University of Alberta

Farm-level Costs and Benefits of Beneficial Management Practices for Irrigated Crop Production Systems in Southern Alberta

by

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Abstract

This study conducted analysis to model adoption of Beneficial Management Practices (BMPs) by a representative irrigated cropping operation in southern Alberta. Three base rotations were developed that include combinations of cereals/oilseeds, dry beans, potatoes and sugar beets. Stochastic irrigation application costs, crop prices and yields were incorporated in the analysis, along with participation in public business risk management programs. Farm-level costs and benefits of BMPs, including adding alfalfa and green manure into rotations, applying cattle manure, crop residue management, and nutrient management planning, were estimated using Monte Carlo simulation and Net Present Value analysis methods.

According to this study, most of the BMPs are costly to producers except for applying cattle manure and nutrient management planning BMPs. Thus, to encourage the adoption of BMPs, economic incentives may be required for the "costly" BMPs, while information programs may be used for the economically feasible BMPs.

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Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1. Background

Alberta is the major center of irrigated crop production in Canada. Irrigated farms in Alberta account for 65% of the national irrigated area (AARD 2000). Most of these farms are located in the southern part of the province (AARD 2000). Irrigated farmland in Alberta, while it accounts for only 5% of the provincial cultivated land, generates almost 20% of the province's gross primary agricultural production (AARD 2010).

Irrigation is used in southern Alberta because the annual precipitation (300-450 mm) is not enough for crop growth in the growing season (approximately 150 days) (AARD 2010). For example, in the southeast, the combination of abundant sunshine, suitable temperatures and a long growing season results in an additional 380 mm of water supply being required annually for agriculture (AARD 2010). In the other southern parts of the province, the additional water demand for agriculture is less than in the southeast, but there is still a moisture deficit due to a combination of warm windy conditions (AARD 2010). Irrigation is crucial to agriculture in southern Alberta (AARD 2000). Moreover, with irrigation, a farm can have more choices of crops (AARD 2010). In addition to cereal and forage, oil seeds and specialty crops such as potatoes and sugar beets can be grown on the farm. The diverse crop planting also encourages the development of local value-added processing and the agricultural industry (AARD 2010).

Coupled with the advantages of irrigation, there are environmental concerns, especially water quality issues, due to the expanded agricultural production and irrigation. Prior research work in Alberta has demonstrated increases in concentrations of nutrients, bacteria, and pesticides in surface water as agriculture production is intensified (CAESA 1998-a; Lorenz et al. 2008). Irrigated crop production is an intensive agricultural activity because it requires high rates of fertilizer and pesticides (Little et al. 2010). Irrigation return flows have degraded the water quality in the Lower Little Bow River in southern Alberta (Little et al. 2003). Along with the degraded water quality, human and ecosystem health are both threatened (Shortle et al. 2001). The degraded water carries sediments and pollutants, which can harm the drinking water supply (Shortle et al. 2001). The agricultural products produced by using the contaminated water might not be safe to consume (Ongley 1996). In addition, the lower quality of water threatens the aquatic and riparian habitat, as well as impairs the water for public recreation use (Shortle et al. 2001).

To reduce or eliminate the environmental detriments from farming, farmers may adopt Beneficial Management Practices (BMPs) (AAFC 2000-a). BMPs are any on-farm practices that aim to improve the environment as well as maintain agricultural production through decreasing runoff and protecting habitats (Chambers et al. 2012). Agriculture and Agri-Food Canada (AAFC) (2000-a) classified BMPs into three general types: input reduction, erosion and runoff control, and barriers and buffers. Reducing inputs means less fertilizer, pesticides, and/or herbicides are needed, thus reducing the potential for pollution (AAFC 2000-a). One example is nutrient management planning. In this BMP, fertilizer is applied to fill the difference between the available nutrients in the soil and the required nutrients based on the target yield (AAFC 2000-b). BMPs such as shelterbelts, cover crops, and residue management are used to control erosion and runoff (AAFC 2000-a). The barriers and buffer zones are used to intercept contaminants from farmland to water bodies (AAFC 2000-a).

