationship between the discount rate and expected NPVs is consistent with expectations and no unusual patterns are observed in the simulated results for farms by varying the discount rate.

Table 5.13 Mean NPVs ($), assuming different discount rates in Camrose

Rotation	8%	10% (base)	12%
SW-C	7,264,029.83	5,925,722.97	5,018,042.00
SW-C-C	7,289,434.03	5,948,061.86	5,034,748.15
SW-C-C-C	7,311,886.10	5,966,352.59	5,050,954.67
SW-C-C-B	6,211,943.85	5,073,310.22	4,294,775.06
SW-C-C-O	6,190,716.12	5,048,802.68	4,276,092.79
SW-C-B	5,881,098.44	4,788,947.91	4,068,411.51
SW-C-B-SW-C-O	5,809,855.82	4,740,001.69	4,015,308.64
SW-C-B-FP	5,723,228.34	4,673,173.00	3,954,173.80
SW-C-O-FP	5,800,545.92	4,710,822.11	3,993,655.41
SW-C-B-FP-SW-C-O-FP	5,747,548.26	4,689,902.03	3,968,915.48

5.3.3 Time Horizon

Sensitivity analysis of the time horizon is also performed to examine whether model results are influenced by the choice of simulation length. In the baseline scenario a twenty-year period is chosen to be the appropriate time horizon for the simulation analysis. A shorter ten-year period is selected to be the alternative time horizon in the sensitivity analysis as 10 years would still be sufficient for all rotations in the study to complete their cycles.

Table 5.14 Ranking of mean NPVs ($), simulated using 20 and 10 years, Camrose

Rotation	Mean NPV in 20 years (default)	Rotation	Mean NPV in 10 years
SW-C-C-C	5,966,352.59	SW-C-C-C	5,996,116.38
SW-C-C	5,948,061.86	SW-C-C	5,972,101.51
SW-C	5,925,722.97	SW-C	5,945,868.57
SW-C-C-B	5,073,310.22	SW-C-C-B	5,098,640.20
SW-C-C-O	5,048,802.68	SW-C-C-O	5,073,519.22
SW-C-B	4,788,947.91	SW-C-B	4,799,209.56
SW-C-B-SW-C-O	4,740,001.69	SW-C-B-W-C-O	4,759,444.68
SW-C-O-FP	4,710,822.11	SW-C-O-FP	4,721,462.27
SW-C-B-FP-SW-C-O-FP	4,689,902.03	SW-C-B-FP-W-C-O-FP	4,695,059.39
SW-C-B-FP	4,673,173.00	SW-C-B-FP	4,679,213.65

Table 5.14 provides the expected NPVs in perpetuity simulated by using time horizons of 20 years and 10 years, along with simulated standard deviations in Table 5.15. NPVs resulting from a 10-year simulation period are slightly higher than those using a 20-year period, but the change in time horizon has no impact on rotation ranking.

Table 5.15 Standard deviations ($), simulated using 20 and 10 years, Camrose

Rotation	Standard Deviation in 20 years (default)	Rotation	Standard Deviation in 10 years
SW-C-B	730,573.24	SW-C-C-C	942,236.14
SW-C-C-B	659,203.17	SW-C-C	903,647.82
SW-C-B-FP	653,519.84	SW-C	872,990.06
SW-C-C-C	635,988.40	SW-C-B	868,650.52
SW-C-C	609,171.40	SW-C-C-B	831,965.17
SW-C	584,233.67	SW-C-B-FP	812,050.18
SW-C-B-FP-SW-C-O-FP	554,606.67	SW-C-C-O	811,874.85
SW-C-B-W-C-O	554,011.55	SW-C-O-FP	805,147.68
SW-C-O-FP	552,180.66	SW-C-B-FP-W-C-O-FP	767,762.35
SW-C-C-O	550,720.62	SW-C-B-W-C-O	746,597.83

5.4 Results of Supplementary Scenarios

Additional simulations are running for models with assumptions modified from the baseline model. Adjustments made from the baseline model including first the effect of preceding crops and then participation in business risk management (BRM) programs. Differences between simulated NPVs for the baseline and modified scenarios are used to determine the impact on the simulation results and ranking of rotations associated with including either the yield adjustment effects or participation in BRM programs.

5.4.1 No Yield Adjustment

The yield adjustment effect of preceding crops is removed from the model with all other parameters remaining unchanged. In this scenario, it was assumed that there were no yield impacts associated with the specific preceding crop. Comparisons of NPVs for models with and without yield adjustments are presented in the following (Tables 5.16 to 5.18).

Table 5.16 Mean NPV and percentage change of NPV with and without yield adjustments, Camrose

Rotation	Baseline NPV	No Yield Adjustment	% Difference
SW-C-C-O	$5,048,802.68	$5,318,132.50	5.33
SW-C-B-FP	$4,673,173.00	$4,436,611.95	-5.06
SW-C-B-FP-SW-C-O-FP	$4,689,902.03	$4,478,381.93	-4.51
SW-C-O-FP	$4,710,822.11	$4,527,891.14	-3.88
SW-C-C-C	$5,966,352.59	$6,164,733.02	3.32
SW-C-C-B	$5,073,310.22	$5,233,146.55	3.15
SW-C-B-SW-C-O	$4,740,001.69	$4,870,433.44	2.75
SW-C-C	$5,948,061.86	$6,054,065.34	1.78
SW-C	$5,925,722.97	$5,843,408.87	-1.39
SW-C-B	$4,788,947.91	$4,812,889.68	0.50

Note: Rotations are ranked by the absolute percentage change of NPV between baseline and no yield adjustment scenarios.

Table 5.17 Mean NPV and percentage change of NPV with and without yield adjustments, with and without yield adjustments, Smoky River

Rotation	Baseline NPV	No Yield Adjustment	% Difference
SW-C-C-O	$2,917,856.86	$3,124,264.59	7.07
SW-C	$3,791,569.45	$3,596,177.41	-5.15
SW-C-O-FP	$3,404,593.21	$3,273,102.22	-3.86
SW-C-B-FP	3,611,352.57	$3,487,956.66	-3.42
SW-C-B-FP-SW-C-O-FP	$3,451,962.52	$3,336,092.64	-3.36
SW-C-B-SW-C-O	$3,034,723.61	$3,127,529.10	3.06
SW-C-C-B	$3,242,159.04	$3,341,176.01	3.05
SW-C-C-C	$3,496,852.93	$3,583,499.19	2.48
SW-C-B	$3,267,802.13	$3,276,553.31	0.27
SW-C-C	$3,587,673.86	$3,583,422.96	-0.12

Note: Rotations are ranked by the absolute percentage change of NPV between baseline and no yield adjustment scenarios.

Table 5.18 Mean NPV and percentage change of NPV with and without yield adjustments, Saskatchewan

Rotation	Baseline NPV	No Yield Adjustment	% Difference
SW-C-B-FP	$3,382,796.99	$3,132,968.28	-7.39
SW-C-C-O	$3,891,173.44	$4,153,960.48	6.75
SW-C-B-FP-SW-C-O-FP	$3,504,174.16	$3,272,702.27	-6.61
SW-C-O-FP	$3,626,096.03	$3,402,556.54	-6.16
SW-C-B-F	$3,748,663.35	$3,536,214.24	-5.67
SW-C-C-B	$3,734,796.78	$3,882,138.35	3.95
SW-C-C-C	$4,471,244.89	$4,633,608.17	3.63
SW-C-B-SW-C-O	$3,723,025.68	$3,858,151.21	3.63
C-SW-F-SW	$4,575,597.72	$4,412,799.69	-3.56
SW-C-B-F-SW-C-O-F	$3,788,082.66	$3,669,947.52	-3.12
C-SW-F-C	$4,168,195.89	$4,273,772.56	2.53
SW-C	$4,854,480.70	$4,750,700.28	-2.14
SW-C-C	$4,584,248.84	$4,660,390.15	1.66
SW-C-B	$3,628,125.32	$3,681,382.16	1.47
SW-C-O-F	$3,835,717.87	$3,808,430.70	-0.71

Note: Rotations are ranked by the absolute percentage change of NPV between baseline and no yield adjustment scenarios.

The impact on expected NPVs by removing yield adjustment effects are mixed but relatively small, with percentage changes in NPV less than 10% for all rotations in three representative farms. First, removing the previous crop yield effect results in increased NPVs in canola-intensive rotations and diversified rotations with barley and oats. Increases in NPV for these rotations were attributed to exclusion of yield penalties from growing the same subsequent crop (C-C), crops in the same family (B-SW and O-SW), and cereals after oilseeds (C-B and C-O). These results were consistent with empirical evidence from MAFRD (2014) which suggested that relative yield performance of barley and oats after spring wheat yielded only 80% to 90% and growing cereal after oilseed resulted in yield loss of up to 10%.

Conversely, greater negative NPV changes are associated with more diversified rotations that included field peas. The NPV reduction is due to removal of the positive yield adjustment from field peas, reducing yields for subsequent crops in rotations (e.g. SW-C-B-FP and SW-C-O-FP). The base rotation and diversified rotation with flax (Saskatchewan only) also showed slight decreases in NPV. NPV reductions in the base rotation for all farms were due to exclusion of positive yield adjustment from wheat after canola. Moreover, NPV reduction in flax rotations were caused by absence of positive yield effect by growing flax after cereals (Flax Council of

Canada, 2019). As for changes in the NPV standard deviations, there is no consistent pattern found across farms.

5.4.2 Removing BRM Participation

The economic impact of alternative crop rotations under changing assumptions about business risk management (BRM) programs was examined. There are two stages being examined in terms of removing participation from BRM programs: no AgriStability and no BRMs at all. Percentage change of NPVs resulting from non-participation in the AgriStability and all BRM programs for each farm are provided in Tables 5.19 to 5.21. The numerical NPV results of alterative BRM scenarios are provided in Appendix F.

Table 5.19 Percentage change of NPVs relative to baseline results without AgriStability and all BRM payments, Camrose

Rotation	Baseline NPV	No AgriStability % Difference	No BRM % Difference
SW-C-C-C	$5,966,352.59	-4.25	-11.25
SW-C-C	$5,948,061.86	-4.04	-11.44
SW-C	$5,925,722.97	-3.83	-11.83
SW-C-C-B	$5,073,310.22	-2.95	-10.18
SW-C-C-O	$5,048,802.68	-4.65	-13.89
SW-C-B	$4,788,947.91	-2.89	-11.07
SW-C-B-SW-C-O	$4,740,001.69	-3.59	-12.52
SW-C-O-FP	$4,710,822.11	-5.54	-17.28
SW-C-B-FP-SW-C-O-FP	$4,689,902.03	-4.69	-15.43
SW-C-B-FP	$4,673,173.00	-3.83	-13.67

Note: Rotations are ranked by the baseline NPV in descending order.

Table 5.20 Percentage change of NPVs relative to baseline results without AgriStability and all BRM payments, Smoky River

Rotation	Baseline NPV	No AgriStability % Difference	No BRM % Difference
SW-C	$3,791,569.45	-2.72	-9.68
SW-C-B-FP	$3,611,352.57	-2.63	-11.55
SW-C-C	$3,587,673.86	-2.98	-9.20
SW-C-C-C	$3,496,852.93	-3.28	-9.13
SW-C-B-FP-SW-C-O-FP	$3,451,962.52	-3.00	-12.67
SW-C-O-FP	$3,404,593.21	-3.50	-14.23
SW-C-B	$3,267,802.13	-2.90	-11.45
SW-C-C-B	$3,242,159.04	-2.89	-10.47
SW-C-B-SW-C-O	$3,034,723.61	-3.33	-12.73
SW-C-C-O	$2,917,856.86	-3.94	-13.18

Note: Rotations are ranked by the baseline NPV in descending order.

Table 5.21 Percentage change of NPVs relative to baseline results without AgriStability and all BRM payments, Saskatchewan

Rotation	Baseline NPV	No AgriStability % Difference	No BRM % Difference
SW-C	$4,854,480.70	-7.41	-22.01
SW-C-C	$4,584,248.84	-6.99	-20.12
C-SW-F-SW	$4,575,597.72	-7.64	-23.61
SW-C-C-C	$4,471,244.89	-7.12	-19.43
C-SW-F-C	$4,168,195.89	-6.83	-20.53
SW-C-C-O	$3,891,173.44	-6.53	-20.19
SW-C-O-F	$3,835,717.87	-6.19	-21.09
SW-C-B-F-SW-C-O-F	$3,788,082.66	-6.47	-21.58
SW-C-B-F	$3,748,663.35	-6.91	-22.27
SW-C-C-B	$3,734,796.78	-7.50	-21.95
SW-C-B-SW-C-O	$3,723,025.68	-7.23	-22.85
SW-C-B	$3,628,125.32	-8.08	-24.31
SW-C-O-FP	$3,626,096.03	-8.05	-26.25
SW-C-B-FP-SW-C-O-FP	$3,504,079.20	-8.54	-27.49
SW-C-B-FP	$3,382,796.99	-9.48	-28.92

Note: Rotations are ranked by the baseline NPV in descending order.

As expected, a decrease in NPV is observed for all rotations in the both scenarios while the degree of impact varied among farms. Specifically, Alberta farms experienced relatively smaller changes in NPV than the Saskatchewan farm in either of two scenarios. The larger economic impact detected in Saskatchewan by opting out BRM programs is attributed to the greater variability in farm revenues. Greater revenue variability probably triggered more AgriStability and/or crop insurance payments in the Saskatchewan farm than for the Alberta farms. The variability in yields or prices themselves do not necessarily explain the impact of public support program payments since correlations between crop yields and prices may exert an effect on revenue variability.

Compared to the non-BRM scenario with crop insurance program only, the percentage NPV difference from non-participation in both BRM programs is larger in magnitude. This is not surprising given the degree of support provided by AgriStability. Moreover, greater NPV reductions were observed in Saskatchewan than for the two Alberta farms. Likewise, greater variability found in total revenues for Saskatchewan farm which likely contributed to triggering more BRM payments in protecting against price and production risk.

There are also variations in the percentages of NPV change across rotations for each farm. Two general patterns observed in Camrose while opting out of AgriStability are: 1) rotations with more canola tended to have a greater NPV reduction by removing AgriStability, and 2) rotations with barley had less reduction in NPV. Canola-intensive rotations were more significantly affected than more diversified rotation by removing the AgriStability since canola is a riskier crop. Further, rotations with barley are less affected as barley is the least risky crop in terms of price. Similar patterns are observed in Smoky River with the same reasons contributing to the pattern in NPV reductions. The only exception is SW-C-O-FP that has the greatest drop in NPV when AgriStability is removed. This is attributed to the higher yield risk associated with field peas. In Saskatchewan, greater reduction in NPV is associated with rotations with field peas and canola, whereas those with oats and barley are less affected. This is because field peas has higher risk in yields and canola has higher risk in price. Conversely, oats and barley are less risky in that respect.

There are also two patterns observed with respect to the expected NPV changes in Camrose and Smoky River when all BRM payments are removed. First, rotations with oats and/or field peas experienced bigger decreases in NPV whereas rotations with barley had smaller decrease in NPV.

Higher variabilities were found in oats and field peas yields in both farms, which make them more risky than other crops. Rotations with barley are the least risky again due to lower price variability. In Saskatchewan, the same pattern is observed for cases without AgriStability and BRM programs; field pea and canola rotations suffered more from removing partial or all BRM support and the opposite was true for barley and oat rotations. The same reasons as mentioned in the end of last paragraph are again applicable here.

Compared to the baseline scenario, Tables 5.22 to 5.24 indicated increase in NPV standard deviations in all rotations at each farm both in the no AgriStability and no BRM scenarios. This finding is consistent with the hypothesis that participation in AgriStability and/or BRM programs do contribute to lower risk. As discussed in Chapter 4, AgriStability and crop insurance provide protection on farm income and crop production, respectively based on all commodities. The increasing variability in farm income and crop production are indicated by higher NPV standard deviations.

Table 5.22 Percentage changes of NPV standard deviations relative to baseline results without AgriStability and all BRM payments, Camrose

Rotation	Baseline	No AgriStability % Difference	No BRM % Difference
SW-C-B	$722,486.93	0.56	5.59
SW-C-C-B	$659,203.17	0.54	5.10
SW-C-B-FP	$653,519.84	0.32	5.14
SW-C-C-C	$635,988.40	1.25	12.17
SW-C-C	$609,171.40	1.85	13.50
SW-C	$584,233.67	2.51	15.58
SW-C-B-FP-SW-C-O-FP	$554,606.67	0.34	10.11
SW-C-B-SW-C-O	$554,011.55	1.01	9.47
SW-C-O-FP	$552,180.66	1.24	13.59
SW-C-C-O	$550,720.62	1.74	13.28

Note: Rotations are ranked by the baseline NPV in descending order.

However, the degree of impact on expected NPV observed in case of no BRM is greater than in the case of no AgriStability. It is true in terms of the change in variances because more risk will be encountered in production if neither crop insurance nor AgriStability payment is available. Given the significant changes in expected returns and variances in the non-BRM scenario, there are greater incentives for producers to participate in business risk management programs to protect against economic losses resulted from production risk, no matter which cropping system is adopted. The numerical NPV standard deviation results of alterative BRM scenarios are provided in Appendix F.

Table 5.23 Percentage changes of NPV standard deviations relative to baseline results without AgriStability and all BRM payments, Smoky River

Rotation	Baseline	No AgriStability % Difference	No BRM % Difference
SW-C-C-C	$345,753.32	4.10	14.43
SW-C	$339,026.29	2.77	16.01
SW-C-C	$335,724.25	3.63	14.69
SW-C-O-FP	$335,654.44	2.45	13.49
SW-C-B-FP	$319,200.25	2.56	14.37
SW-C-B-FP-SW-C-O-FP	$315,349.73	2.34	14.98
SW-C-B	$305,874.32	1.90	14.61
SW-C-C-O	$303,996.66	3.98	15.34
SW-C-C-B	$299,713.97	3.25	15.11
SW-C-B-SW-C-O	$292,953.85	2.27	15.81

Note: Rotations are ranked by the baseline NPV in descending order.

Table 5.24 Percentage changes of NPV standard deviations relative to baseline results without AgriStability and all BRM payments, Saskatchewan

Rotation	Baseline	No AgriStability % Difference	No BRM % Difference
SW-C	$617,366.42	3.90	17.43
C-SW-F-SW	$588,120.15	3.54	17.89
SW-C-C	$573,209.72	4.80	17.42
SW-C-C-C	$567,281.30	4.85	17.25
C-SW-F-C	$520,777.19	3.23	16.63
SW-C-B-FP	$493,920.53	4.07	16.21
SW-C-B	$491,878.27	4.59	16.91
SW-C-O-FP	$489,988.14	3.35	15.38
SW-C-B-FP-SW-C-O-FP	$488,754.05	3.57	15.72
SW-C-C-B	$486,810.81	5.28	17.31
SW-C-C-O	$479,037.82	4.37	16.47
SW-C-B-SW-C-O	$478,886.99	4.30	16.62
SW-C-B-F	$464,632.08	4.70	17.72
SW-C-B-F-SW-C-O-F	$456,623.88	4.34	17.39
SW-C-O-F	$452,907.50	4.34	17.58

Note: Rotations are ranked by the baseline NPV in descending order.

5.5 Results of Risk Efficiency (SERF)[31] *Analyses*

Simulated net present value distributions for each rotation with 5000 iterations were exported from @RISK and then used in SERF analysis to rank cropping systems over a range of absolute risk aversion coefficients (1.0^{7} to 8.0^{-7})[32]. The SERF results of the baseline scenario along with results from alternative scenarios are presented and interpreted in this section. The section is divided into four sub-sections with each describing the baseline results and the results of three sensitivity parameters being manipulated in farm models.

5.5.1 Baseline Scenario

The baseline scenario models include yield adjustment effects and full participation in BRM programs. Figure 5.2 shows the SERF result for all cropping systems in Camrose. The dots represent CE values obtained at the corresponding level of risk aversion. Three subgroups formed in the plot with more specialized rotations are the most risk efficient, followed by diversified rotations with barley and oats, and even more diversified rotations with field peas. Within each subgroup, the annual RP required to adopt a less preferred rotation within the group was extremely small with a value less than \$1 on a per acre basis. However, larger gaps resulted across subgroups. Specifically, the annualized[33] risk premium[34] required by producers to diversify more specialized rotations ranged from \$4 to a maximum of \$35 over the pre-defined range of risk aversion coefficients in Camrose. Therefore, producers are less likely to diversify rotations as more risk premium would be required to perform the action.

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[31] Crops in SERF graphs included spring wheat, barley, canola, oats, field peas and flax are abbreviated as SW, C, B, O, FP and F, respectively as shown in the legend. These are applied consistently through all of section 5.5.

[32] This range of absolute risk aversion is roughly applied to all three farms. The specific range for each farm is provided in section 5.4.1.

[33] CE terms (wealth) are converted to annualized values by multiplying by the discount rate (0.1). This computation allows more direct comparison between individual rotations in terms of risk efficiency for each farm and it is applied to discussions in this chapter.

[34] The risk premiums presented and discussed in this chapter are on a "per acre" basis, which is calculated by dividing the annualized values by the size of representative farm.