1.2. Economic Problem

It takes money and time to implement a BMP on a farm (Brethour et al. 2007). Adopting BMPs might bring about potential yield benefits and input savings due to better growing conditions and more efficient use of inputs. However, in many cases, these benefits may not totally offset the costs of implementation and maintenance (Koeckhoven 2008; Trautman 2012). The net on-farm cost of BMP adoption can discourage farmers from implementing BMPs. Since BMPs are beneficial for providing ecosystem services (e.g., improving water and air quality and biodiversity) but not all come with net on-farm benefits, policy interventions are often required to encourage farmers to adopt the practices.

According to the framework developed by Pannell (2008), an appropriate policy decision on a land-use change or production practice is based on the relative signs and magnitudes of private net benefit and public net benefit. The private net benefit is equal to benefits minus costs that a producer gains from changing land use or adopting a new practice (Pannell 2008). The public net benefit equals benefits minus costs for everyone else (Pannell 2008). For example, when buffer strips are implemented on a farm, a part of farmland which is used for cash crop production is left idle. The farm will generate less revenue than before. Thus, the net benefit for the farmer to adopt buffer strips is negative. For the public, buffer strips can work as a potential filter to reduce runoff of agricultural chemicals and sediments. The public net benefit of producers adopting buffer strips is positive.

Pannell (2008) indicated that if the private net benefit of a practice is positive, land holders will adopt the practice without any incentive; If public net benefits are greater than private net cost[1], positive incentives are necessary to encourage the adoption. In order to develop an appropriate policy on BMP adoption, it is essential that farmers and the public understand the private and public benefits of BMPs. However, there is currently limited information on the private and public net benefits of BMPs, especially on irrigated farms in Alberta. This limits the ability of stakeholders to make informed policy decisions. To fill this gap in literature, this study will evaluate the private net benefit of BMPs on an irrigation farm.

1.3. Research Problem and Objectives

The overall objective of this study is to analyze the on-farm costs and benefits of BMP adoption for an irrigated crop production system in southern Alberta. More specifically, it will:

- identify relevant characteristics for a representative irrigated crop production system in southern Alberta,
- determine the water-related BMPs that can be used on the irrigated representative farm,
- quantify each on-farm cost and benefit from BMP adoption,
- establish whether BMP adoption is economically feasible on the representative farm.

The results of this study can provide a basis both for irrigated farmers to make informed decisions on implementing a BMP and for policy makers to develop a better policy intervention to encourage BMP adoption. The BMPs chosen and analyzed are aimed at crop production maintenance and water quality preservation and protection. These BMPs are:

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[1] The negative private net benefit is also known as private net loss.

- adding alfalfa into rotations,
- adding green manure into rotations,
- crop residue management,
- applying cattle manure,
- nutrient management planning.

The farm-level costs and benefits from BMP adoption will be quantified using capital budgeting techniques in conjunction with a Monte Carlo simulation. The Monte Carlo simulation is applied to imitate the cash flows over time. The capital budgeting technique is used to convert the cash flows over time to net present values, enabling the comparisons between the scenarios with and without BMP adoption. By the scenario and sensitivity analyses, several research problems will be addressed:

- Is it economically feasible to adopt a BMP in a specific rotation on an irrigated farm in southern Alberta?
- Is there any difference in net on-farm benefit or cost for a BMP across the rotations? If yes, what causes the differences?
- How sensitive are the results of economic feasibility of BMPs to changes in economic variables (e.g., crop prices, fertilizer prices) and production variables (e.g., crop yields, crop rotations)?

1.4. Organization of the Thesis

There are six chapters following this introduction. Chapter 2 provides a detailed literature review on the BMPs evaluated in this study and the empirical methods used to analyze the economics of BMPs. Chapter 3 presents the information on the study area, which is the Lower Little Bow Watershed. The methodology applied in this study is discussed in Chapter 4. Chapter 5 includes the detailed description of the representative farm, BMPs evaluated, and the simulation models. The results and discussion are presented in Chapter 6, followed by conclusions, model limitations and future research in Chapter 7.

Chapter 2. Literature Review of BMPs

This chapter presents a summary of knowledge and studies that have been established on BMPs. The main purpose is to introduce the BMPs that are included in this study and the empirical methods for economic evaluation of BMPs. There are many BMPs that can be considered for inclusion in this study. Examples include establishing buffer strips or shelter belts, adjusting crop rotations, adopting conservation tillage, wetland restoration or nutrient management planning. For the purposes of this study, two criteria were used in identifying the BMPs of interest. First, since the focus of the study is to address the effects of agricultural production on water quality, the BMPs selected for modeling had to be shown or hypothesized in the scientific literature to have a positive effect on water quality in some way. Second, BMPs modeled in this study had to be ones that would actually be considered by irrigated crop production operations. Expert opinion and review of relevant literature were used to identify BMPs that satisfied the second criterion.