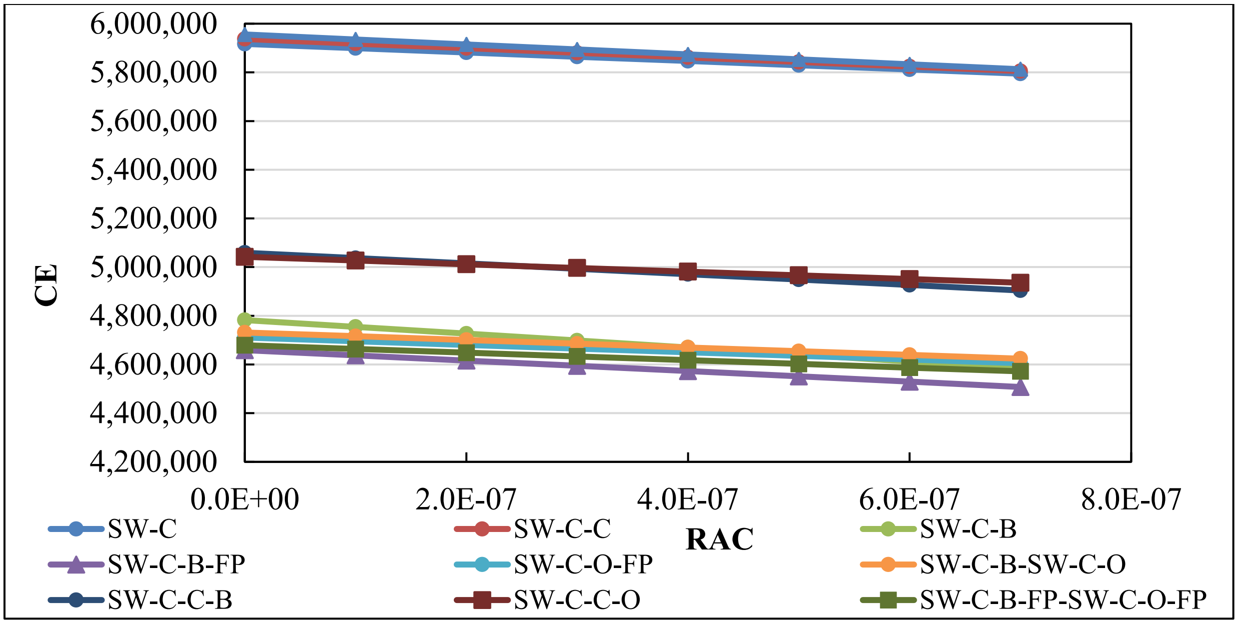

Figure 5.2 Baseline SERF results for ten rotations over the absolute risk aversion range of 0.0 – 8.0E-7, Camrose

On the other hand, although preferences suggested by SERF analysis are well matched to the pattern of expected returns, it did not necessarily follow the standard deviation pattern. For example, producers would rather prefer a rotation that offers greater profitability with moderate risk (SW-C-C-C) than a less risky rotation that offers lower returns (SW-C-C-O).

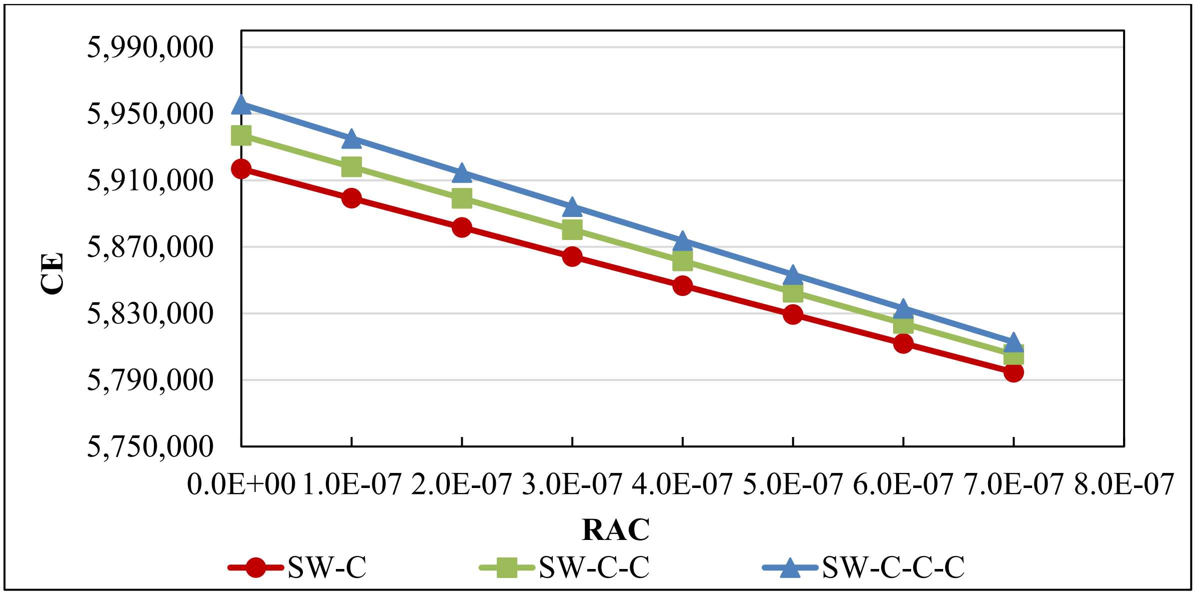

Figure 5.3 Top three risk efficient rotations over the absolute risk aversion range of 0.0 – 8.0E-7 in baseline scenario, Camrose

In Figure 5.3, rotation SW-C-C-C (blue curve) is the risk efficient set resulting for Camrose. It slightly dominated the other two rotations and the RP required to adopt less efficient rotations was small (less than $1) and relatively constant at all levels of risk aversion. It indicated that producers would be relatively indifferent between the three canola-intensive rotations.

Figure 5.4 provided baseline SERF results for the Smoky River farm. Less clustering was found in CE curves in comparison to Camrose, while risk efficiency of rotations was still consistent with the NPV ranking. More specialized rotations and field pea rotations were more risk efficient than other diversified rotations with oats and barley. Accordingly, RPs resulting between rotations in Smoky River were more of a mixture but increased as compared to Camrose, which meant a greater penalty resulting from adopting a less risk efficient rotation.

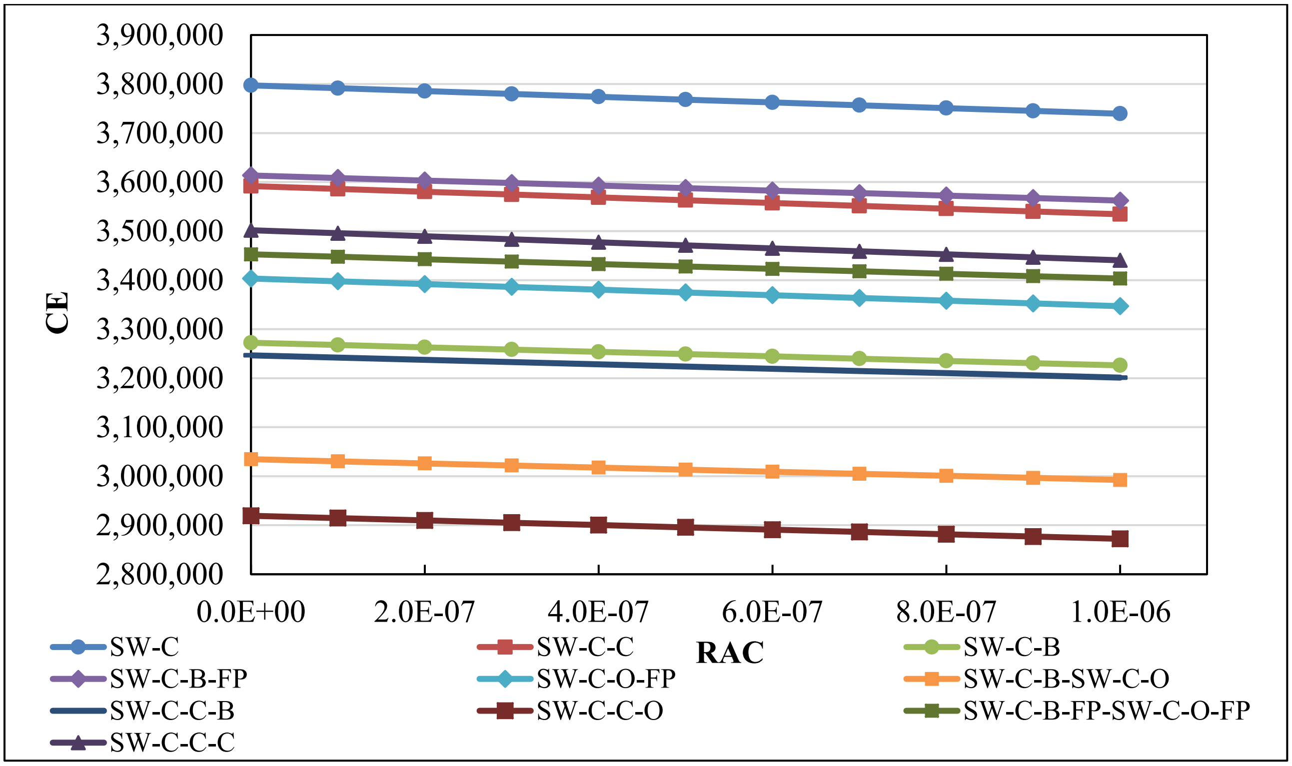

Figure 5.4 Baseline SERF results for ten rotations over the absolute risk aversion range of 0.0 – 1.1E-6, Smoky River

For the Saskatchewan farm, more specialized rotations along with rotations diversified with flax only were more risk efficient than diversified rotations that included oats, barley and field peas. The RP required to specialize the base rotation and/or diversify with flax was approximately $9, and penalties would increase significantly to further diversify the risk efficient rotation. Moreover, producers are likely to be relatively indifferent between diversified rotations of barley and oats as indicated by the relatively small and constant RPs in Figure 5.5.

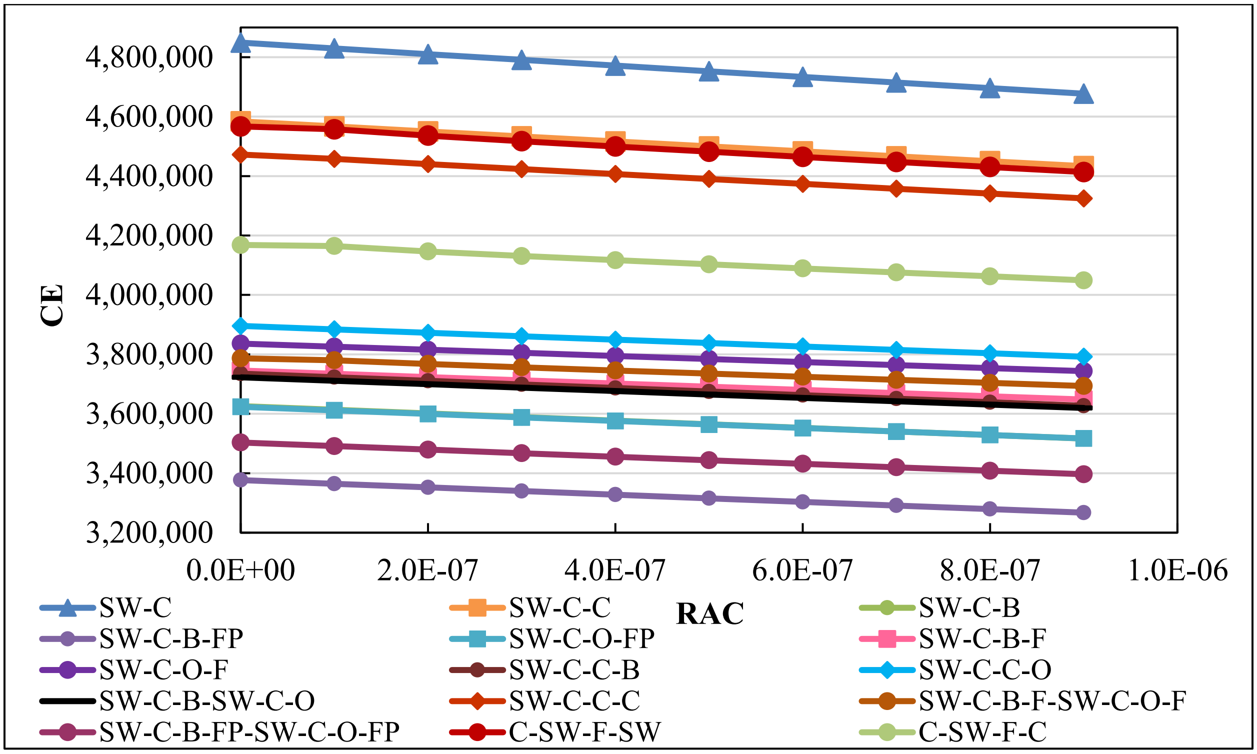

Figure 5.5 Baseline SERF results for fifteen rotations over the absolute risk aversion range of 0.0 – 1.0E-6, Saskatchewan

The efficient sets for the Smoky River and Saskatchewan farms were different from Camrose as presented below in Figures 5.6 and 5.7. Specifically, the efficient sets contain only the base rotation SW-C. Different from Camrose, there are some diversified rotations in Smoky River and Saskatchewan that are close to be risk efficient that included SW-C-B-FP and SW-C-C in Smoky River, and SW-C-C and SW-C-F-W in Saskatchewan.

Therefore, compensation is provided to producers to diversify or specialize rotations as opposed to Camrose, where an RP is required to de-specialize rotation. According to graphs, the RP required to switch from the risk efficient set to the less preferred rotation has increased significantly from $1 for Camrose to approximately $10 for Smoky River and Saskatchewan. Below the efficient set, nonetheless, RPs remained small between two less efficient rotations with approximately $1. These results were partially explained by the high profitability of canola that increased the risk efficiency advantage of more specialized rotations.

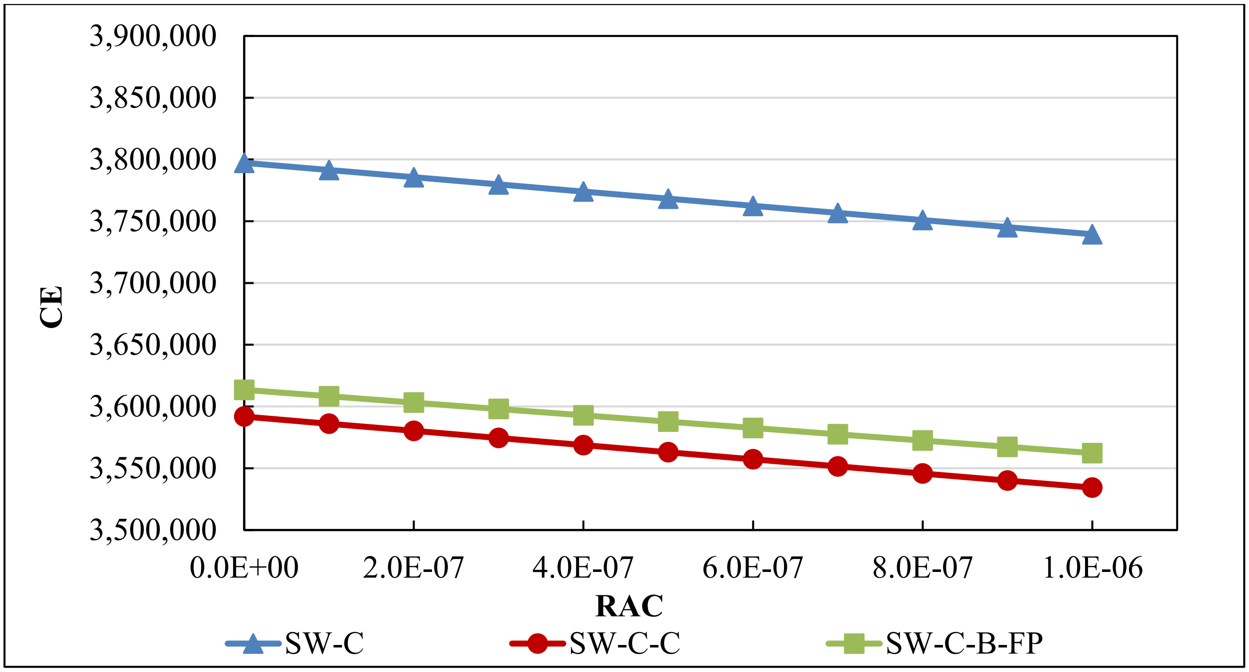

Figure 5.6 Top three risk efficient rotations over the absolute risk aversion range of 0.0 – 1.1E-6 in baseline scenario, Smoky River

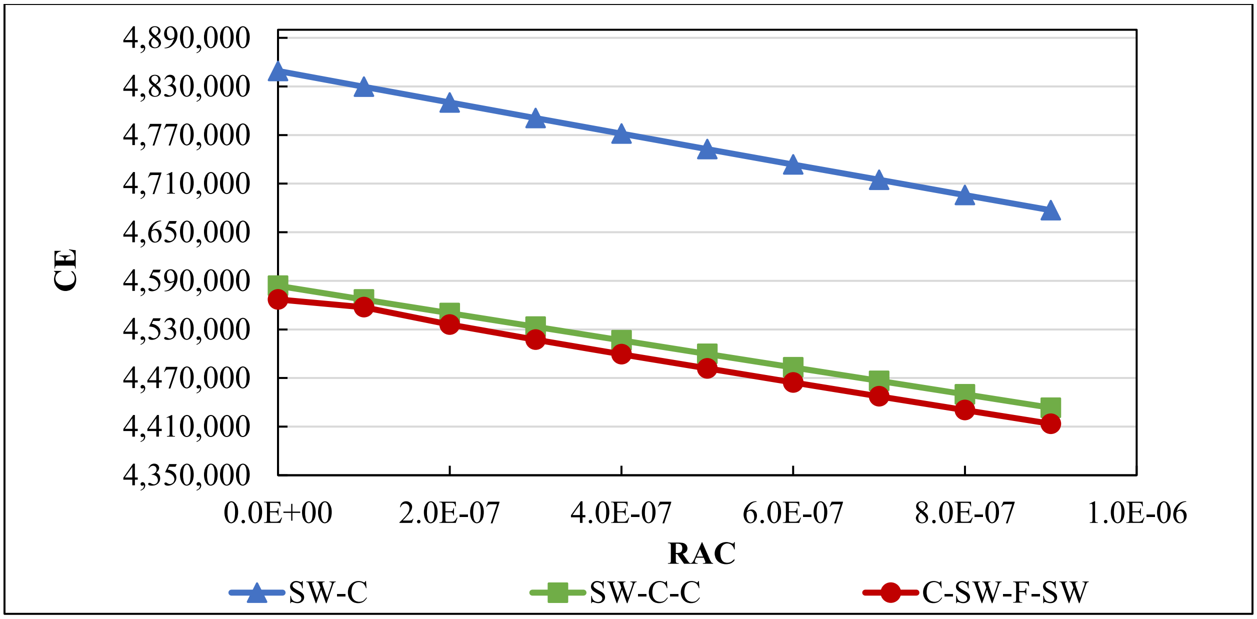

Figure 5.7 Top four risk efficient rotations over the absolute risk aversion range of 0.0 – 1.0E-6 in baseline scenario, Saskatchewan

5.5.2 No Yield Adjustment

CE graphs assuming no yield adjustments for the three farms are presented in Appendix G. Overall, the exclusion of yield adjustment effects from previous crops had no impact on producer preferences for the rotations. As indicated by lower CE values, wealth was decreased in more diversified rotations with field peas, flax (Saskatchewan only), as well as for the base rotation. Wealth reduction of certain rotations was attributed to removal of positive yield adjustment effects from previous crop such as field peas.

Another difference to be noted was that removing yield adjustments resulted in canola-intensive rotations in Smoky River and Saskatchewan being more risk efficient than diversified field pea rotations. This is due to the absence of yield penalties imposed on rotations with two or more consecutive years of canola. Furthermore, smaller RPs were required in Camrose and Saskatchewan to adopt more diversified rotations than for Smoky River. Figures 5.8 to 5.10 provide the top three rotations in risk efficiency terms, assuming no yield adjustments in each farm.

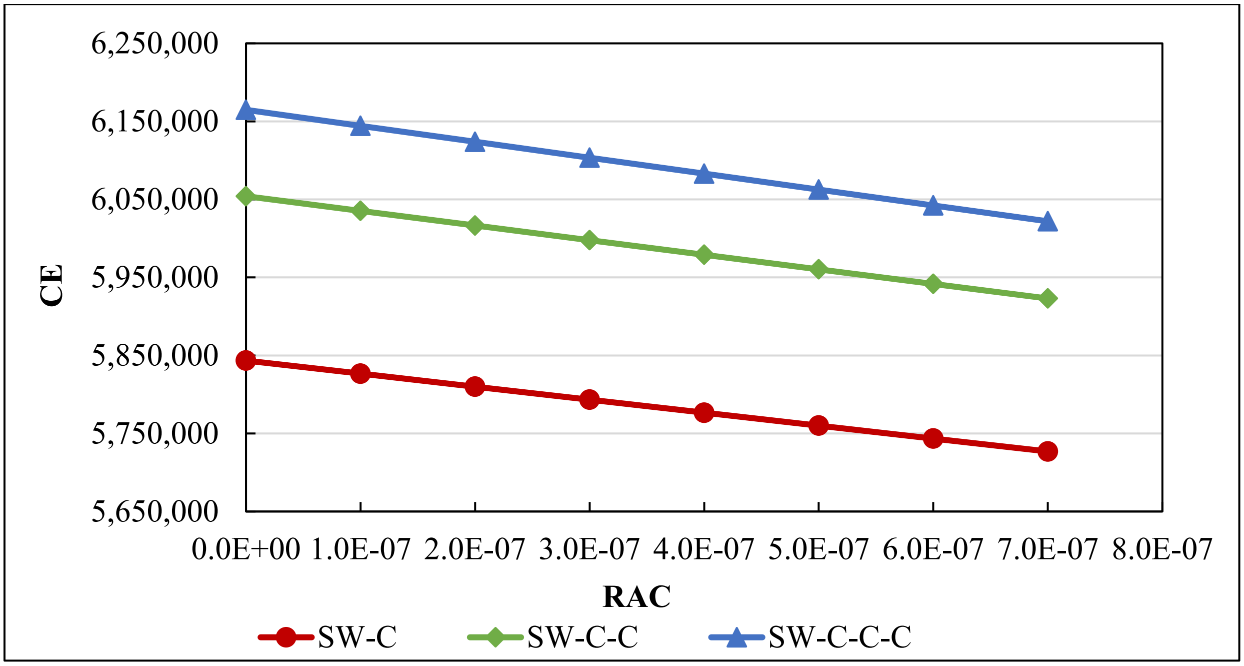

Figure 5.8 Top three risk efficient rotations without yield adjustment over the absolute risk aversion range of 0.0 – 8.0E-7, Camrose

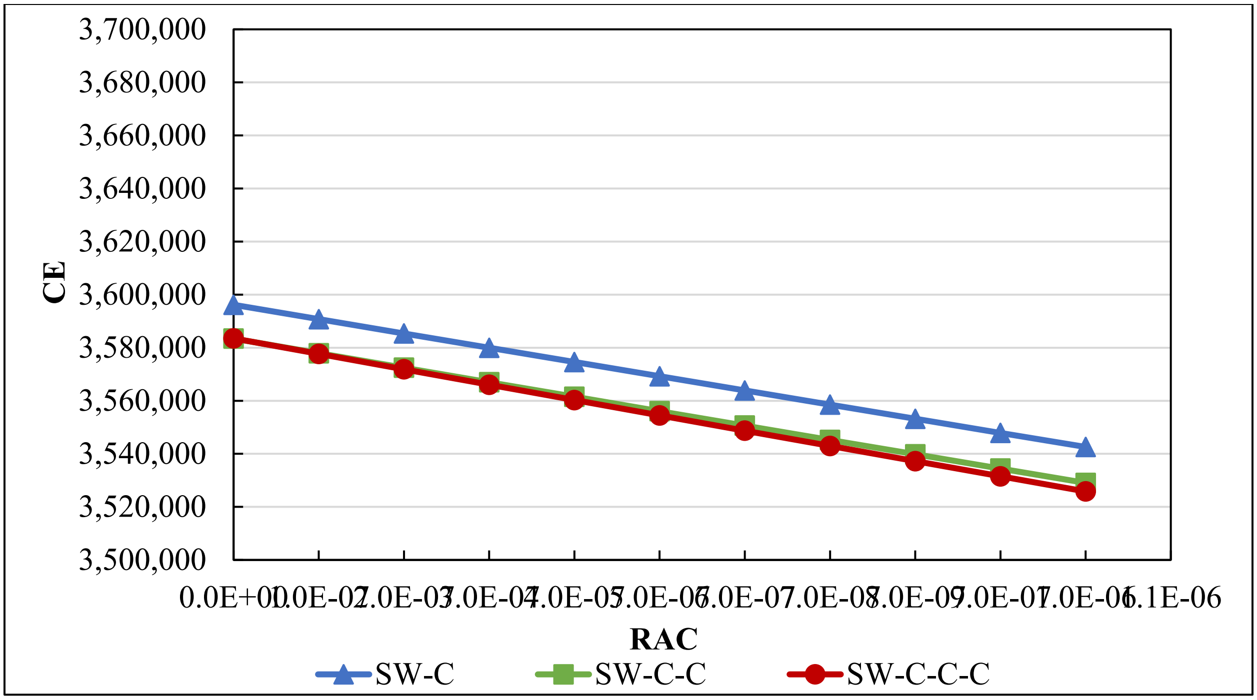

Figure 5.9 Top three risk efficient rotations without yield adjustment over the absolute risk aversion range of 0.0 – 1.1E-6, Smoky River

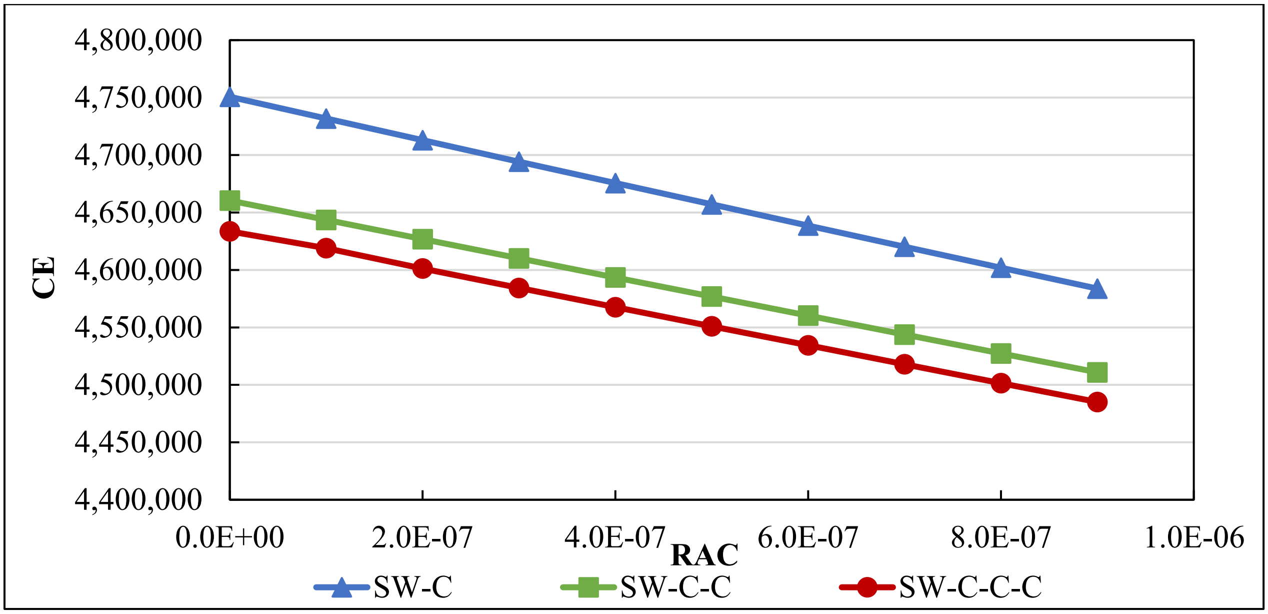

Figure 5.10 Top three risk efficient rotations without yield adjustment over the absolute risk aversion range of 0.0 – 1.0E -6, Saskatchewan

The efficient set remained the same as for the baseline model, while other two rotations that are close to being risk efficient have changed to all canola intensive rotations, especially for Smoky River and Saskatchewan. Compared to the baseline scenario, a greater RP was required to move to more diversified rotations in Camrose (from $0.50 to $4 or more as crop diversity increased). Conversely, a smaller RP was associated with further intensifying the base rotation with canola; values dropped from $10 to $0.76 in Smoky River and $3 in Saskatchewan. Although the RP shifted in opposite ways due to the different risk efficient set across farms, the pattern still suggested that rotation specialization is more viable than diversification.

5.5.3 No AgriStability

Similar to discussion in section 5.4.1, risk efficiency ranking of rotations in the model without AgriStability payments followed the corresponding simulated NPV results and was consistent with the baseline model except for a parallel downward shift in CE levels. This is expected as wealth would decrease due to economic losses from opting out of the AgriStability program. The resulting RPs between alternative rotations were also similar to the baseline scenario of each farm which is presented in Appendix G. Overall, no changes were found in the risk efficient set for farms in the non-AgriStability scenario (Figures 5.11 to 5.13) as compared to the baseline analysis.

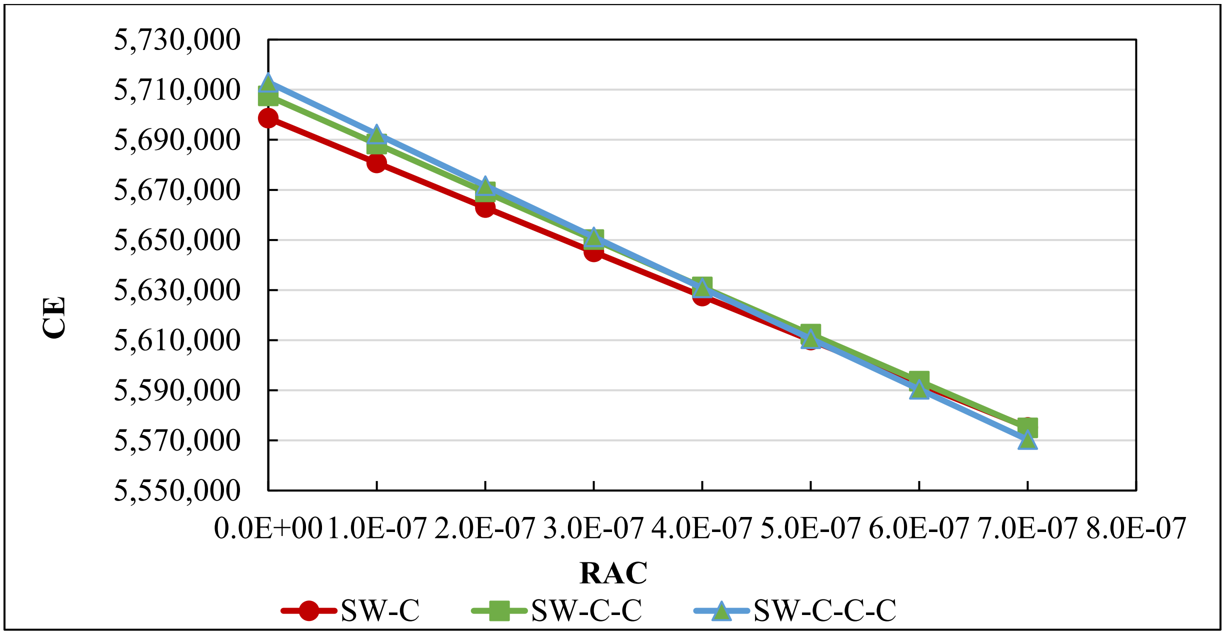

Figure 5.11 Top three risk efficient rotations without AgriStability over the absolute risk aversion range of 0.0 – 8.0E-7, Camrose

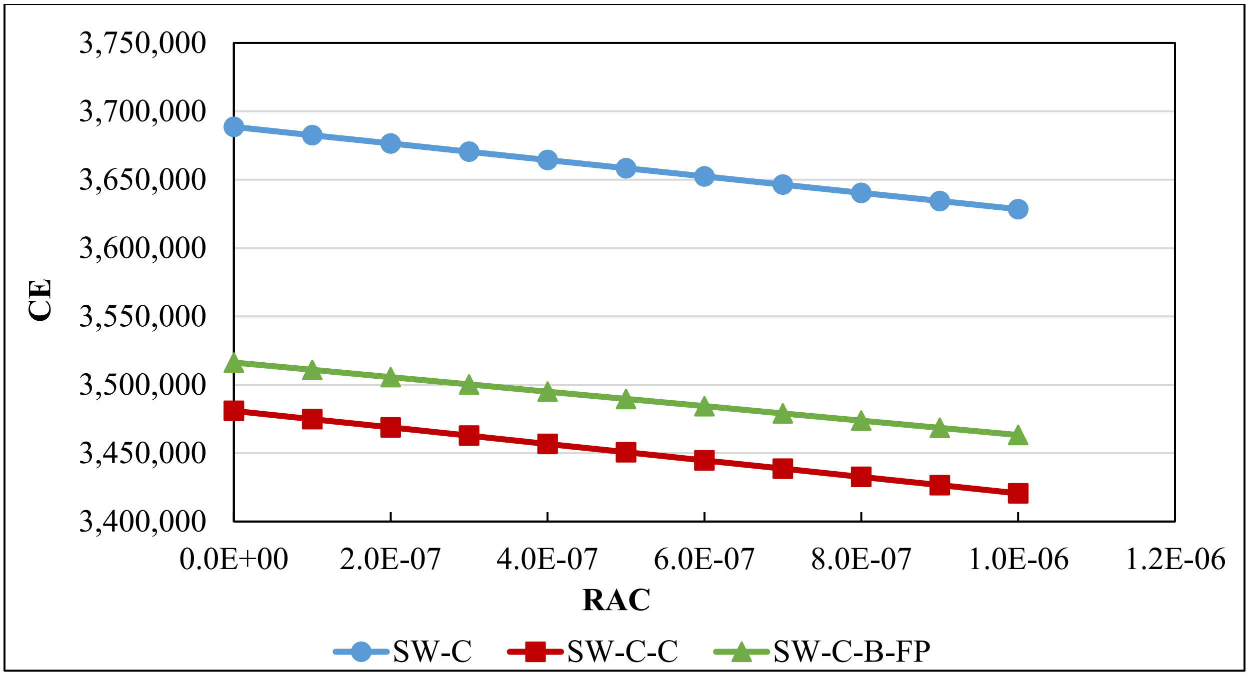

Figure 5.12 Top three risk efficient rotations without AgriStability over the absolute risk aversion range of 0.0 – 1.1E-6, Smoky River

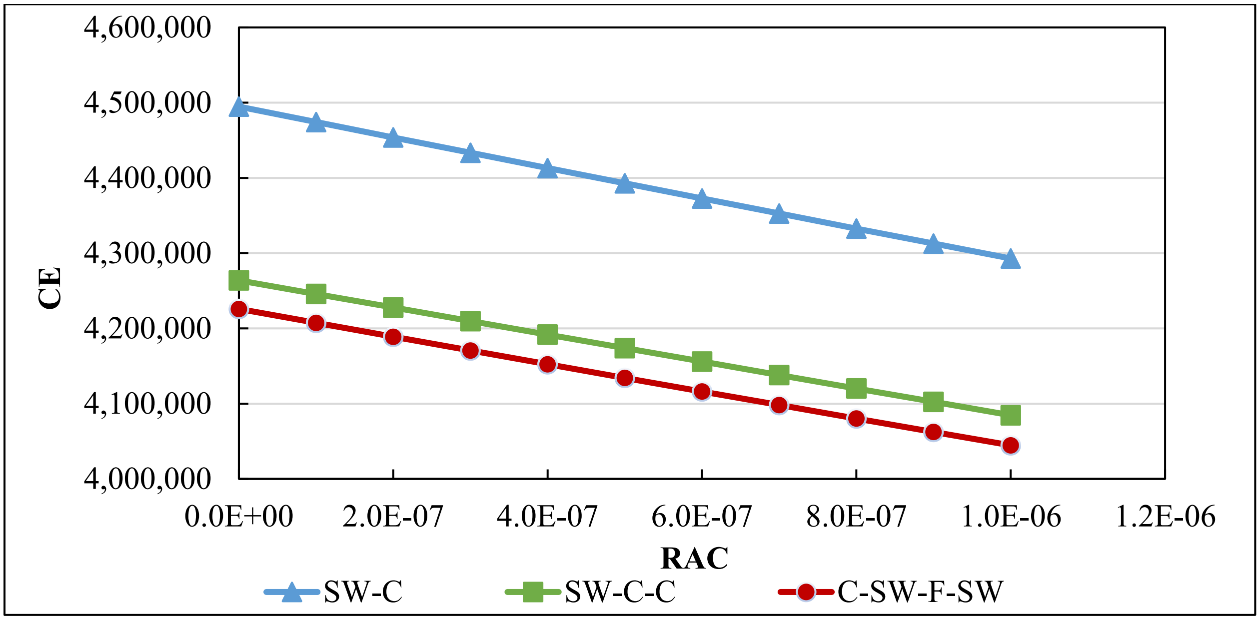

Figure 5.13 Top three risk efficient rotations without AgriStability over the absolute risk aversion range of 0.0 – 1.0E-6, Saskatchewan

The vertical distances between CE curves of three rotations are identical to the baseline model for all farms, with smaller RPs required for diversification in Camrose and higher RPs for specialization in Smoky River and Saskatchewan. Overall, no changes have been made to the efficient set by withdrawing from the AgriStability program, but the expected returns of all rotations are significantly decreased.

5.5.4 No BRM Programs

The exact same risk efficiency pattern was found for rotations in the non-BRM scenario except that a greater CE reduction resulted for all rotations in three farms as presented in Appendix G. More wealth reduction of rotations is expected as there were no BRM payments contributing to the farm wealth. Figures 5.14 to 5.16 provide the top three rotations in each farm with no changes in the efficient set.

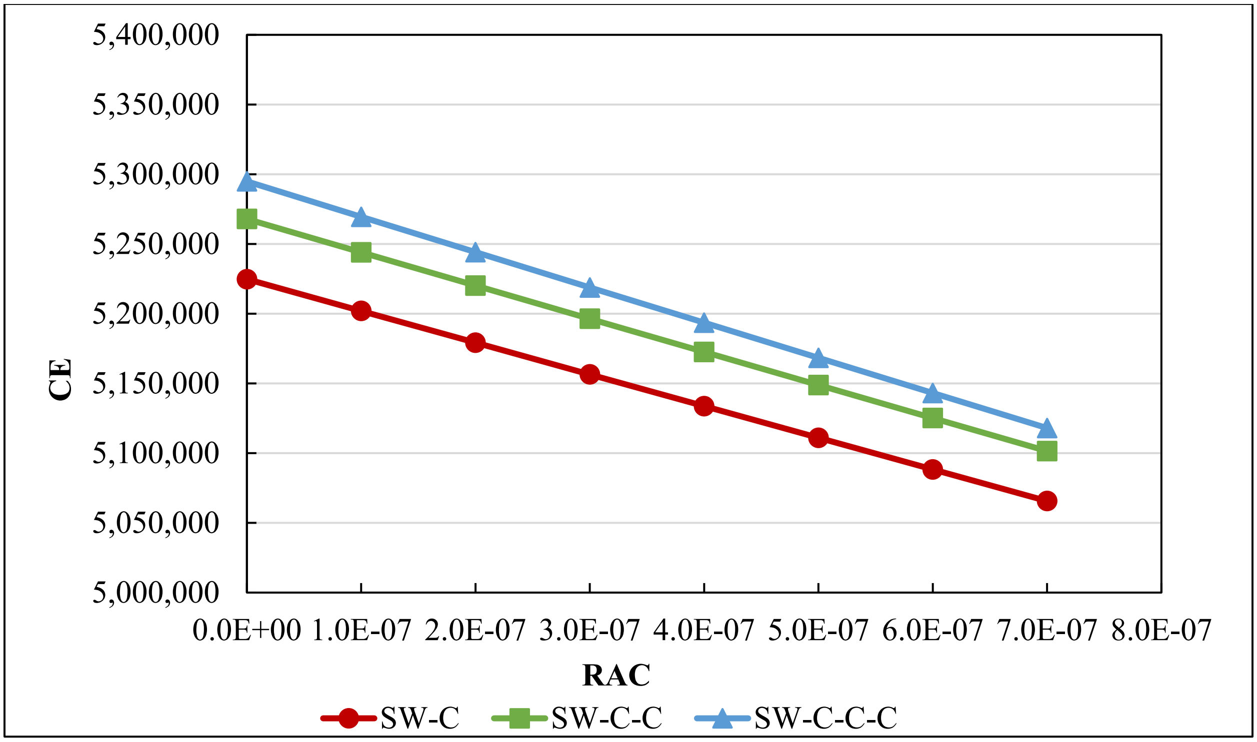

Figure 5.14 Top three risk efficient rotations without BRM over the absolute risk aversion range of 0.0 – 8.0E-7, Camrose

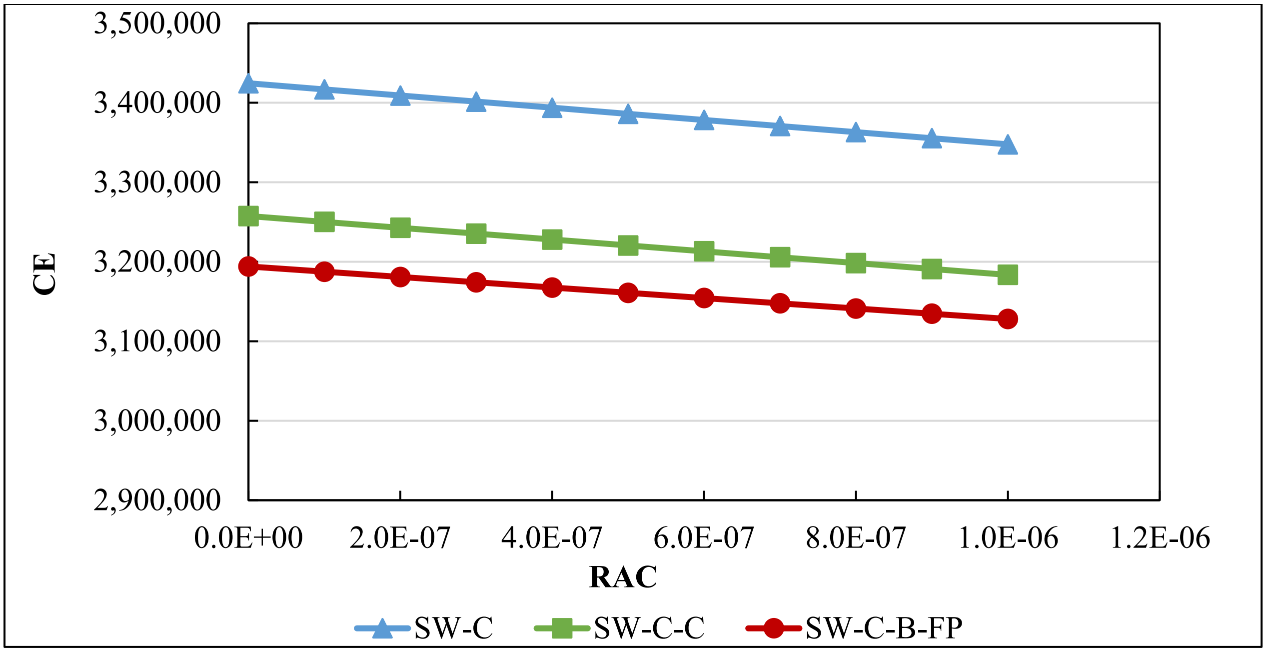

Figure 5.15 Top three risk efficient rotations without BRM over the absolute risk aversion range of 0.0 – 1.1E-6, Smoky River