Five BMPs were selected on the basis of these two criteria. These are adding alfalfa into the crop rotation, adding a green manure crop into the crop rotation, adopting crop residue management, applying cattle manure on fields to replace a portion of inorganic fertilizer, and nutrient management planning.

For each BMP, the background information covers the effects of BMPs both on the environment and crop production. Generally, most of the information on the environmental effect of BMPs is from government and organization reports and projects. The effects of BMPs (or farming practices) in farming are from prior scientific research. The historical research provides a basis for evaluating and quantifying the changes in net private benefit when the representative farm adopts BMPs. The previous empirical methods for economic evaluation of BMPs can be used to identify alternative methods applied in this study and any information gaps in the literature. Since this study is evaluating the farm-level costs and benefits of BMPs, the literature review focuses more on the impacts of BMPs on production and empirical methods for economic evaluation of BMPs.

2.1. Beneficial Management Practices of Interest

2.1.1. Adding Alfalfa into Rotation

Alfalfa, a perennial legume, is known and widely grown for its hardiness, productivity and high nutritional value (SMA n.d.). It was first planted successfully in Alberta in 1908 and is currently the most widely used legume in the province (AARD 2009-a).

2.1.1.1. Environmental Effects of Adding Alfalfa into Rotation

Adding alfalfa into rotations results in a series of environmental benefits. Firstly, alfalfa can fix nitrogen from the air to its roots (Putnam et al. 2001; AARD 2009-a). The yearly nitrogen fixation is 121 kg/acre by alfalfa under irrigation in southern Alberta (AARD 2009-a). Once the organic nitrogen fixed by the alfalfa is decomposed by soil microbes, it provides a significant source of nitrogen to the subsequent crops (SMA n.d.). Less inorganic nitrogen is needed in the following production, thus reducing the inorganic nitrogen in runoffs and improving water quality (Putnam et al. 2001). Secondly, alfalfa has vigorous canopies to cover and stabilize the soil from wind and water erosion (Putnam et al. 2001). In addition, the canopy can intercept the sedimentation in the runoff, protecting water from sedimentation (Putnam et al. 2001). Thirdly, alfalfa has an extensive and deep root structure (Putnam et al. 2001; Putman 2003). This root system can hold and sustain the soil (Putnam et al. 2001). The channels generated by the roots can be used for water infiltration and as habitats for microorganisms (Putnam et al. 2001). Lastly, growing alfalfa is an effective means to control diseases, insects and weeds in cereals and oilseeds production (SMA n.d.). It can reduce the use of pesticides and herbicides, leading to fewer residues in the soil and lower runoffs in the water (Putnam et al. 2001).

Alfalfa is a high water-demand crop (AARD 2011-a). Coupled with the benefits come drawbacks, one of which is that adding alfalfa into rotations has been found to cause soil moisture shortages in the following year. Brandt and Keys (1982) indicated that including alfalfa into rotations in the Dark Brown soil zone led to soil moisture shortages in following year. Hoyt and Leitch (1983) and Entz (1994) found that in Black and Gray soil zones, subsoil was drier when growing alfalfa.

2.1.1.2. Effect of Alfalfa into Rotations on Crop Production

2.1.1.2.1. Effect of Alfalfa/Forage into Cereal (wheat and barley) Rotation

Hoyt and Henning (1971) studied the effect of alfalfa and grasses on the yield of wheat following it. In the research, fertilizers were only applied on the fifth year of wheat following the breakup of alfalfa in the rotation. Hoyt and Henning found that compared with yields of wheat following fallow with no additional fertilizer applied, yields of the first, second, fourth and fifth wheat following alfalfa increased by 71%, 82%, 75% and 68% respectively. Yields of subsequent wheat were not affected by the age of the forage stand in a range of two to six years. Hoyt and Henning also found that adding alfalfa into rotations when growing wheat could increase the permeability of subsoil, leading to strong growing tap roots of wheat.

Hoyt and Leitch (1983) determined the effect of different legume hay species on the yield of barley crops following it. Five legume species were used in this study: alfalfa, bird's-foot trefoil, alsike clover, red clover, and sweet clover. If a high rate of N fertilizer coincided with P and K, and S fertilizers were applied to barley production, there was no difference in barley yields between following legume and following fallow. However, if only K, P, and S fertilizers were added to barley production, yields of barley following legumes were much higher than those following fallow in three of five study regions. However, it is not clear if total nitrogen available for the subsequent crops was controlled in this analysis. Therefore, it is not possible to determine to what degree the yield increase was due to increased N fertilizer available versus some other type of yield effect.

Entz et al. (1995-a) conducted a survey to learn whether farmers get weed control and yield benefit from including perennial forage into the rotations, and to determine whether the rotational benefits of adding perennial forage differ from one agroclimatic zone to another in western Canada. According to the survey, 67% of producers reported an increase in yield when including forage in dryland rotation. The biggest yield benefit was found in wetter areas. About 93% of farmers reported having fewer weeds in grain crops following forage. Many farmers also reported that they used less herbicide in grain crops following forage. In addition, the results of the survey showed that most producers tried to maximize forage stand life and only broke up forage when its productivity declined and weeds became too much to control. Tillage was the most widely used method to terminate the forage stand.

Entz et al. (1995-b) argued that although many farmers have observed the benefits of including forage, few included the forage into the rotation. The authors suggested shortening the forage stand to three or four years. That is because the benefits of a three-year stand of weed suppression and nitrogen are almost the same as those for a six-year stand. The result of reducing weed population from the one-year forage hay and silage crops is the same as herbicides applied in cereal crops. The authors also found that the no-till approach in forage stand establishment and termination has benefits that include enhancing weed suppression, improving the efficiency of alfalfa nitrogen, and increasing the economics of shorter forage stands.

2.1.1.2.2. **Effect of Adding Alfalfa/Legumes into Potato Rotation**

The potential benefits of growing legumes in the potato rotation are as follows: supplying biologically fixed N to the soil, increasing the yield and quality of the potato, suppressing potato diseases (especially soil-borne diseases), creating better physical properties in the soil, and providing N to succeeding crops (Griffin and Hesterman 1991; Stark and Poster 2005).

Emmond and Ledingham (1972) studied the effect of crop rotation on the same soil-borne pathogens of potatoes. The yields of potato tuber were significantly higher in the potato-sweet clover (two years) rotation (23.4% higher than the continuous rotation), followed by the potato-alfalfa (four years)-grass rotation (11.69% higher than the continuous rotation), and the continuous potato rotation. The one-year potato and two-year sweet clover rotations performed best in disease control, while the continuous rotation was the worst.

A similar result was found by Honeycutt et al. (1996). Tuber yields of potato grown in two-year rotations with either annual alfalfa or hairy vetch were higher than yields in continuous rotation. Honeycutt et al. (1996) indicated that the yield increase was from reduced stem infection by disease and N contribution from alfalfa and vetch.

Although some research found yield benefits from including legume into potato rotations, several studies indicated that growing legume did not affect the potato yield. For example, Griffin and Hesterman (1991) found that although vine dry matter and N content were higher in potato following legumes than in potato following non-legume, potato tuber yields did not change in different rotations. That was because the N released from the legume might come too late in the growing season to affect tuber initiation. In Plotkin's (2000) research, legumes were found to provide N to subsequent potato crops. However, the benefit of N from legume was found to be significantly affected by weather and can vary greatly (Plotkin 2000).

2.1.1.2.3. Effect of Adding Alfalfa/Legume into Sugar Beet Rotation

Stockinger et al. (1963) demonstrated that legume could influence sugar beet yield and quality by changing the availability and supply of soil nitrogen. The cropping system, including alfalfa with no fertilizer application, generated the highest yield of sugar beet compared to the non-forage/non-fertilizer system, non-forage /adding low or high fertilizer systems, sesbania[2]/non-fertilizer system, and adding steer manure/non-fertilizer system. The sugar beet yield in the alfalfa/non-fertilizer systems was 58% higher than the yield from the non-forage/non-fertilizer system. Once additional N fertilizer was applied at a rate of 180 lb/acre to grow sugar beets, the alfalfa/fertilizer system generated the highest yield of sugar beet, which was 15% greater than the yield from the system without fertilizer application. The yields from other systems (the sesbania/fertilizer system, the steer manure/ertilizer system) were not significantly different from the yield in the system of adding only fertilizer and non-forage. If the N fertilizer was applied at 420 lb/acre, yields of sugar beet from different systems were all the same. Moreover, it was found that increasing the N fertilizer application reduced the percentage of sucrose and the purity of sugar in the sugar beets.