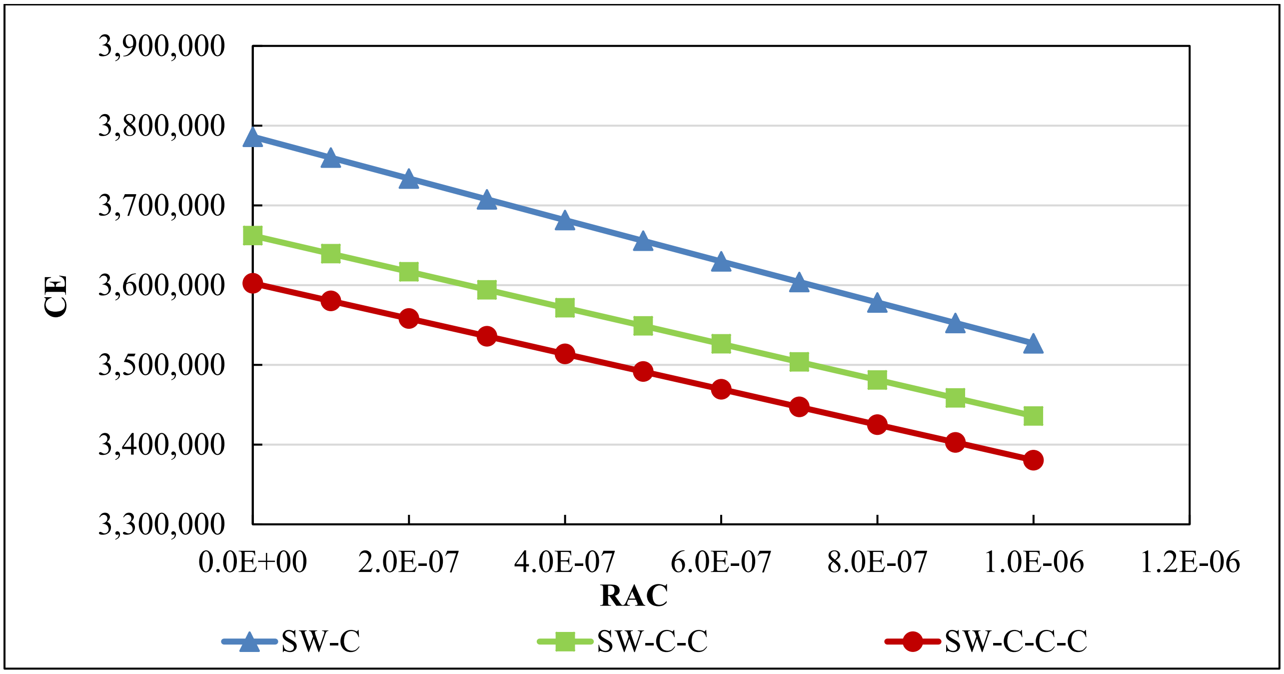

Figure 5.16 Top three risk efficient rotations without BRM over the absolute risk aversion range of 0.0 – 1.0E-6, Saskatchewan

RPs resulting between the risk efficient rotation and the two rotations that are close to being risk efficient were consistent with the baseline SERF results. This was true across all three farms. Comparing the non-AgriStability and non-BRM scenarios, CE values decreased more significantly for rotations in the latter scenario, but there was little difference in the RP from choosing the most efficient versus other more efficient rotations. Therefore, rotation specialization is still more preferred than diversification by producers when not participating in BRM programs.

5.6 Chapter Summary

The chapter presents the empirical results for the baseline scenario as well as several modified scenarios. In this study, three important variables were analyzed, including yield adjustment effect, no AgriStability, and no BRM. Results of risk efficiency analysis for baseline and different scenarios are also presented in the chapter.

The simulation results suggest that canola intensive rotations are more economically profitable than diversified rotations for representative farms in both baseline and alternative scenarios. The production risk, measured by standard deviations of NPV, is accordingly greater for rotations with canola intensification. Results with modified model conditions demonstrate significant negative impact on farm wealth and variabilities that were brought by opting out of AgriStability or all BRM programs (i.e., crop insurance and AgriStability). The degree of impact is greater in case of fully withdrawing from BRM programs relative to partial withdrawal. When yield adjustment is removed, the economic impact is relatively small in comparison to the BRM modified scenarios. Expected returns of rotations with field peas are adversely affected by the removal of yield adjustment due to yield loss from subsequent crops of field peas. Conversely, a moderate increase in NPV is shown in canola intensive rotations since the negative yield effect of crop grown on the same stubble is removed.

Regarding the SERF results, the same efficient set is generated for each farm in the baseline and various alternative scenarios. The results indicate positive yield adjustment effects and BRM programs contributed positively to the wealth of crop farms, the latter also mitigated risks associate with cropping decisions. There are few changes observed in terms of the optimal cropping decision either with and without BRM programs. Canola intensive rotations are preferred to diversified rotations by producers in almost all cases. This preference is not necessarily influenced by the changing assumptions in the model. The only impact is that BRM programs improved the returns of every rotation regardless of the associated level of risk.

CHAPTER 6: Summary and Conclusions

Cropping decisions have affected crop farmers from across Western Canada in many ways, either regarding the farm-level economic impacts or the health of the production system. Adoption of rotations of wheat and canola is profitable in the short-term, especially when canola is grown intensively as it is a high-value crop. Although short specialized rotations are currently profitable, the lack of diversification in cropping systems can cause many unintended consequences such as increase in crop disease, weeds, pests, increasing risk in profitability and moreover, reduce yield and profitability in the long-term. Moreover, patterns in the historical cropping activities showed an increasing intensity of canola production over time, that further resulting in less diversified rotations on the individual farm basis. However, there is a lack of knowledge about the economics of various cropping systems, especially at the farm-level.

To fill this information gap, a farm-level economic analysis was conducted to evaluate costs and benefits associated with a group of crop rotations for three representative farms of Western Canada. In particular, a representative farm analysis was conducted to examine costs and benefits of more specialized and/or more diversified rotations. A related objective was to examine the risk efficiency of these crop rotations through an assessment of the potential distribution of net returns. This study uses two locations in Alberta; Camrose County, located in the Black soil zone, and the M.D. of Smoky River which is located Dark Gray soil zone. A representative farm defined using four Black soil zone rural municipalities (St. Peter, Leroy, Spalding, Lakeside) in Saskatchewan is also used. These areas were chosen due to the significance of cropping agriculture and the suitability for agriculture, especially commercial crop production. The size of representative farms, crops, and crop rotations are determined based on agricultural census data combined with expert opinion.

Historical crop yield and price data and other cropping farm data (e.g., cropping costs) were collected and used in developing the Monte Carlo simulation model. Yields and prices were modeled stochastically to incorporate risk in the simulation analysis. The representative farms were assumed to participate in the AgriInsurance and AgriStability BRM programs. The impact of the crop grown in the previous year on yields in the current year was also incorporated, based on data from AFSC. Net present value (NPV) in perpetuity was calculated as a proxy for wealth, to measure the economic performance of the individual cropping system by simulating the model over twenty years period. The study compared economic performances using NPV analysis of the representative farms with and without consideration of BRM programs or yield adjustment effect from previous crops.

This chapter provides a summary of key findings from the analysis and implications for cropping operations in Alberta and southern Saskatchewan. Conclusions drawn from the study are discussed next. Finally, a brief discussion of limitations in the study and areas for future research are also presented.

6.1 Summary of Key Findings

Three farms were modeled to simulate representative crop production in Alberta and Saskatchewan specifically focused on the Black and Dark Gray soil zones. The same base rotation was defined for each of the three representative farms: spring wheat – canola (SW-C). Barley, oats, field peas, and flax were included in alternative rotations to increase the degree of crop diversification relative to the base rotation. As well, rotations with increased frequency of canola were also modeled. Results of the base rotation were obtained and compared between farms. Baseline results of all rotations with full participation in BRM programs were obtained for each farm and further compared to scenarios with modified assumptions in terms of BRM participation and yield adjustment effects.

The expected wealth associated with the base rotation was approximately \$2314.74, \$1974.78, and \$1896.28 per acre for farms in the Black and Dark Gray soil zone of Alberta, and in the Black soil zone of Saskatchewan, respectively. The difference in expected wealth between representative farms was attributed to the lower modeled canola yield, which affected the production of canola in this case.

Compared across rotations for the three representative farms, baseline results suggested higher wealth was associated with more specialized (i.e., canola-intensive) rotations relative to the base rotation, while expected wealth was lower for rotations with greater crop diversity. However, the increasing wealth was not necessarily associated with increasing canola intensity in rotations, especially in Smoky River and Saskatchewan. This was due to the fact that less wealth was generated as historically lower canola yields are modeled for these two farms relative to Camrose.

Table 6.1 provides simulation results for the baseline scenario modeled for each representative farm. Specifically, the range of NPV changes of alternative rotations to the base rotation are presented. These NPV changes are annualized and converted to a per acre basis for ease of interpretation. Results in Table 6.1 showed that in comparison to the base rotation, the range and variation of NPV changes of more specialized rotations were smaller than more diversified rotations. The upper and lower bounds of annualized NPV per acre difference in Camrose was approximately \$0.9 to \$1.6, which was the smallest across all farms. Additionally, Camrose was the only farm observed with positive NPV change as canola intensified in base rotation; that is, increasing canola intensity of base rotation increased farm wealth. The positive wealth contribution in Camrose was attributed to higher modeled canola yield that allowed higher revenue to be generated from canola intensification. In Smoky River and Saskatchewan, wealth of rotation decreased as canola intensity increased in the base rotation. The resulted ranges of NPV change were similar between two farms with values ranged from \$11 to \$15 per acre annually.

Table 6.1 Annualized NPV changes resulted in the baseline scenario (\$/acre)

	Camrose	**Smoky River**	**Saskatchewan**
Base Rotation	\$2,314.74	\$1974.78	\$1896.28
Annualized NPV	\$231.47	\$197.48	\$189.63
Range[a] of annualized per acre NPV change for more specialized rotation	\$0.87 - \$1.59	(\$10.62 - \$15.35)	(\$10.56 - \$14.97)
Range of annualized per acre NPV change for more diversified rotations	(\$34.25) – (\$48.93)	(\$9.39) – (\$45.51)	(\$10.89) – (\$57.49)

Note: Brackets indicate negative changes.

[a] The range of NPV changes is obtained by calculating the annualized per acre NPV difference of each alternative crop rotations relative to the base rotation in the baseline scenario, and used the minimum and maximum values as lower and upper bounds.

Conversely, the range of NPV changes of more diversified rotations varied significantly both internal to and across farms, and all expected changes relative to the base rotation were negative.

Likewise, the smallest variation was observed in Camrose with expected annualized change per acre between diversified and the base rotations ranging between $34 and $49. Slightly bigger intervals were obtained for Smoky River and Saskatchewan, with annualized changes varying from $9 to $46 and $11 to $57, respectively. With similar upper bounds (approximately $50) across farms, smaller values were resulted in lower bounds for Smoky River and Saskatchewan (both at $10) relative to Camrose ($34.25). The small range of expected annualized changes obtained for Camrose was due to the fact that modeled canola yield was in similar in magnitude to other crops in the farm. Therefore, wealth of rotations did not vary significantly as the level of crop diversity changed from base rotation. Conversely, greater differences were found between modeled yields of canola and diversified crops in other two farms. Hence, a larger wealth gap resulted when rotations were diversified. Moreover, this gap widened if yields of crops added to the base rotation were significantly different from canola (e.g. field peas and barley).

Variability of net returns resulted for the baseline copping systems were not entirely consistent with the general expectation noted in Chapter 5 that rotations with higher net returns also have greater variability. In fact, patterns of net return variability differed across farms. For the Camrose farm, higher variability was found in rotations that included barley. Conversely, canola intensive rotations were found to have the greatest variability for Smoky River and Saskatchewan farms. A relative consistent pattern across farms was that rotations with oats generally had lower variability compared to rotations with field peas. It indicated growing field peas to diversify rotations is more risker than oats on both Black and Dark Gray soil zones. Another pattern specific to the Saskatchewan farm was higher variability associated with rotations that included flax. This was caused by greater variability in simulated flax prices. Although there is no absolute consistency in the pattern of net return variability, it cannot be denied that in general variability decreased as cropping rotations became more diversified. In other words, more specialized/canola-intensive rotations are riskier than more diversified rotations in each farm.

Risk efficiency analysis was implemented to evaluate returns and risk of cropping systems for each representative farm to determine the risk efficient cropping rotations for producers, by incorporating the risk attitudes. Baseline SERF results suggested the most risk efficient cropping system in Camrose was SW-C-C-C, and SW-C for Smoky River and Saskatchewan. The vertical distance between CE values, or risk premiums received by producers to adopt more diversified crop rotations were approximately $34, $2.30, and $11 in Camrose, Smoky River and Saskatchewan, respectively, for the baseline scenario. Thus, more specialized rotations are preferred over more diversified rotations as producers' risk aversions are taken into consideration.

Alternative scenarios were also simulated to examine whether the pattern of results changed with model parameters. Additional models tested in the study included those of no yield adjustments, no AgriStability and no BRM programs. In the case of removing yield adjustments, no significant changes were observed in the rotation ranking based on NPV results. However, in comparison to diversified rotations, a bigger range of changes were found in expected returns of more specialized rotations within farms when yield adjustments are disregarded, as the wealth associated with canola intensive rotations were increased due to absence of negative yield effect from canola after canola, relative to the baseline model.

Similarly, rotation rankings remained the same across all three farms for both the non-AgriStability and non-BRM scenarios. An obvious change was that all crop rotations had lower net returns in both cases without BRM coverages. Concerning the variability of net returns in alternative scenarios, removal of BRM program participation significantly increased the level of variability for crop rotations. This shows wealth associated with the different rotations is sensitive to both changes in BRM program participation and yield adjustment effect, whereas the variability of net returns is only sensitive to changes in BRM program participation.

Changes to model parameter assumptions did not affect the risk efficient set for the representative farms. However, the CE levels and the risk premiums for producers to adopt more diversified rotations (i.e., the vertical distance between CE values) did change. First, lower CE values were resulted in all rotations by taking out BRM programs regardless of the level of crop diversity. Risk premiums of adopting more diversified rotations decreased gradually when AgriStability and/or all BRM programs are removed from models. Specifically, RMs resulted in the non-AgriStability scenario reduced to $30 in Camrose, $1.4 in Smoky River and $10 in SK.

Further, risk premiums required to adopt more diversified rotations were even lower in the non-BRM scenario with $27 in Camrose, $1.2 in Smoky River and $4.5 in Saskatchewan.
Lastly, sensitivity analysis was conducted for several key parameters associated with the representative farm model. This included the starting crop prices for price equations, discount rate and time horizon. Although these sensitivity analysis scenarios caused the numerical simulation results to change for rotations, they did not affect the overall rotation ranking in terms of the economic performance.

6.2 Main Conclusions and Implications

The research was aimed to evaluate the long-term benefits, costs and risk of adopting cropping systems with different rotation length and diversity of crops, as well as participation in business risk management programs by Alberta and southern Saskatchewan crop producers.

The study results confirm the economic viability of more specialized crop production in the Canadian Prairie region. While there are agronomic benefits associated with greater diversity in rotations, the short-term economic benefits associated with specialization outweigh the costs. The impact of increasing canola intensity over and above the level in the base rotation was mixed, while consistently outperforming more diversified rotations. Additionally, the variability in wealth generally followed the expected pattern of decreasing variability with increasing diversification.

The study also confirms the existence of unintended consequences associated with the current BRM program structures. Specifically, participation in BRM programs provided more wealth to producers; the risk efficiency advantage of more specialized rotations is reinforced by participation in BRM programs; and the effect of BRM programs is more than compensates for any increased risk resulting from greater specialization as indicated by the risk efficiency analysis. It means BRM programs provided more incentives for producers to be more specialized in terms of cropping decisions since a lower risk premium would be required to adopt more diversified rotations if no BRM programs present.

Nonetheless, there are policy responses that might potentially encourage greater crop diversification for producers. One is the possibility of tying participation in BRM programs with cross-compliance conditions. For example, producers could be required follow agronomically sound rotation practices to be eligible to receive support from BRM programs. However, the experience of implementing cross-compliance in Canadian agriculture is limited and only introduced for AgriInvest program (AAFC, 2020). Another policy response that would potentially encourage less specialization, at least with respect to canola, is regulatory management in the form of enforcing certain production practices for canola production. These might include practices intended to limit the incidence and/or spread of canola diseases such as clubroot. Although this policy instrument could be more effective in encouraging crop diversification, producers may find it less favorable due to the mandatory nature and the impact on production costs.

6.3 Limitations and Assumptions

It should be noted that the results of the study are specific to representative farms located in three specific areas of Alberta and southern Saskatchewan. Although the models are designed to simulate representative commercial crop production in the study area, these results may not necessarily apply to the larger population of farms due to heterogeneity in growing conditions, production management practices, etc. In developing the model for the representative farms, many of the same parameter calculations and assumptions are applied to both Black soil zone farms. For example, the same assumptions were made to two Black soil zone farms in Alberta and Saskatchewan regarding the size of representative farm and production (e.g. use of yield adjustment ratios and yield correlation matrix). The simulation results may vary significantly if assumptions in terms of defining the farm characteristics are made to distinguish between Alberta and Saskatchewan.

Results are also limited by the lack of availability for some data. Lack of information about the probability of canola diseases associated with specific crop rotations resulted in an inability to quantitatively model the negative productivity impact on crop production, which was one of the objectives listed for the research. While the impact of crop disease will be partly captured by the yield adjustments for prior crop, the full impact of a “disease event” are not accounted for in the analysis. The resulting relative and absolute net benefits of different cropping systems could significantly change if canola disease were explicitly modeled. Significant costs could be incurred from disease events, such as revenue loss from crop sales and additional costs for disease management. Related to this is the lack of data on how producers may adjust input use when in order to minimize disease problems, when growing more canola-intensive rotations. As noted in the discussion of methodology, the production costs per acre for each crop are unchanged regardless of the rotation being modeled.

Actual yield impacts of preceding crops passed on to following crops may be long-lasting in some cases, given the fact that crop rotations are long-term in nature. However, accurate yield adjustment effects of preceding crops are not captured in this study as yield effects were available for the preceding crop only. Specifically, the yield effect from preceding crops can be estimated for only one subsequent year. For example, the benefit of growing field peas (e.g., fixing atmospheric nitrogen) not only affects the yield of following crop (e.g., wheat) but also the crop after that. The simulated crop yields and resulting economic performance of alternative rotations might be different if more detailed data were available on yields for crops in longer-term sequences.

Lastly, the SERF analysis was conducted by assuming that it was appropriate to model producer behavior with a negative exponential utility function. This specific utility function can yield the same results as other functions over a small risk aversion interval, which makes visual presentation and interpretation simpler. Nonetheless, it might limit the flexibility in modeling producer's behavior in terms of risk. By using other forms of utility function such as power and logarithmic, there are possible changes in the current risk efficient set of cropping systems.

6.4 Future Research

This study is carried out in three representative farms across Alberta and Saskatchewan that are confined to two different farm sizes. It may be worth looking at representative farms of other sizes in the study area for future research. The expansion analysis would be informative to producers in terms of the potential impact of different farm sizes on the economics of commercial crop production.

Furthermore, this study did not assess the marginal cost of disease events due to a lack of appropriate data. Therefore, knowledge about the probability of crop diseases is required to be able to estimate the associated costs. This may affect the cropping decisions resulted from the current study as producers would have a better understanding of the opportunity cost of adopting canola-intensive rotations. Another area of future research would require obtaining longer term data on prior crops rather than just one year to improve the ability of modeling yield adjustment effects.

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APPENDIX A – Counties or Rural Municipalities Considered in Each Soil Zone After Soil Coding Assessment

Table A.1 – Counties located on the Black and Dark Gray soil zones of Alberta

Soil Zone	County
Black	Beaver Camrose Flagstaff Foothills Lamont Lacombe Minburn Mountain View Ponoka Red Deer Rocky View Sturgeon Vermillion River Wetaskiwin
Dark Gray	Athabasca Barrhead Birch Hills Fairview Grande Prairie Lac Ste Anne Parkland Peace Smoky River Spirit River St. Paul Thorhild Westlock

Note: Counties in each soil zone are sorted by alphabetical order.

Table A.2 – Rural municipalities located on the Black soil zone of Saskatchewan

Rural Municipality
Abernethy
Antler
Argyle
Battle River
Battleford
Big Quill
Birch Hills
Blaine Lake
Britannia
Buchanan
Buckland
Calder
Cana
Chester
Churchbridge
Cupar
Cut Knife
Douglas
Duck Lake
Elcapo
Eldon
Elfros
Emerald
Fertile Belt
Fish Creek
Flett's Springs
Foam Lake
Good Lake
Grayson
Great Bend
Hazelwood
Hillsdale
Hoodoo
Humboldt
Indian Head
Insinger
Invermay Lake
Ituna Bon
Kellross
Keys
Kingsley
Kinistino
Laird
Lakeside
Lakeview
Langenburg
Leroy
Lipton
Martin
Maryfield
Mayfield
Mcleod
Meota
Moose Mountain
Moosomin
Mount Pleasant
North Qu'Appelle
Orkney
Paynton
Ponass Lake
Prairie Rose
Prince Albert
Reciprocity
Redberry
Rocanville
Rosthern
Round Hill
Saltcoats
Sasman
Silverwood
Sliding Hills
South Qu'Appelle
Spalding
Spy Hill
St. Louis
St. Peter
Stanley
Storthoaks
Touchwood
Tullymet
Turtle River
Wallace
Walpole
Wawken
Willowdale
Wilton
Wolseley
Wolverine

Note: Rural municipalities are sorted by alphabetical order.

APPENDIX B – County Level Crop Farm Data (2016)

Table B.1 – Total farms and cropping farms, by county/municipal district for Black and Dark Gray soil zone regions in Alberta, 2016

Soil Zone	County/ Municipal District	Total Farms	Crop Farms	% Crop Farms
Black (South)	Foothills	1083	200	18.7%
	Rocky View	1135	270	23.8%
	Mountain View	1542	377	24.5%
	Red Deer	1460	420	28.8%
	Lacombe	1034	329	31.8%
	Ponoka	1097	218	19.9%
Black (North)	Flagstaff	638	415	65.1%
	Camrose	962	504	52.4%
	Beaver	631	298	47.2%
	Minburn	594	352	59.3%
	Vermilion	1052	447	42.5%
	Lamont	689	373	54.1%
	Wetaskiwin	954	229	24.0%
	Sturgeon	730	301	41.2%
Dark Gray (East)	St. Paul	680	163	24.0%
	Barrhead	681	229	33.6%
	Westlock	744	326	43.8%
	Thorhild	382	153	40.1%
	Athabasca	650	157	24.2%
Dark Gray (South)	Parkland	679	107	15.8%
	Lac Ste. Anne	794	96	12.1%
Dark Gray (NW)	Grande Prairie	1113	328	29.5%
	Smoky River	306	251	82.0%
	Birch Hills	182	121	66.5%
	Spirit River	110	68	61.8%
	Peace	202	119	58.9%
	Fairview	129	61	47.3%

Source: Statistics Canada (2016)

Table B.2 – Total farms and cropping farms, by rural municipality for Black soil zone region in Saskatchewan, 2016

Black	Rural Municipality	Total Farms	Crop Farms	% Crop Farms
SE	Argyle	72	37	51.4%
	Mount Pleasant	95	46	48.4%
	Reciprocity	106	66	62.3%
	Storthoaks	72	52	72.2%
	Antler	124	77	62.1%
	Moose Mountain	119	70	58.8%
	Wawken	97	33	34.0%
	Walpole	90	41	45.6%
	Maryfield	84	46	54.8%
	Hazelwood	73	35	47.9%
	Moosomin	87	38	43.7%
	Martin	93	39	41.9%
	Silverwood	106	47	44.3%
	Kingsley	118	65	55.1%
	Chester	105	68	64.8%
	Willowdale	90	42	46.7%
	Rocanville	117	49	41.9%
	Wolseley	118	71	60.2%
	Elcapo	120	65	54.2%
	South Qu' Appelle	206	97	47.1%
	Indian Head	91	50	54.9%
East	Spy Hill	79	36	45.6%
	Langenburg	113	69	61.1%
	Fertile Belt	154	80	51.9%
	Grayson	98	63	64.3%
	Mcleod	154	111	72.1%
	Cana	172	73	42.4%
	Saltcoats	137	84	61.3%
	Churchbridge	146	96	65.8%
	Aberbethy	114	90	78.9%
	North Qu' Appelle	76	45	59.2%
	Stanley	124	84	67.7%
	Calder	114	75	65.8%
	Wallave	134	101	75.4%
	Orkney	179	87	48.6%
	Ituna Bon Accord	129	94	72.9%
	Kellross	117	76	65.0%
	Touchwood	107	56	52.3%
	Lipton	124	77	62.1%
	Tullymet	83	58	69.9%
	Insinger	117	69	59.0%

Black	Rural Municipality	Total Farms	Crop Farms	% Crop Farms
NE	Good Lake	128	77	60.2%
	Sliding Hills	108	92	85.2%
	Keys	74	53	71.6%
	Buchanan	107	89	83.2%
	Ivermay	106	67	63.2%
	Emerald	130	109	83.8%
	Foam Lake	194	137	70.6%
	Elfros	104	87	83.7%
	Big Quill	108	78	72.2%
	Prairie Rose	85	56	65.9%
	Leroy	108	92	85.2%
	Lakeview	73	54	74.0%
	Lakeside	94	76	80.9%
	Sasman	153	116	75.8%
	Wolverine	111	74	66.7%
	Ponass	125	97	77.6%
	Spalding	117	95	81.2%
N & NW	Duck Lake	106	27	25.5%
	Buckland	149	59	39.6%
	Round Hill	105	63	60.0%
	Meota	100	67	67.0%
	Turtle River	83	37	44.6%
	Paynton	48	17	35.4%
	Eldon	149	72	48.3%
	Wilton	166	97	58.4%
	Britannia	187	59	31.6%
	Battle River	184	114	62.0%
	Hillsdale	86	56	65.1%
	Cut Knife	76	55	72.4%
	Prince Albert	257	140	54.5%
	Birch Hills	87	66	75.9%
	Kinistino	125	85	68.0%
	Redberry	129	88	68.2%
	Douglas	115	78	67.8%
	North Battleford	162	115	71.0%
	Laird	157	103	65.6%
	Rosthern	219	98	44.7%
	Fish Creek	100	74	74.0%
	Hoodoo	146	131	89.7%
	Flett's Springs	155	132	85.2%
	St. Louis	127	103	81.1%
	Mayfield	94	64	68.1%
	Great Bend	104	62	59.6%

Black	Rural Municipality	Total Farms	Crop Farms	% Crop Farms
	Blaine Lake	101	72	71.3%
	St. Peter	137	116	84.7%
	Humboldt	139	114	82.0%

Source: Statistics Canada (2016)

APPENDIX C - Crop Yield Data

Table C.1 - Detrended crop yields in county of Camrose (tonne/acre) 1987 - 2017

Year	Barley	Canola	Spring Wheat	Oats	Field Peas
1987	1.664	1.138	1.384	1.564	N/A
1988	1.885	1.154	1.773	1.747	N/A
1989	1.558	1.060	1.522	1.480	N/A
1990	1.781	1.125	1.653	1.595	N/A
1991	1.594	1.070	1.624	1.498	N/A
1992	1.516	1.019	1.385	1.294	N/A
1993	1.715	1.037	1.601	1.550	N/A
1994	1.460	0.936	1.426	1.364	N/A
1995	1.757	1.039	1.521	1.467	0.871
1996	1.632	1.028	1.625	1.607	1.242
1997	1.460	1.000	1.425	1.423	1.114
1998	1.546	1.063	1.302	1.450	1.136
1999	1.903	1.147	1.637	1.648	1.446
2000	1.693	1.049	1.657	1.655	1.177
2001	1.695	1.089	1.573	1.505	1.205
2002	0.445	0.424	0.568	0.384	0.161
2003	1.398	0.895	1.399	1.096	0.891
2004	1.637	1.129	1.604	1.383	1.245
2005	1.737	1.228	1.632	1.559	1.319
2006	1.283	1.062	1.357	0.861	0.935
2007	1.359	0.962	1.423	1.172	1.061
2008	1.753	1.150	1.759	1.130	1.41
2009	1.218	0.616	1.249	0.737	0.895
2010	1.655	1.109	1.542	1.406	0.97
2011	1.600	0.998	1.351	1.566	0.718
2012	1.613	1.049	1.406	1.531	1.206
2013	2.014	1.269	1.871	2.031	1.602
2014	1.746	1.110	1.595	1.631	1.422
2015	1.616	1.183	1.380	1.988	1.271
2016	1.784	1.080	1.674	1.660	1.112
2017	1.696	1.026	1.618	1.448	1.276

N/A denotes values that are unavailable due to zero acreage or confidentiality (i.e., too few producers growing the crop).

Table C.2 - Detrended crop yields in the M.D. of Smoky River (tonne/acre) 1987 - 2017

Year	Barley	Canola	Oats	Spring Wheat	Field Peas
1987	1.433	0.932	1.05	1.317	1.374
1988	1.913	1.011	1.458	1.737	1.328
1989	1.732	0.917	1.099	1.514	1.283
1990	1.662	0.894	1.048	1.625	1.237
1991	1.652	0.926	0.891	1.558	1.191
1992	1.599	0.888	1.015	1.37	1.145
1993	1.781	0.854	1.476	1.386	1.099
1994	1.693	0.874	1.213	1.291	1.054
1995	1.908	0.98	1.379	1.636	2.151
1996	1.211	0.753	N/A	1.333	1.589
1997	1.212	0.623	0.604	1.286	1.509
1998	1.408	0.785	0.906	1.148	1.441
1999	1.393	0.701	0.964	1.207	1.391
2000	1.915	0.788	1.688	1.851	1.853
2001	1.901	0.886	1.522	1.512	2.04
2002	1.503	0.979	1.055	1.217	1.513
2003	1.77	1	1.514	1.64	1.585
2004	1.551	0.993	1.195	1.358	1.486
2005	1.961	1.154	1.546	1.674	1.737
2006	1.824	0.95	1.575	1.697	1.497
2007	1.907	0.924	1.584	1.639	1.628
2008	1.396	0.779	1.26	1.467	1.185
2009	1.529	0.809	1.471	1.211	1.37
2010	1.315	0.727	1.11	1.119	1.171
2011	2.101	0.844	1.963	1.758	1.073
2012	1.35	0.966	1.501	1.583	1.502
2013	1.573	0.955	N/A	1.421	1.481
2014	1.522	0.786	1.331	1.35	1.318
2015	1.56	0.906	1.209	1.281	1.107
2016	1.716	0.913	2.008	1.661	1.35
2017	1.815	0.931	0.982	1.481	1.425

N/A denotes values that are unavailable due to zero acreage or confidentiality (i.e., too few producers growing the crop).

Table C.3 - Detrended crop yields in Saskatchewan, by rural municipality, (tonne/acre) 1987 - 2018

Rural Municipality	Year	Barley	Canola	Spring Wheat	Oats	Field Peas	Flax
St. Peter	1987	1.746	1.113	1.634	2.099	0.947	0.790
	1988	1.241	0.939	1.221	1.428	1.141	0.521
	1989	1.308	0.858	1.411	1.726	1.357	0.529
	1990	1.571	0.843	1.450	1.789	1.411	0.604
	1991	1.745	1.053	1.739	1.803	1.183	0.875
	1992	1.847	0.985	1.526	1.616	1.184	0.612
	1993	1.782	0.931	1.347	1.892	1.258	0.626
	1994	1.904	1.055	1.454	2.630	1.457	0.951
	1995	1.977	1.024	1.639	2.156	1.311	0.898
	1996	1.942	1.056	1.580	1.959	1.059	0.796
	1997	1.796	0.983	1.638	1.986	0.542	0.810
	1998	1.890	0.995	1.643	2.087	1.111	0.771
	1999	2.127	1.016	1.589	2.187	1.216	0.836
	2000	1.878	1.021	1.614	1.959	1.097	0.769
	2001	1.665	0.968	1.265	1.634	1.018	0.629
	2002	1.233	0.689	1.073	1.249	1.141	0.564
	2003	1.775	0.888	1.510	1.777	1.229	0.693
	2004	1.897	0.728	1.324	1.651	1.259	0.440
	2005	1.851	1.098	1.469	1.851	0.408	0.815
	2006	1.265	0.843	1.460	1.475	1.250	0.581
	2007	1.520	0.835	1.398	1.724	1.158	0.496
	2008	1.772	1.023	1.454	1.820	1.308	0.737
	2009	1.809	0.954	1.504	1.773	0.773	0.568
	2010	0.787	0.481	0.912	1.675	1.190	0.746
	2011	1.843	1.050	1.468	2.060	1.218	0.788
	2012	1.290	0.727	1.413	1.658	1.558	0.598
	2013	1.993	0.946	2.048	2.235	1.352	0.698
	2014	1.507	0.825	1.444	1.794	1.209	0.708
	2015	1.769	0.945	1.519	1.977	0.853	0.753
	2016	1.872	1.039	1.532	1.931	0.987	0.787
	2017	1.900	1.141	1.843	1.959	1.137	0.486
	2018	1.798	1.124	1.442	1.719	1.108	0.442

Rural Municipality	Year	Barley	Canola	Spring Wheat	Oats	Field Peas	Flax
	1987	1.724	1.122	1.593	1.933	1.386	0.616
	1988	1.141	0.835	1.145	1.403	1.291	0.720
	1989	1.234	0.780	1.383	1.422	1.273	0.637
	1990	1.582	0.825	1.594	1.627	0.667	0.669

Rural Municipality	Year	Barley	Canola	Spring Wheat	Oats	Field Peas	Flax
Leroy	1991	1.591	0.944	1.628	1.649	0.536	0.671
	1992	1.749	1.066	1.398	1.616	0.945	0.715
	1993	1.586	0.945	1.377	1.584	1.259	0.756
	1994	1.522	0.967	1.509	1.473	1.124	0.648
	1995	1.625	0.975	1.543	2.058	0.925	0.776
	1996	1.725	1.013	1.509	1.796	1.117	0.750
	1997	1.568	0.858	1.461	1.733	1.145	0.612
	1998	1.744	0.968	1.553	1.785	1.071	0.588
	1999	1.780	0.936	1.472	1.902	0.514	0.495
	2000	1.541	0.935	1.331	1.750	1.054	0.444
	2001	1.144	0.741	1.124	1.379	0.894	0.384
	2002	1.016	0.701	0.983	1.183	1.109	0.769
	2003	1.623	0.808	1.274	1.419	0.637	0.817
	2004	1.514	0.710	1.250	1.155	1.076	0.602
	2005	1.585	0.982	1.409	1.406	1.311	0.660
	2006	1.341	0.793	1.190	1.517	1.384	0.555
	2007	1.352	0.710	1.055	1.624	1.227	0.393
	2008	1.580	0.885	1.241	1.350	1.129	0.713
	2009	1.491	0.813	1.298	1.563	0.801	0.580
	2010	0.748	0.513	0.988	1.120	1.098	0.810
	2011	1.488	0.876	1.376	1.484	1.104	0.522
	2012	1.042	0.655	1.329	1.222	0.941	0.747
	2013	1.718	0.912	1.637	1.769	1.035	0.645
	2014	1.210	0.650	1.221	1.344	1.195	0.715
	2015	1.440	0.925	1.273	1.568	1.302	0.633
	2016	1.668	0.989	1.502	1.527	1.219	0.741
	2017	1.691	0.975	1.590	1.489	0.760	0.527
	2018	1.458	0.959	1.407	1.256	0.531	0.458

Rural Municipality	Year	Barley	Canola	Spring Wheat	Oats	Field Peas	Flax
Lakeside	1987	1.666	1.085	1.563	1.894	0.714	0.621
	1988	1.178	0.803	1.254	1.456	1.153	0.723
	1989	1.204	0.737	1.552	1.416	1.002	0.460
	1990	1.367	0.788	1.684	1.372	1.059	0.621
	1991	1.521	0.923	1.962	1.649	0.970	0.773
	1992	1.564	0.930	1.398	1.616	1.104	0.771
	1993	1.595	0.868	1.195	1.506	1.126	0.807
	1994	1.620	0.930	1.653	2.013	0.487	0.775
	1995	1.668	0.965	1.693	1.904	0.986	0.733

Rural Municipality	Year	Barley	Canola	Spring Wheat	Oats	Field Peas	Flax
	1996	1.738	0.982	1.593	1.905	1.096	0.692
	1997	1.628	0.887	1.630	1.889	1.349	0.843
	1998	1.794	0.988	1.743	1.896	0.792	0.573
	1999	1.896	0.991	1.720	1.914	1.323	0.404
	2000	1.628	0.944	1.574	1.741	1.147	0.538
	2001	1.314	0.841	1.437	1.436	1.218	0.293
	2002	1.105	0.696	1.046	1.164	0.816	0.589
	2003	1.651	0.897	1.404	1.712	1.336	0.591
	2004	1.594	0.667	1.275	1.482	0.798	0.712
	2005	1.631	0.923	1.482	1.463	1.411	0.704
	2006	1.685	0.947	1.286	1.586	1.164	0.593
	2007	1.461	0.796	1.251	1.767	1.107	0.796
	2008	1.754	0.984	1.549	1.748	1.127	0.788
	2009	1.841	1.015	1.458	1.887	1.179	0.736
	2010	0.944	0.730	1.190	1.445	1.457	0.802
	2011	1.619	1.034	1.642	1.730	1.257	0.744
	2012	1.401	0.845	1.462	1.732	0.800	0.643
	2013	1.856	1.078	1.994	2.103	0.463	0.726
	2014	1.387	0.898	1.473	2.040	0.888	0.554
	2015	1.767	1.054	1.717	2.053	1.025	0.534
	2016	1.807	1.110	1.761	1.926	1.113	0.624
	2017	1.968	1.217	1.934	2.117	0.898	0.705
	2018	1.765	1.199	1.905	1.511	1.283	0.587

Rural Municipality	Year	Barley	Canola	Spring Wheat	Oats	Field Peas	Flax
Spalding	1987	1.722	1.119	1.631	1.933	1.055	0.578
	1988	1.315	0.925	1.202	1.622	1.088	0.773
	1989	1.474	0.869	1.476	1.570	0.479	0.688
	1990	1.804	0.875	1.684	1.681	1.021	0.807
	1991	1.780	1.093	1.878	1.679	1.528	0.734
	1992	1.632	0.942	1.575	1.785	0.522	0.753
	1993	1.403	0.809	1.459	1.695	1.261	0.732
	1994	1.671	0.880	1.547	1.705	1.245	0.705
	1995	1.799	0.895	1.731	1.981	1.395	0.670
	1996	1.886	0.927	1.681	1.665	1.088	0.534
	1997	1.703	0.928	1.665	1.944	N/A	0.561
	1998	1.750	0.979	1.683	1.822	N/A	0.448
	1999	1.979	0.986	1.755	1.834	N/A	0.617
	2000	1.562	0.944	1.642	1.533	N/A	0.588

Rural Municipality	Year	Barley	Canola	Spring Wheat	Oats	Field Peas	Flax
	2001	1.597	0.957	1.396	1.524	N/A	0.733
	2002	1.059	0.782	0.997	1.133	N/A	0.436
	2003	1.573	0.829	1.524	1.527	N/A	N/A
	2004	1.731	0.662	1.302	1.506	N/A	N/A
	2005	1.466	0.894	1.643	1.596	N/A	N/A
	2006	1.407	0.890	1.248	1.719	N/A	N/A
	2007	1.456	0.796	1.276	1.465	N/A	N/A
	2008	1.953	0.994	1.601	1.703	N/A	N/A
	2009	1.800	0.949	1.537	1.745	N/A	N/A
	2010	0.929	0.631	1.032	1.478	N/A	N/A
	2011	1.680	0.982	1.618	1.779	N/A	N/A
	2012	0.776	1.037	1.516	2.306	N/A	N/A
	2013	2.163	0.785	1.819	1.855	N/A	N/A
	2014	1.359	0.990	1.387	1.631	N/A	N/A
	2015	1.645	1.044	1.569	1.863	N/A	N/A
	2016	1.679	1.016	1.701	1.980	N/A	N/A
	2017	1.799	1.000	1.753	1.859	N/A	N/A
	2018	1.637	N/A	1.581	N/A	N/A	N/A

N/A denotes values that are unavailable due to zero acreage or confidentiality (i.e., too few producers growing the crop).