The relationship between N fertilizer and sugar beet yield is summarized by Carlson and Bauder (2005) as follows: too much N fertilizer application leads to a high root yield, low sucrose content, and high impurities in concentration. Too little N causes an increase in sucrose yield and quality, and a reduction of the root yield.

2.1.2. Adding Green Manure into Rotation

Green manuring is a practice that involves growing a crop and incorporating it into the soil after the growing season (AARD 1993). Generally almost every crop can be grown as green manure, but legumes are most widely used due to their natural ability to fix N

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[2] Sesbania is an annual summer legume.

(AARD 1993). Legumes used for green manure include peas, clover, lentil, and vetch (AARD 1993).

2.1.2.1. Environmental Effects of Adding Green Manure

The environmental benefits of including legume green manure were summarized by AARD (1993) and MAFRI (2012) as follows. Firstly, legumes can fix nitrogen from the atmosphere, which is available to following crops. Thus, less inorganic nitrogen is applied on crops following green manure, decreasing runoffs of inorganic nitrogen. Secondly, incorporating green manure can maintain or increase soil organic matter and improve the physical quality in the soils (i.e., water infiltration, moisture storage capacity, soil stability, and resistance to erosion). Thirdly, growing green manure crops is a method similar to establishing cover crops; it can reduce soil lost to wind and water erosion during the growing season. Lastly, an effective green manure practice can smother weed growth and suppress insect and disease cycles. It can decrease the need for pesticides and herbicides, thus reducing the residues in both in the soil and water. One environmental concern for green manure is the moisture use (GOS 2008). The green manure crops can deplete the soil moisture, resulting in not enough moisture being available for crops in the following year (GOS 2008).

2.1.2.2. Effects of Adding Green Manure on Crop Production

As mentioned above, nitrogen fixed by green manure crops can provide nitrogen for subsequent crops, thus saving inorganic nitrogen fertilizer application. However, Dunn (2011) indicated that it is not common for conventional farmers to grow legume just for nitrogen supply. Implementing green manure BMP turns a field from cash crop production to green manure crop production for one year, generating no income in that year but leading to the nitrogen benefit to the succeeding crops (Dunn 2011; Martens and Entz 2011). Conventional farmers do not consider the practice economically feasible (Martens and Entz 2011). Moreover, some research findings are not consistent with ARRD (1993) or MAFRI (2012). Pang and Letey (2000) argued that a great part of organic nitrogen from green manure is too stable to be decomposed and absorbed by subsequent crops.

Another benefit from green manure is that it creates better growing conditions for subsequent crops, such as improving soil structure and reducing weeds, diseases and insects (AARD 1993; MAFRI 2012). Dunn (2011) indicated that growing green manure crops prior to potato may control disease in potato production. The disease suppression from green manure is more valuable than nitrogen credit for potato growers. In addition, potato is a high revenue crop, making it possible to justify forgoing one year of crop revenue in exchange for reaping the benefits of green manure.

The increase of potato yield following green manure was found by Sincik et al. (2008). They did a study to determine the effect of three different green manure crops (common vetch, fababean, and winter wheat) on tuber yield and quality of potato with four rates of nitrogen application. They found that when taking the average over all fertilizer rates, tuber yields of potato grown succeeding common vetch and fababean increased 12.7% and 15.0%, respectively, in comparison to potato following winter wheat. If no fertilizer was applied, tuber yields of potato succeeding common vetch and fababean increased from 36% to 38%, compared with potato following winter wheat. The highest tuber yield of potato was in the rotation with green legume manure and nitrogen fertilizer application. Similar research by Boydston and Hang (1995) found that the tuber yield of potato after green manure (rapeseed) was 17% greater than after fallow due to the function of weed control from rapeseed.