Figure C.1 – Detrended crop yields in Camrose county (1987 – 2017)

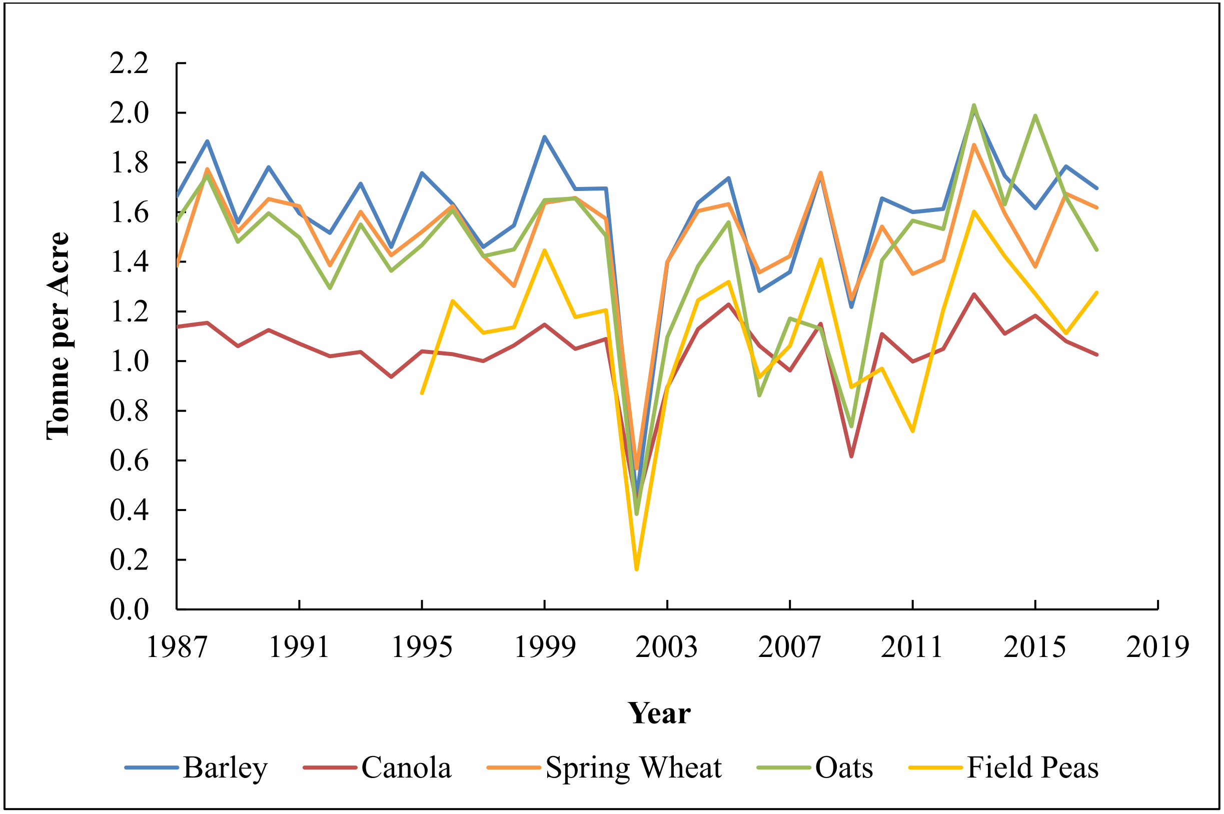


Figure C.2 – Detrended crop yields in M.D. of Smoky River (1987 – 2017)

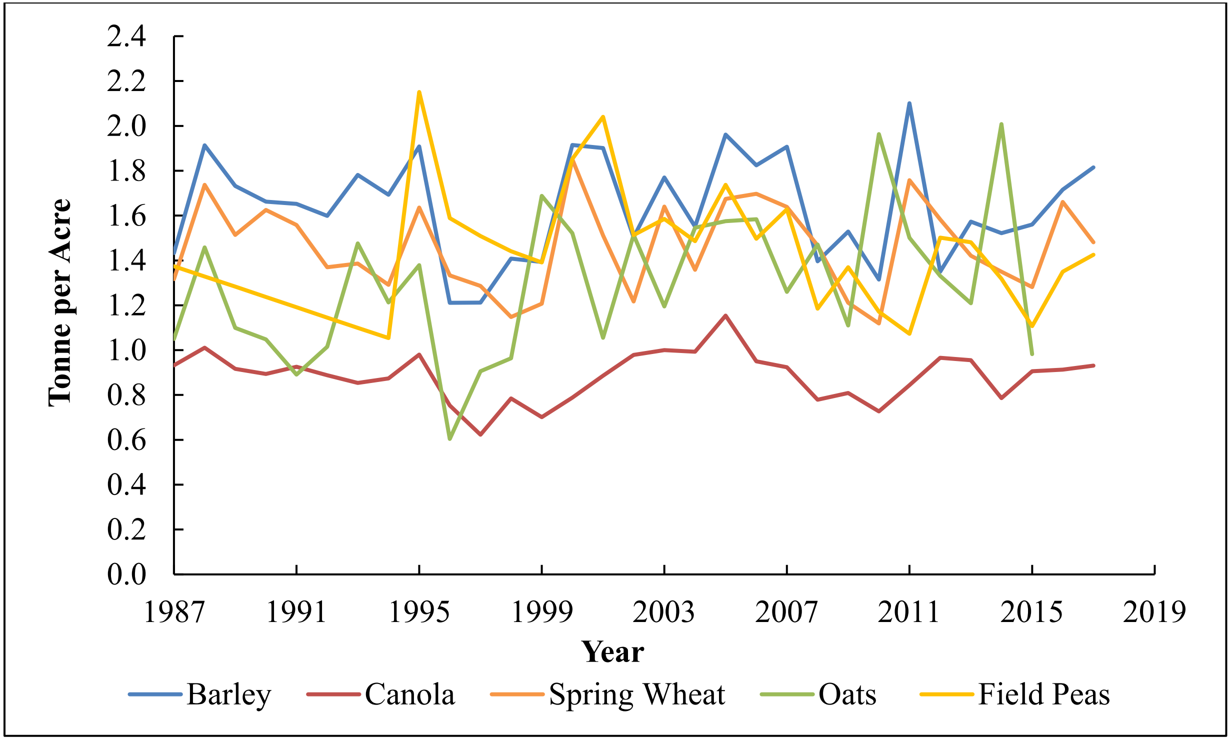


Figure C.3 – Detrended crop yields in RM St. Peter of Saskatchewan (1987 – 2018)

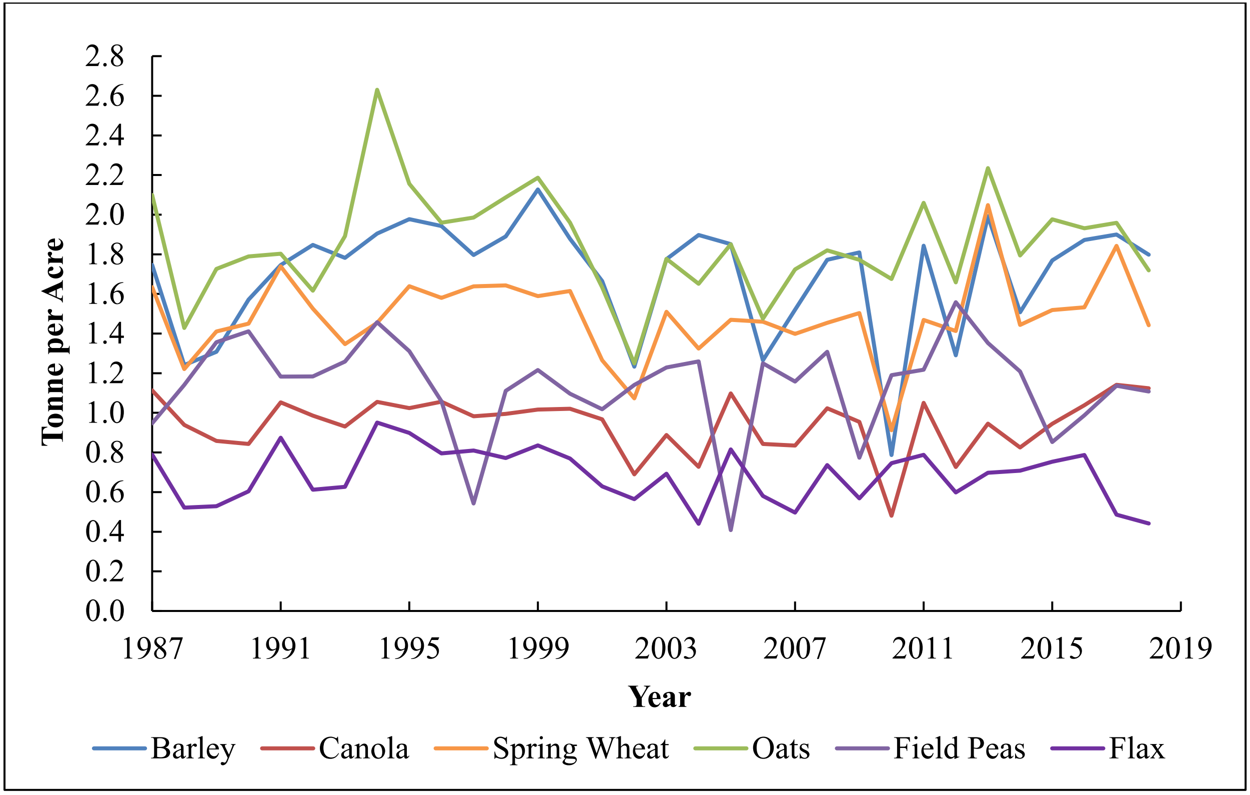


Figure C.4 – Detrended crop yields in RM Leroy of Saskatchewan (1987 – 2018)

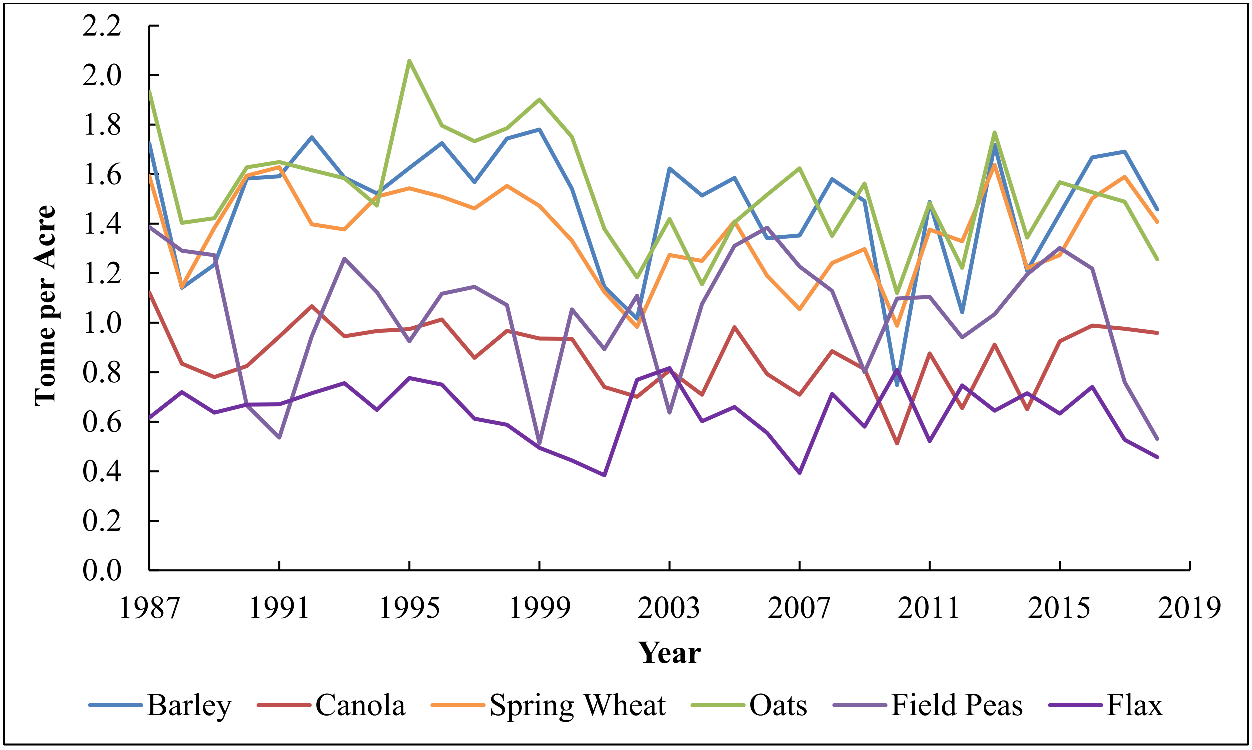


Figure C.5 – Detrended crop yields in RM Lakeside of Saskatchewan (1987 – 2018)

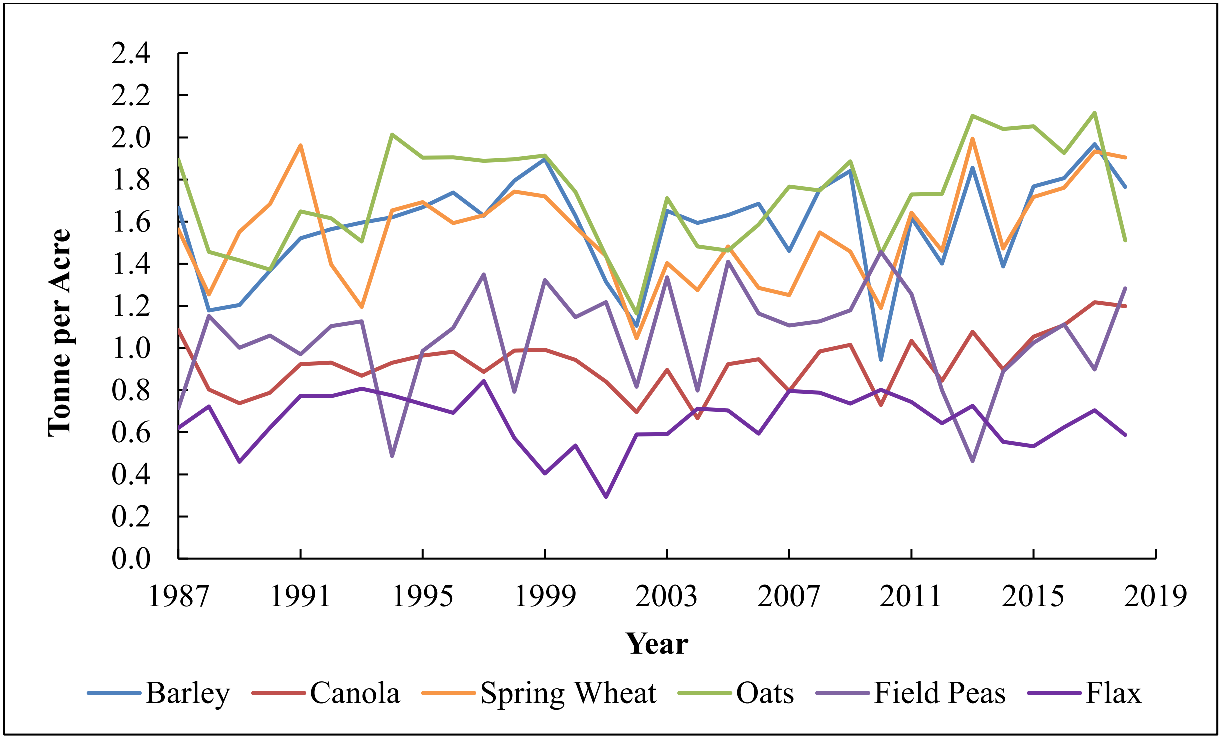
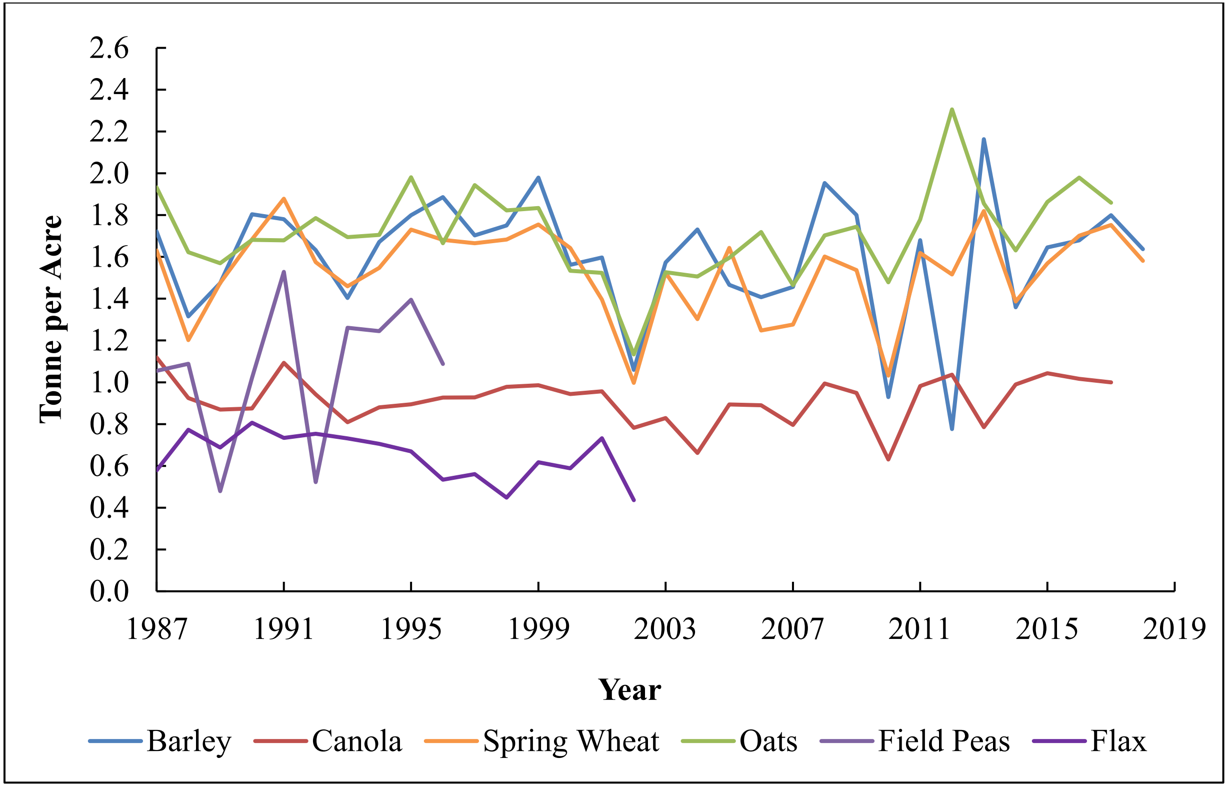


Figure C.6 – Detrended crop yields in RM Spalding of Saskatchewan (1987 – 2018)



APPENDIX D - Yield Adjustment Distribution Statistics (2000 - 2018)

Table D.1 - Yield adjustment statistics of crop combinations in Camrose, risk area 12

Previous Crop	Current Crop	Mean	Min	Max
C	B	1.031	0.987	1.088
C	C	0.992	0.897	1.386
SW	C	0.990	0.865	1.020
B	SW	0.969	0.774	1.020
C	SW	1.023	0.995	1.054
O	SW	0.861	0.730	1.013
FP	SW	1.073	1.017	1.165
C	O	1.139	0.962	1.477
B	FP	0.993	0.937	1.093
O	FP	0.850	0.536	1.088

Note: Yield adjustment ratios are calculated using raw yields prior to de-trending.

Table D.2 - Yield adjustment statistics of crop combinations in Smoky River, risk area 19

Previous Crop	Current Crop	Mean	Min	Max
C	B	1.032	0.997	1.014
C	C	0.953	0.818	1.041
SW	C	1.024	0.980	1.064
B	SW	0.923	0.648	1.295
C	SW	1.022	0.985	1.077
O	SW	0.794	0.546	1.014
FP	SW	1.033	0.847	1.190
C	O	1.115	0.990	1.304
B	FP	0.968	0.788	1.195
O	FP	0.933	0.708	1.279

Note: Yield adjustment ratios are calculated using raw yields prior to de-trending.

APPENDIX E - Crop Prices

Table E.1 - Alberta inflation-corrected crop prices ($/tonne) 1987 - 2017

Year	Barley	Canola	Spring Wheat	Field Peas	Oats	Flax
1987	132.13	509.98	237.34	343.22	178.81	420.98
1988	222.67	572.28	243.51	383.65	253.72	698.82
1989	190.26	485.46	351.50	327.03	153.15	615.83
1990	143.31	447.11	274.43	275.79	116.89	346.67
1991	126.65	390.79	191.21	274.66	139.42	254.58
1992	133.75	445.13	189.00	262.76	158.41	347.76
1993	119.59	497.01	229.92	239.76	140.00	365.01
1994	155.14	555.16	270.47	264.16	139.84	425.14
1995	240.13	577.32	288.29	309.76	262.55	454.39
1996	181.15	611.34	358.06	340.18	154.63	483.86
1997	179.52	568.06	278.07	282.71	184.23	478.20
1998	157.93	515.20	252.61	222.63	174.70	474.07
1999	147.14	370.88	241.67	190.77	148.92	361.67
2000	143.94	341.69	214.75	160.97	143.17	287.69
2001	183.17	397.64	226.01	229.28	210.84	378.56
2002	212.22	475.77	237.27	286.75	266.12	455.29
2003	174.26	455.82	272.53	227.38	227.16	463.71
2004	156.79	450.41	216.32	206.38	151.50	485.44
2005	124.25	332.65	203.49	160.55	144.95	444.51
2006	131.02	339.97	187.00	182.91	144.58	281.48
2007	202.09	456.80	201.38	270.50	191.26	400.66
2008	250.00	577.68	382.79	361.53	206.21	692.09
2009	199.70	519.07	308.73	270.42	183.33	482.16
2010	175.20	491.20	216.50	230.80	178.51	501.95
2011	217.61	600.71	332.48	319.89	219.75	626.93
2012	268.24	636.63	304.18	330.70	203.47	612.82
2013	276.51	625.07	283.50	344.38	232.50	625.20
2014	195.43	466.64	224.09	281.66	180.18	548.26
2015	223.84	490.82	229.03	323.85	190.02	535.86
2016	207.09	497.94	250.54	351.31	194.22	483.76
2017	193.38	514.66	267.44	303.54	193.27	510.39

N/A denotes values that are unavailable due to zero acreage or confidentiality (i.e., too few producers growing the crop).

Table E.2 - Saskatchewan inflation-corrected crop prices ($/tonne) 1987 - 2017

Year	Barley	Canola	Spring Wheat	Oats	Field Peas	Flax
1987	123.1	432.07	377.48	208.31	N/A	320.5
1988	168.42	597.47	374.99	288.21	N/A	544.9
1989	183.63	510.54	325.37	156.25	N/A	615.88
1990	150.52	471.84	298.50	112.67	N/A	532.31
1991	117.7	406.05	288.95	136.23	N/A	264.96
1992	122.84	418.84	256.18	153.7	252.14	286.06
1993	114.24	469.49	194.14	150.82	228.52	337.28
1994	127.62	590.78	172.64	137.86	295.02	389.63
1995	179.79	564.83	218.29	173.81	281.59	422.72
1996	202.71	594.36	252.98	223.92	338.4	488.77
1997	157.44	555.86	207.03	165.09	299.55	466.75
1998	142.26	548.53	170.57	129.29	242.29	505.28
1999	121.04	412.29	171.57	107.25	225.1	346.88
2000	115.08	326.92	174.08	100.71	196.74	278.14
2001	152.97	398.11	352.51	156.88	251.36	369.87
2002	186.63	486.55	348.83	249.71	308.36	466.25
2003	146.66	447.98	254.80	163.54	244.39	432.77
2004	119.13	429.03	205.78	142.84	226.19	485.15
2005	90.55	321.14	383.01	133.95	167.08	492.91
2006	99.46	324.79	373.61	155.07	172.77	281.75
2007	176.22	450.34	372.87	196.11	296.11	419.73
2008	203.64	592.78	180.86	196.57	371.77	690.92
2009	146.93	475.06	206.91	136.19	243.3	446.37
2010	144.96	480.64	203.63	162.58	220.61	486.44
2011	189.27	603.39	175.90	204.36	325.7	606.2
2012	224.36	649.71	128.15	199.23	344.69	596.43
2013	208.69	605.25	149.52	216.75	320.74	631.69
2014	134.68	442.18	250.79	153.63	252.6	535.61
2015	172.96	476.3	306.92	160.33	344.26	545.7
2016	151.49	480.39	223.11	153.12	405.35	464.86
2017	142.34	502.36	200.08	175.1	316.73	478.27

N/A denotes values that are unavailable due to zero acreage or confidentiality (i.e., too few producers growing the crop).

Figure E.1 – Historical commodity crop prices in Alberta, corrected for inflation to 2019 Canadian dollars

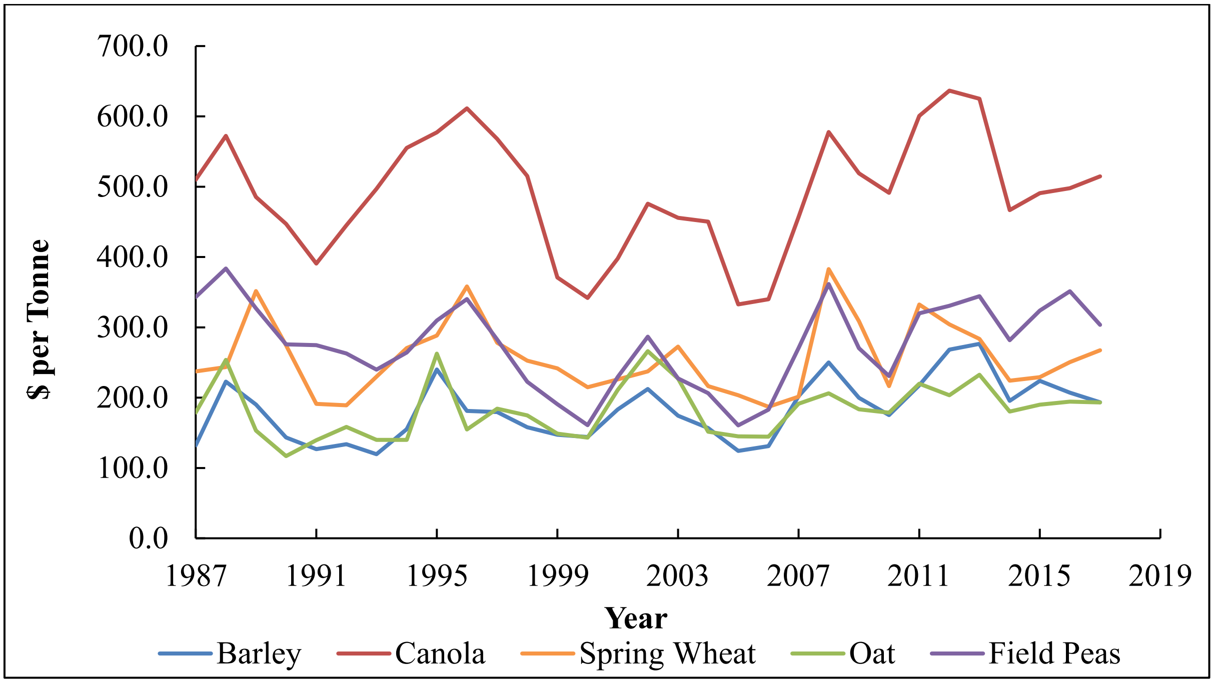
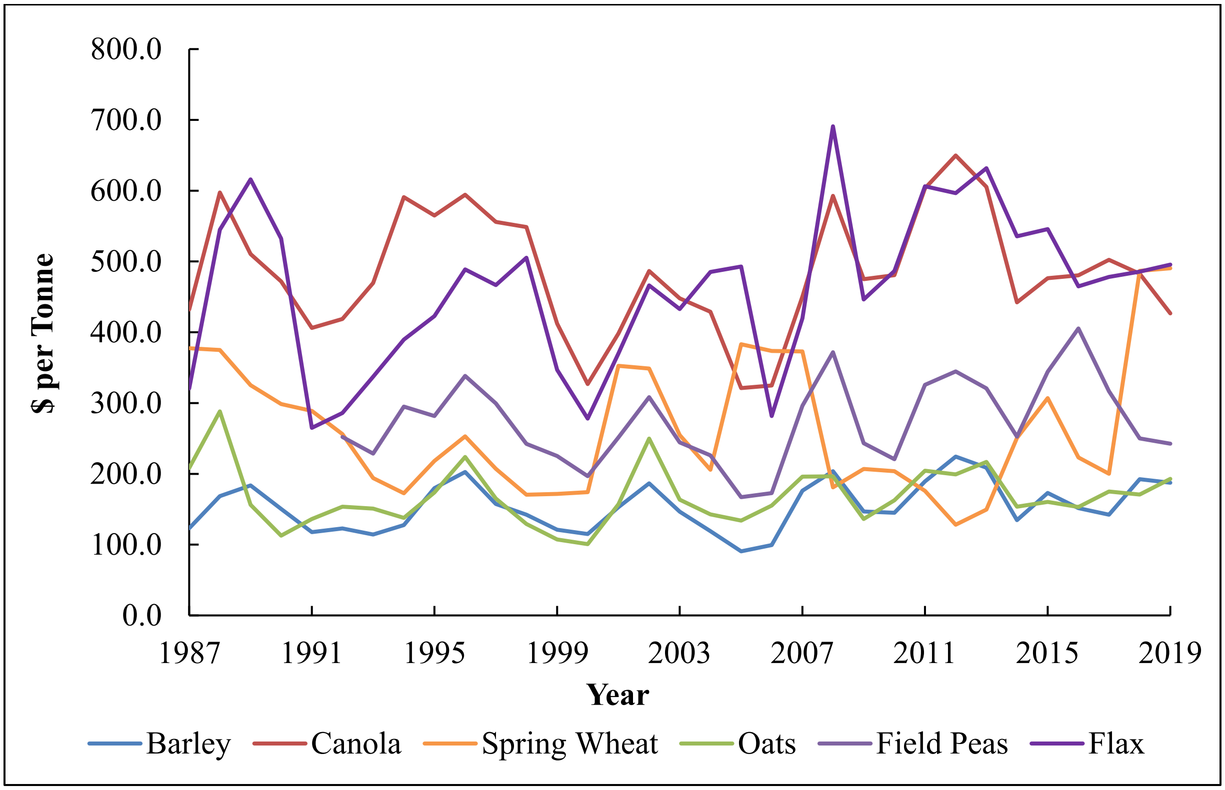


Figure E.2 – Historical commodity crop prices in Saskatchewan, corrected for inflation to 2019 Canadian dollars



APPENDIX F – Expected NPVs and Standard Deviations Resulted in No AgriStability and Non-BRM Scenarios for Representative Farms

Table F.1 – Mean NPVs and standard deviations without AgriStability payment, Camrose

Rotation	NPV	Std. Dev.
SW-C-C-C	$5,712,942.40	$643,919.23
SW-C-C	$5,707,471.82	$620,411.78
SW-C	$5,698,633.09	$598,908.71
SW-C-C-B	$4,923,590.00	$662,777.50
SW-C-C-O	$4,814,115.57	$560,288.83
SW-C-B	$4,650,749.46	$726,565.31
SW-C-B-SW-C-O	$4,569,909.30	$559,609.99
SW-C-B-FP	$4,494,079.15	$655,607.70
SW-C-B-FP-SW-C-O-FP	$4,469,867.43	$556,485.29
SW-C-O-FP	$4,449,719.80	$559,037.00

Note: Rotations are ranked by the expected NPVs without no AgriStability in descending order.

Table F.2 – Mean NPVs and standard deviations without AgriStability payment, Smoky River

Rotation	NPV	Std. Dev.
SW-C	$3,688,604.54	$348,408.60
SW-C-B-FP	$3,516,317.70	$327,380.51
SW-C-C	$3,480,928.56	$347,924.59
SW-C-C-C	$3,382,142.25	$359,924.68
SW-C-B-FP-SW-C-O-FP	$3,348,440.23	$322,718.39
SW-C-O-FP	$3,285,391.96	$343,874.19
SW-C-B	$3,173,078.80	$311,675.29
SW-C-C-B	$3,148,374.96	$309,460.46
SW-C-B-SW-C-O	$2,933,776.25	$299,606.59
SW-C-C-O	$2,802,830.12	$316,101.96

Note: Rotations are ranked by the expected NPVs without no AgriStability in descending order.

Table F.3 – Mean NPVs and standard deviations without AgriStability payment, Saskatchewan

Rotation	NPV	Std. Dev.
SW-C	$4,494,769.88	$641,423.67
SW-C-C	$4,263,773.73	$600,727.31
C-SW-F-SW	$4,225,861.97	$608,951.77
SW-C-C-C	$4,152,792.20	$594,808.68
C-SW-F-C	$3,883,558.57	$537,598.63
SW-C-C-O	$3,637,049.04	$499,966.86
SW-C-O-F	$3,598,301.74	$472,551.37
SW-C-B-F-SW-C-O-F	$3,543,047.43	$476,452.23
SW-C-B-F	$3,489,677.84	$486,446.99
SW-C-C-B	$3,454,553.72	$512,516.39
SW-C-B-SW-C-O	$3,453,720.45	$499,499.59
SW-C-B	$3,335,044.27	$514,478.57
SW-C-O-FP	$3,334,211.45	$506,425.84
SW-C-B-FP-SW-C-O-FP	$3,204,729.81	$506,194.63
SW-C-B-FP	$3,062,223.11	$514,020.58

Note: Rotations are ranked by the expected NPVs without no AgriStability in descending order.

Table F.4 – Mean NPVs and standard deviations without BRM payments, Camrose

Rotation	NPV	Std. Dev.
SW-C-C-C	$5,294,887.48	$713,361.48
SW-C-C	$5,267,897.61	$691,418.08
SW-C	$5,224,755.11	$675,278.83
SW-C-C-B	$4,556,639.49	$692,848.35
SW-C-C-O	$4,347,388.87	$623,851.51
SW-C-B	$4,258,642.78	$762,874.27
SW-C-B-SW-C-O	$4,146,509.12	$606,458.37
SW-C-B-FP	$4,034,391.58	$687,113.33
SW-C-B-FP-SW-C-O-FP	$3,966,033.08	$610,681.01
SW-C-O-FP	$3,896,973.95	$627,210.16

Note: Rotations are ranked by the expected NPVs without no AgriStability in descending order.

Table F.5 – Mean NPVs and standard deviations without BRM payments, Smoky River

Rotation	NPV	Std. Dev.
SW-C	$3,424,583.03	$393,288.44
SW-C-C	$3,257,560.11	$385,056.17
SW-C-B-FP	$3,194,118.42	$365,083.55
SW-C-C-C	$3,177,528.53	$395,634.54
SW-C-B-FP-SW-C-O-FP	$3,014,668.54	$362,588.75
SW-C-O-FP	$2,920,249.58	$380,948.65
SW-C-C-B	$2,902,728.27	$344,996.47
SW-C-B	$2,893,694.76	$350,559.63
SW-C-B-SW-C-O	$2,648,509.06	$339,259.32
SW-C-C-O	$2,533,403.87	$350,630.25

Note: Rotations are ranked by the expected NPVs without no AgriStability in descending order.

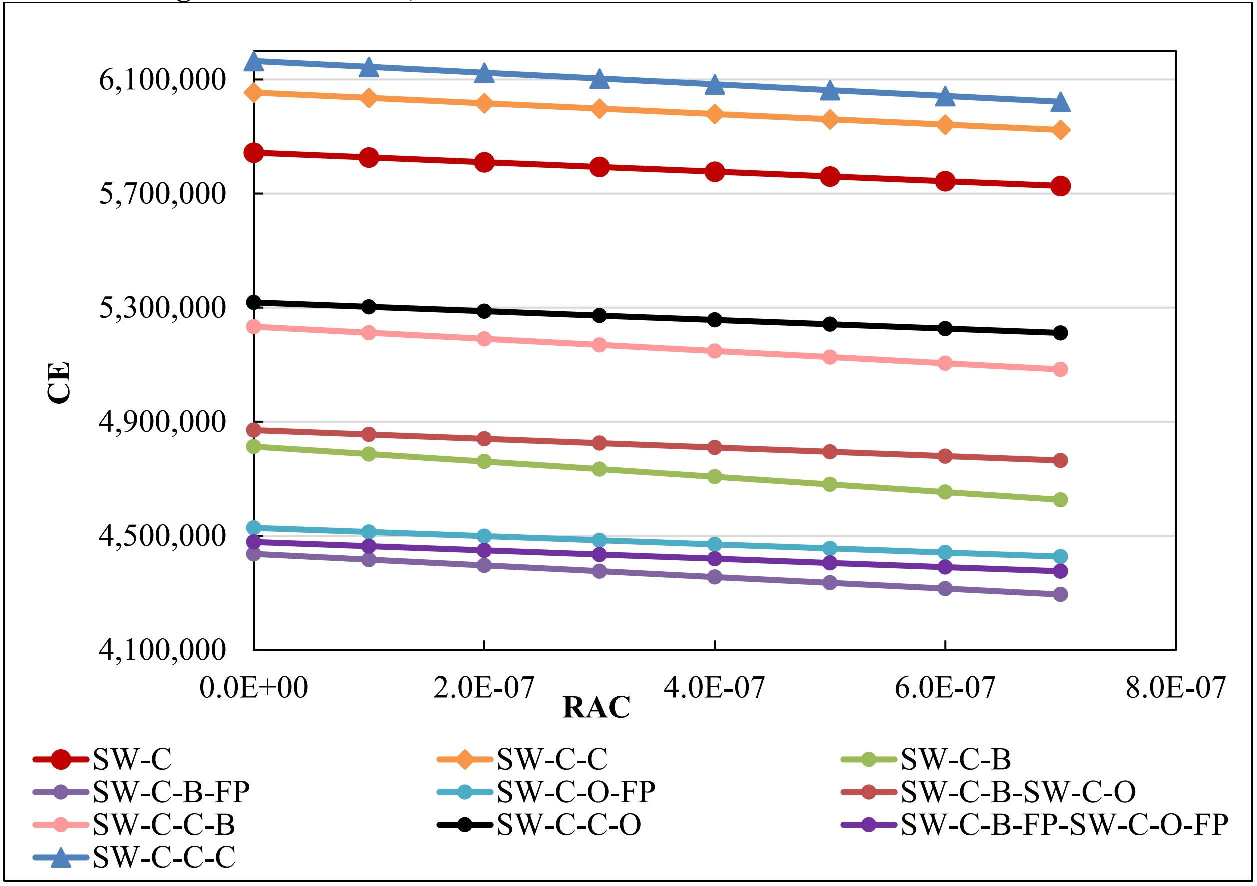
Table F.6 – Mean NPVs and standard deviations without BRM payments, Saskatchewan

Rotation	NPV	Std. Dev.
SW-C	$3,786,070.02	$724,991.56
SW-C-C	$3,662,027.55	$673,060.57
SW-C-C-C	$3,602,284.90	$665,139.17
C-SW-F-SW	$3,495,362.27	$693,310.20
C-SW-F-C	$3,312 ,364.86	$607,358.86
SW-C-C-O	$3,105,473.31	$557,924.60
SW-C-O-F	$3,026,649.45	$532,521.60
SW-C-B-F-SW-C-O-F	$2,970,705.54	$536,015.97
SW-C-C-B	$2,915,184.04	$571,061.71
SW-C-B-F	$2,913,783.14	$546,974.32
SW-C-B-SW-C-O	$2,872,382.31	$558,485.34
SW-C-B	$2,746,092.81	$575,054.22
SW-C-O-FP	$2,674,243.31	$565,337.19
SW-C-B-FP-W-C-O-FP	$2,540,830.87	$565,586.13
SW-C-B-FP	$2,404,351.81	$573,998.74

Note: Rotations are ranked by the expected NPVs without no AgriStability in descending order.

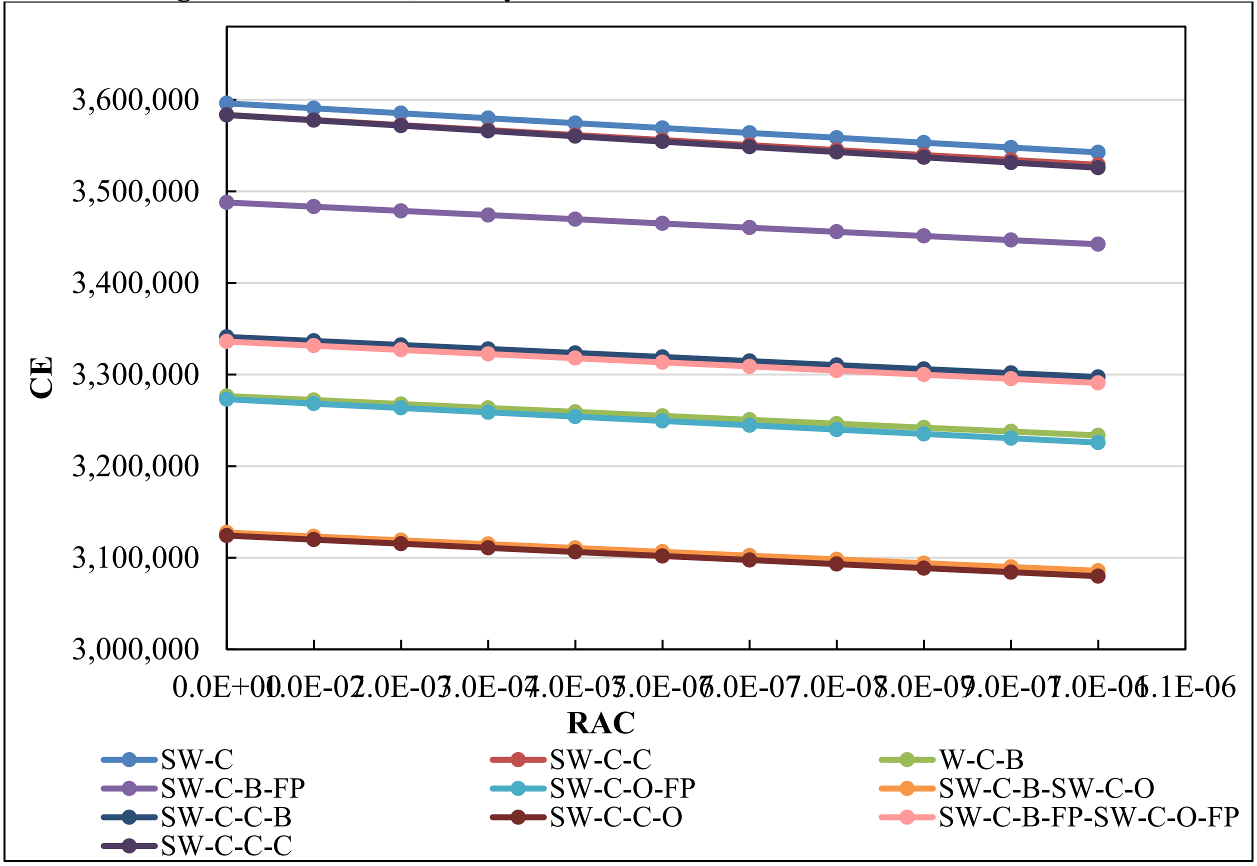
APPENDIX G – SERF Plots of Rotations in Alternative Model Scenarios

Figure G.1 – SERF results of ten rotations without yield adjustment over the absolute risk aversion range of 0.0 – 8.0E-7, Camrose



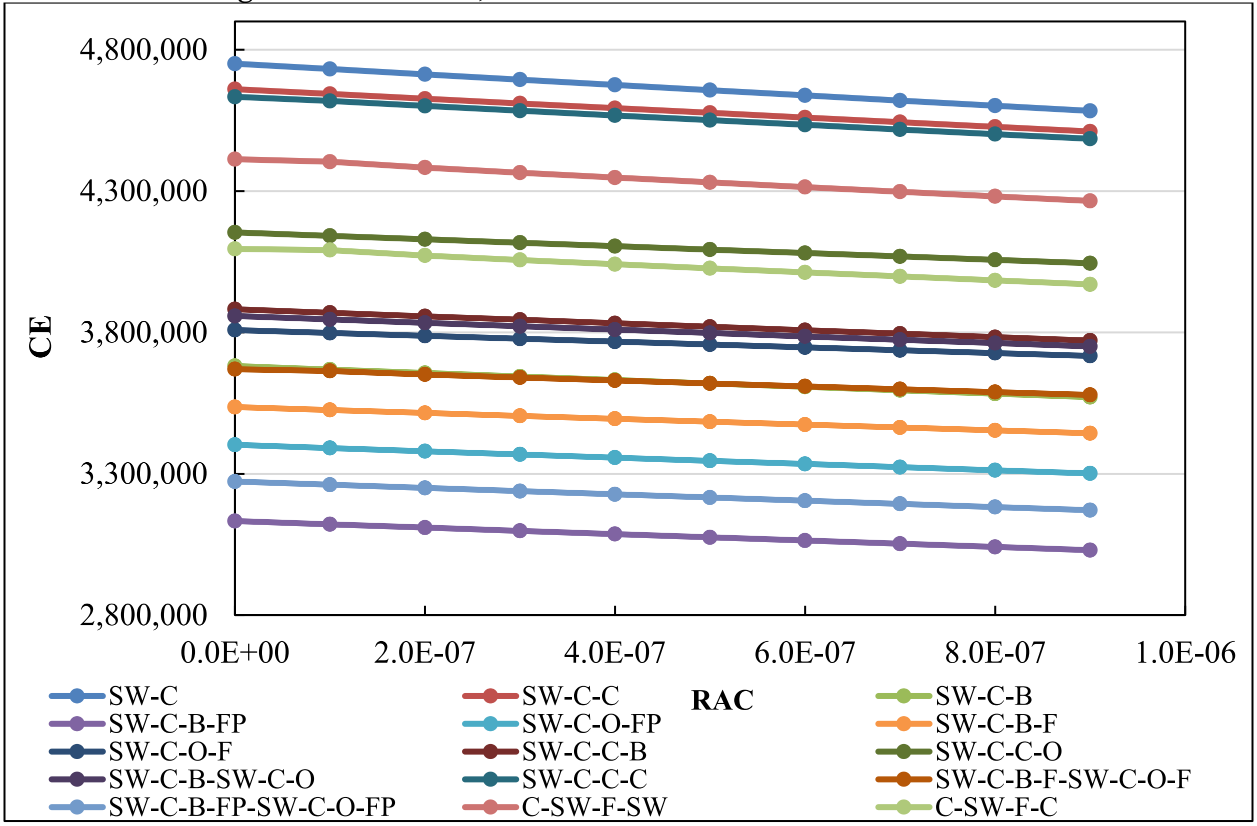
Note: Spring wheat, barley, canola, oats, field peas and flax are abbreviated as SW, C, B, O, FP and F, respectively as shown in the legend.