2.1.3. Crop Residue Management

Crop residues are materials, including straw, chaff and roots, left on the farm after harvesting (AARD 2004-a). The amount of crop residue produced depends on the crop's characteristics (e.g., type and variety) and yield (AARD 2004-a).

There are three methods used to manage crop residues: burning, baling and removing as feed or bedding for livestock, and leaving on the field (Chandiramani et al. 2007). Residue burning is an economical method to remove residue and increase the nitrogen supply to following crops in the short term (Chandiramani et al. 2007). However, burning residues has negative impacts on air quality, soil physical properties, and long-term soil nitrogen and carbon levels (Chandiramani et al. 2007). On an irrigated farm, burning residues can also reduce irrigation efficiency (Verhulst et al. 2009). That is because a farm with residue burned has a larger outflow of irrigation water than a farm with retained residue. On a residue-burned farm, more irrigated water will be released to drainage before it will be used by crops (Verhulst et al. 2009). Residue removal by baling can contribute an additional economic benefit to crop production, while there is a potential long-term cost due to the degradation of soil quality (Smith et al. 2004).

Leaving residues on a farm not only reduces soil erosion, but also enhances water infiltration and the soil's nutrient cycle (Dunn 2008). However, on irrigated farms, to prevent the low seeding vigour and the high risk of frost damage due to low soil temperatures from heavy residues, the residues should not be over-loaded (AARD 2004-a).

2.1.3.1. Effect of Crop Residue Management on the Environment

Carefoot et al. (1994) conducted field studies to assess the effect of straw-tillage treatment on the growth of irrigated cereals in southern Alberta. They found that spring incorporation of straw and direct seeding led to better soil conservation and less soil erosion.

Dormaar and Carefoot (1998) examined the effects of straw management on cereals and the additional application of fertilizer on selected soil properties on an irrigated farm in Lethbridge. There were five straw treatments in their study: chopped straw[3] and fall tillage, chopped straw and spring tillage, straw baled[4] and fall tillage, straw baled and spring tillage, and straw baled and direct seeding. Straw baled and fall tillage was the most widely used method in southern Alberta on irrigated farms, followed by straw baled and spring tillage. Dormaar and Carefoot found that straw baled and direct seeding led to the highest level of soil bulk density[5] while fall tillage treatment led to the lowest. The highest levels of total organic N and C in the soil were in the field with straw baled and tillage treatment. The highest mineralizable C and N levels were found in the field with treatments of chopped straw and fall tillage and high applications of fertilizer. Both straw baled and direct seeding and high fertility treatments caused the highest biomass C.

Potato, sugar beet, and dry bean are all low-residue crops. Although the risk of erosion in those crops could not be eliminated, it could be minimized (AARD 2005-a). Generally, if a crop with a small amount or easily decomposable residues is grown in one year, a different crop with high residues should be grown in the following year to reduce soil erosion and balance the soil organic matter (Dunn 2008). If cereal is grown before or

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[3] In this case, straw is chopped and spread on a farm.
[4] In this case, straw is baled and removed from a field.
[5] Bulk density is used to measure soil compaction (USAD 2008). The bulk density decreases as the soil structure improves (USAD 2008). Growing cover crops, leaving crop residues and/or reducing tillage can reduce soil bulk density by increasing soil organic matter and/or decreasing soil disturbance (USAD 2008).

following sugar beet or potato, leaving all straw on the farm is considered a practical means to improve soil quality, but this practice has not been widely adopted (Dunn 2008).

2.1.3.2. Effects of Crop Residue Management on Crop Production

According to Carefoot et al. (1994), although a farm could have seedbed problems and less N availability with treatments of spring incorporation of straw and direct seeding, irrigated cereal crops were still productive with adding inorganic N fertilizer. Karlen et al. (1984) indicated that removing straw did not affect yields of crops the way that leaving straw on the farm did.