Figure G.2 – SERF results of ten rotations without yield adjustments over the absolute risk aversion range of 0.0 – 1.1E-6, Smoky River



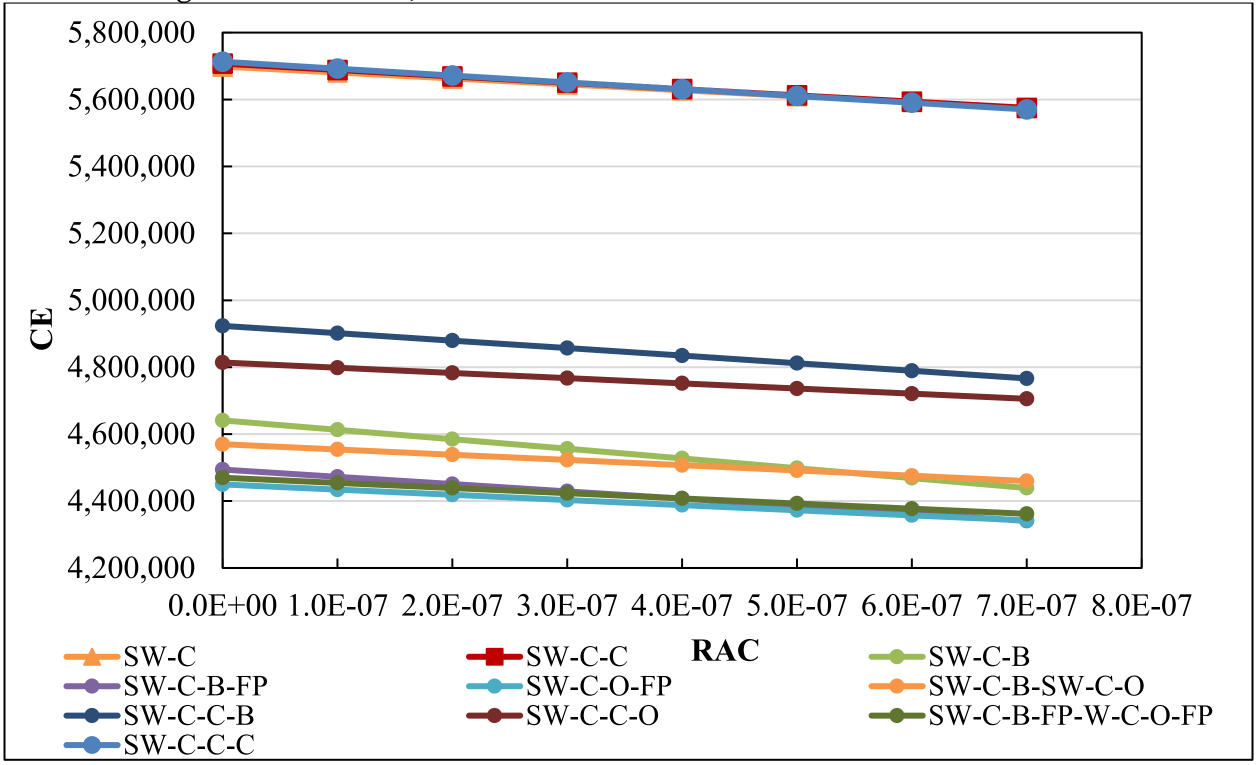
Note: Spring wheat, barley, canola, oats, field peas and flax are abbreviated as SW, C, B, O, FP and F, respectively as shown in the legend.

Figure G.3 – SERF results of fifteen rotations without yield adjustments over the absolute risk aversion range of 0.0 – 1.0E -6, Saskatchewan



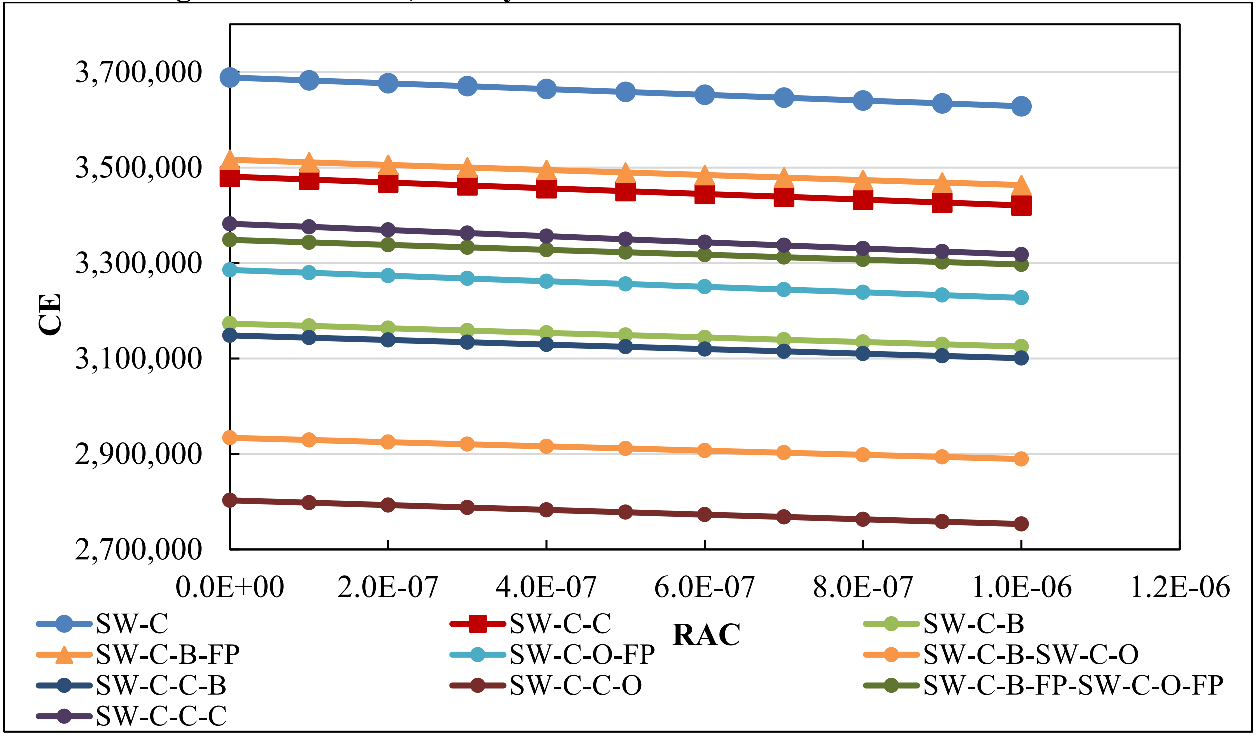
Note: Spring wheat, barley, canola, oats, field peas and flax are abbreviated as SW, C, B, O, FP and F, respectively as shown in the legend.

Figure G.4 – SERF results of ten rotations without AgriStability over the absolute risk aversion range of 0.0 – 8.0E-7, Camrose



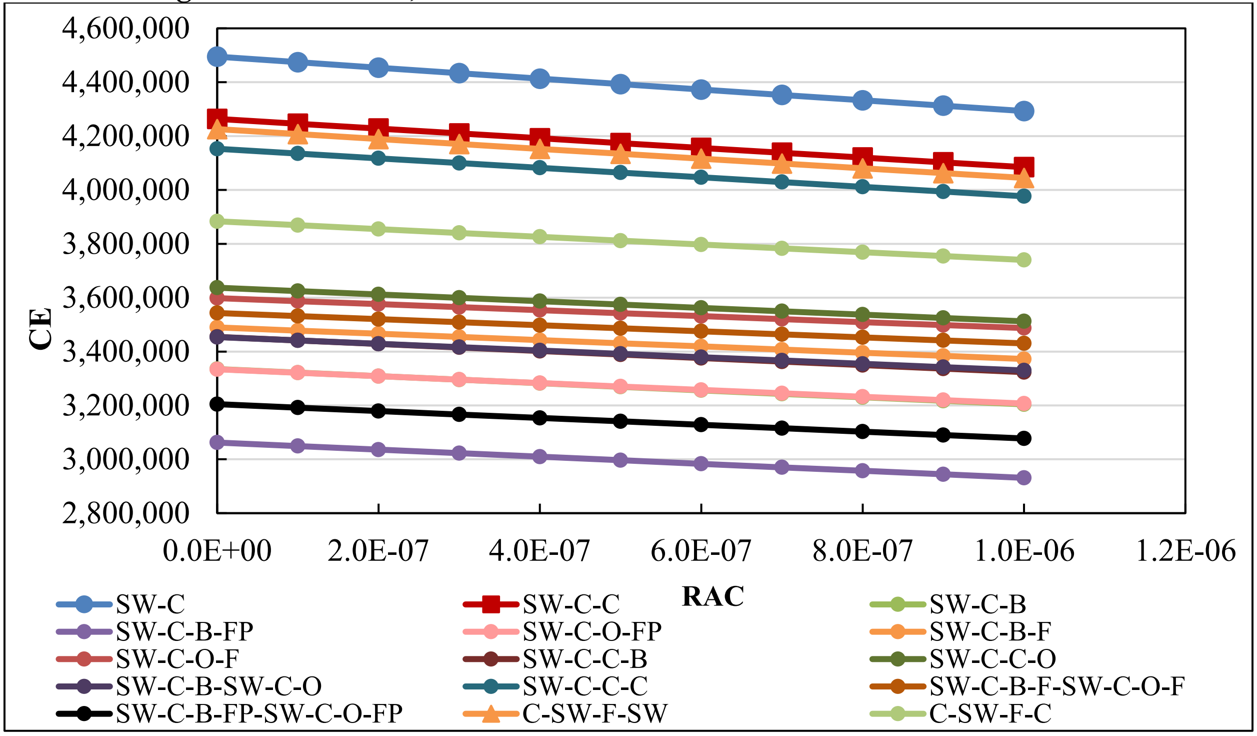
Note: Spring wheat, barley, canola, oats, field peas and flax are abbreviated as SW, C, B, O, FP and F, respectively as shown in the legend.

Figure G.5 – SERF results of ten rotations without AgriStability over the absolute risk aversion range of 0.0 – 1.1E-6, Smoky River



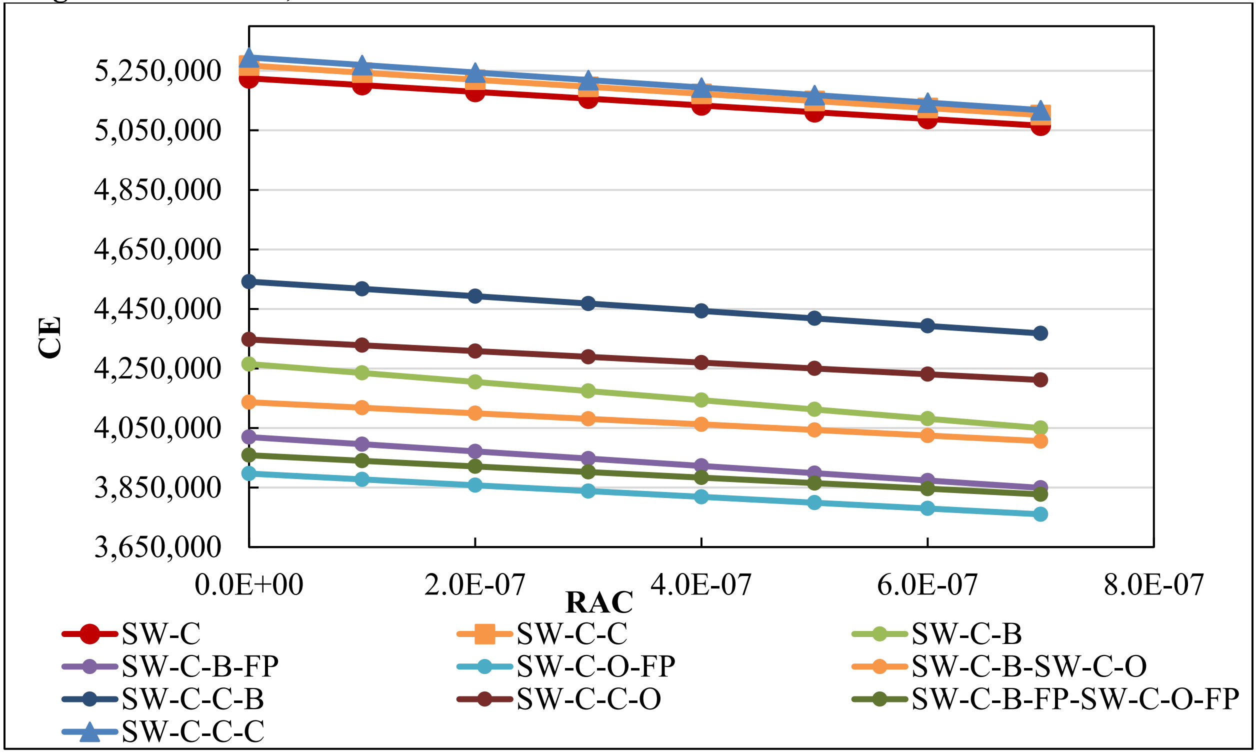
Note: Spring wheat, barley, canola, oats, field peas and flax are abbreviated as SW, C, B, O, FP and F, respectively as shown in the legend.

Figure G.6 – SERF results of fifteen rotations without AgriStability over the absolute risk aversion range of 0.0 – 1.0E-6, Saskatchewan



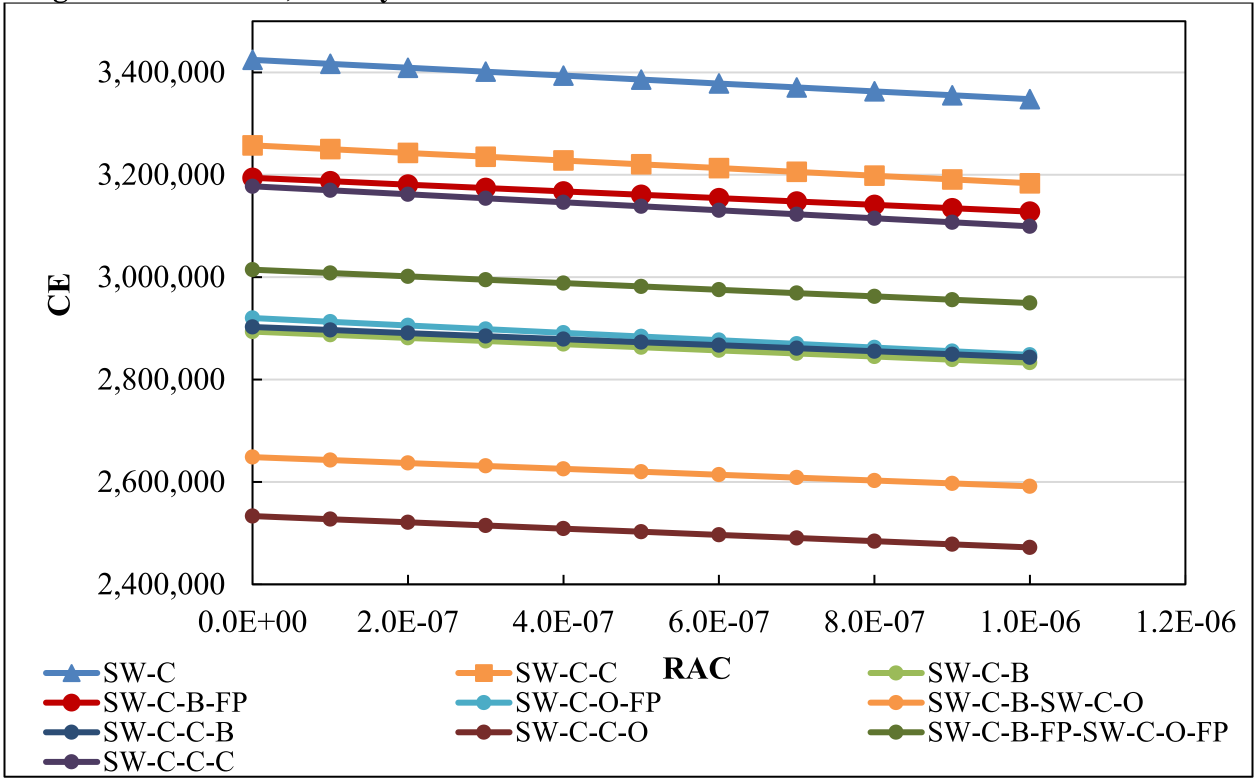
Note: Spring wheat, barley, canola, oats, field peas and flax are abbreviated as SW, C, B, O, FP and F, respectively as shown in the legend.

Figure G.7 – SERF results of ten rotations without BRM over the absolute risk aversion range of 0.0 – 8.0E-7, Camrose



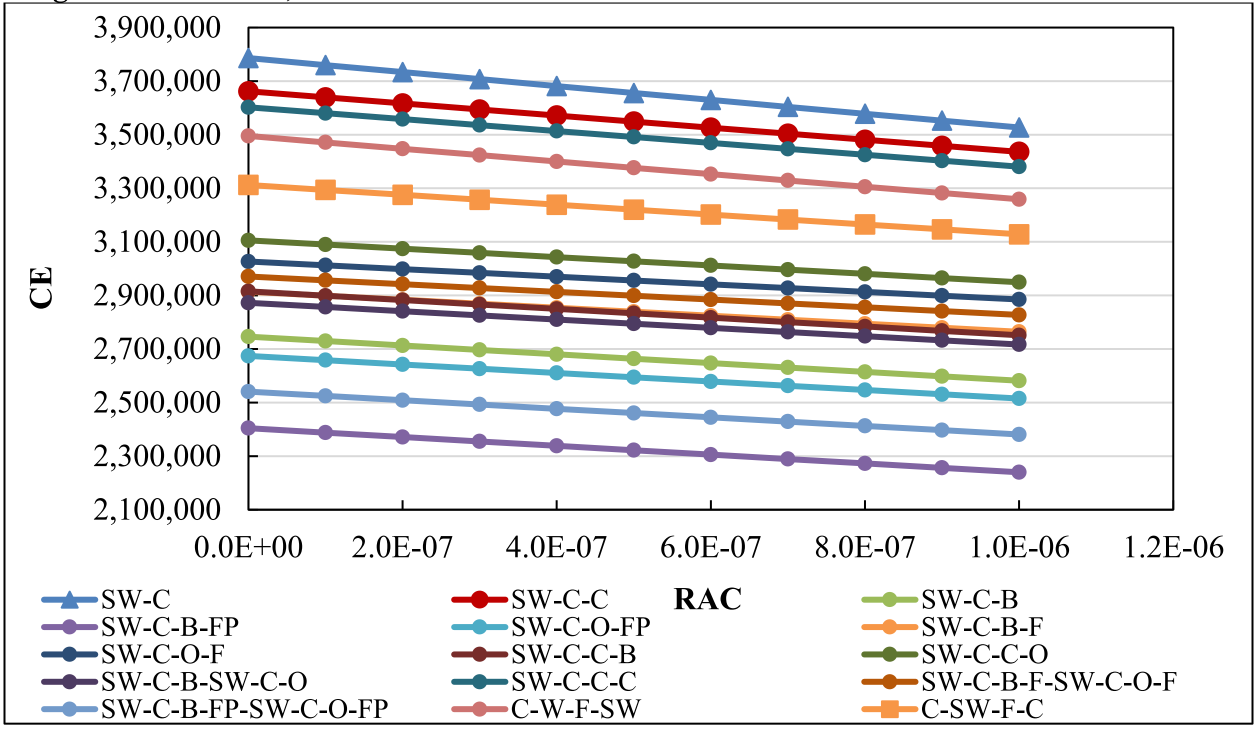
Note: Spring wheat, barley, canola, oats, field peas and flax are abbreviated as SW, C, B, O, FP and F, respectively as shown in the legend.

Figure G.8 – SERF results of ten rotations without BRM over the absolute risk aversion range of 0.0 – 1.1E-6, Smoky River



Note: Spring wheat, barley, canola, oats, field peas and flax are abbreviated as SW, C, B, O, FP and F, respectively as shown in the legend.

Figure G.9 – SERF results of fifteen rotations without BRM over the absolute risk aversion range of 0.0 – 1.0E-6, Saskatchewan



Note: Spring wheat, barley, canola, oats, field peas and flax are abbreviated as SW, C, B, O, FP and F, respectively as shown in the legend.