In recent years, potato, sugar beet and bean production has applied less intensive tillage in land preparation (Dunn 2008). The practices of zone-tillage[6] and growing cover crops can provide extra protection to reduce soil erosion and enhance soil quality (Dunn 2008). Growing post-harvested cereal cover crops or winter wheat tends to be common in potato and bean production (Dunn 2008). However, it is difficult for most potato farms to harvest potatoes in time; thus, cover crops cannot grow large enough to reduce wind erosion (Dunn 2008). In order to prevent wind erosion, fall chiseling is applied on most potato, bean and sugar beet farms (Dunn 2008). Chiseling plow can make a rough surface and leave residue on the surface. Fall chiseling cuts and incorporates residues, making the residues more susceptible than undistributed residues to decomposition and over-winter weathering (University of Nebraska-Lincoln 2012). Broadcasting cereal straws in the winter-spring period is also used on some potato farms with sandier soil types (Dunn 2008). The method helps to maintain soil and reduce erosion (Dunn 2008). There is a potential issue that a farm might not produce enough cereal residues to cover the potato field (AARD 2005-a).

2.1.4. Applying Cattle Manure

Applying livestock manure into soils is an old agricultural practice. Before the use of inorganic fertilizer, manure from livestock was an essential source to maintain soil quality. However, due to the availability of fertilizer, more and more chemical fertilizer is applied on farms to replace livestock manure (Watson et al. 2005).

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[6] Zone-tillage is a modified deep tillage, making a compromise between zero-tillage or reduced tillage (Wolkowski 1997). It just disrupts the soil in a narrow band which is about eight inches wide (Wolkowski 1997). Zone-tillage helps protect farm soil by incorporating residues and improving the seedbed environment (Hoover et al. 2002).

2.1.4.1. Effect of Manure Application on the Environment

Crop production, which relies highly on applying inorganic fertilizer, has led to a degradation of soil, reducing organic matter and biodiversity and increasing top-soil erosion (Zhu et al. 2005; Mozumder et al. 2007). To deal with issues arising from both livestock production and crop production, scientists believe that the most effective practice for using cattle manure is to apply it on farms (Caldwell 1998).

Applying manure to farm land has been found to have many benefits. It increases soil organic matter and thus raises the level of nutrient availability (Hao and Chang 2002; Mooleki et al. 2002). It helps to enhance the physical properties of soil, creating a better structure, drainage and water-holding capacity (Miller et al. 2002; Whalen and Chang 2002; Reynold et al. 2003). Application of manure can change the ecology of soil, such as increasing soil microbial biomass carbon (Lalande et al. 2003; Lupwayi et al. 2005) and enhancing soil enzyme activities (Lalande et al. 2003). There are environmental concerns with application rates and timing associated with the use of manure on cropland. These are discussed below in Section 2.1.4.3.

2.1.4.2. Effect of Manure Application on Crop Production

2.1.4.2.1. Effect of Manure Application on Cereal and Oil Seeds Production

Reddy et al. (2000) studied the effect of applying cattle manure alone or in combination with fertilizer P on crop yields under soybean-wheat rotation in P-deficient soil. The yields of wheat with just manure application at 4, 8, and 16 T/ha/year were 67%, 116%, and 143% higher than the control group (no manure and no fertilizer P). The yields of wheat with application of cattle manure in combination with fertilizer P increased by 159%, 181%, and 197% respectively, in comparison with the control group. Based on the results, the authors stated that the combined use of manure and fertilizer P could obtain better yields than just applying each component separately.

Ghanbari et al. (2012) conducted research on the effect of combining manure and chemical fertilizer on barley yield in Iran. Four combinations of manure and chemical fertilizer were examined: 100% manure, 50% manure and 50% fertilizer, 100% fertilizer, and 0% manure and 0% fertilizer. The highest yield of barley was found on the farm with 50% manure and 50% fertilizer application, which was 1.6% more barley than on the farm that applied only fertilizer. However, yields from farms using 100% fertilizer versus 50% fertilizer and 50% manure were not statistically different. The barley yield from applying only manure was statistically lower than the yield from farms applying only chemical fertilizer or 50% manure and 50% fertilizer. Based on these results, the authors indicated that combining fertilizer and manure could have a greater effect on the increase in grain yield than just applying either only fertilizer or only manure.

In research that Lupwayi et al. (2005) conducted in Northern Alberta, cattle manure, hog manure, or inorganic fertilizer was applied to different fields annually or triennially over three years to meet crop N requirements based on soil test recommendations. The grain yield from each field was compared to a control farm (no manure or inorganic fertilizer). The sequence of rotation was canola, barley, and wheat. In the first year, yields of canola were in the following order: hog manure (1.75*control) > cattle manure (1.49*control) > inorganic fertilizer (1.20*control) > control. But the yield from applying inorganic fertilizer was not statistically different than that from the control farm. In the second year, yields of barley were in the following order: cattle manure (1.25*control) > hog manure (1.06*control) > inorganic fertilizer (1.06* control) >control. The yield from applying cattle manure was statistically different from the yield on the control farm. In the third year, yields of wheat were in the following order: cattle manure (1.50*control) > inorganic fertilizer (1.33*control) > hog manure (1.32*control) > control. The yield from applying cattle manure was 50% higher than the yield from the control farm. Yields from hog manure application and inorganic fertilizer application were not statistically different from each other. According to the results of this study, farms that applied cattle manure produced the highest grain yields among different treatments in the second and third years.

In contrast, Miller et al. (2002) conducted research on both dryland and irrigated farm with cattle manure application in Lethbridge, Alberta. They found that manure application can enhance soil water retention and field water content, but it does not necessarily improve silage yield of studied crops (barley, canola, triticale and corn) in comparison to the yield from inorganic fertilizer application alone.

2.1.4.2.2. Effect of Manure Application on Potato Production

A three-year reduction in potato common scab after a single application of animal manure was found by Conn and Lazarovits (1999). However, Bailey and Lazarovits (2003) were concerned that applying animal manure would raise the incidence of the common scab in potato production.

Black and White (1973) noticed that applying manure could increase potato yields. The authors indicated that the yield increase was due to more soil organic matter, better soil structure and moisture-holding capacity, and improved cation-exchange capacity, rather than effects on nutrient supply.

Porter et al. (1999) found that the potato yield from farms using cattle manure as a soil amendment increased 23% compared to that without the amendment and the application of other fertilizers. They speculated that the possible contributing factors for yield increase in response to the amendment treatment were increased nutrient availability and/or improved soil bulk density.

Mallory and Porter (2007) conducted research to compare the yield and yield stability of potatoes in amended soil (manure, compost, green manure, and supplemental fertilizer) with the yield and yield stability in non-amended soil on dryland in Maine, US. In their research, the nutrient level in the amended soil was approximately the same as for that in the non-amended soil. They found that the tuber yield of potatoes from the amended soil was 4% to 54% higher than the yield from the non-amended soil. Yield stability was also improved in the amended soil. In other words, yield in the amended treatment was less sensitive to changes in rainfall than yield in the non-amended treatment.

2.1.4.2.3. **Effect of Manure Application on Sugar Beet Production**

Nitschelm and Regitnig (2005) conducted research to determine the extractable sugar content and beet yield of sugar beets after the application of composted manure and inorganic fertilizer in Taber, Alberta. Yields of sugar beets increased by 5.16% to 12.35% after a joint application of composted manure and inorganic fertilizer (N and P), in comparison with those using only inorganic fertilizer (N+P). A high rate of fresh manure application was usually found to reduce extractable sugar content due to high levels of nitrogen in the manure.

Lentz and Lehrsch (2012) studied the difference in yields of sugar beets that had been treated with either dairy manure or urea fertilizer. The amount of dairy manure and urea fertilizer were determined based on a target yield and results of a soil test. They found that the yield of sugar beets from farms that had applied only dairy manure was 1.2 times greater than that from farms that had applied only fertilizer.

2.1.4.2.4. Effect of Manure Application on Dry Bean Production

Robbins et al. (1997) found that the dry bean yield increased on farms that had applied fresh dairy manure and fertilizer, compared with farms that had applied only fertilizer. The authors indicated that soil organic carbon concentration was one of the factors that correlated with the yield increase.

2.1.4.3. Challenges and Regulations on Manure Application

Crop production would benefit from manure application. However, it is a challenge to use manure on farms. That is because “Manure is a dichotomy: a valuable resource if used judiciously as a soil amendment or an environmental polluter if mismanaged” (Larney and Janzen 2011, p. 1). If the manure is applied inappropriately, it will cause environmental problems (Caldwell 1998). The major concerns are the accumulation of surplus nitrogen and phosphorus in the soil, which may degrade the quality of surface and ground water (Olson et al. 2011); and greenhouse gas emission (Larney and Janzen 2011).

To address or minimize the potential negative effects of manure application, manure application regulations have been developed. In Alberta, manure management is regulated by the Agricultural Operation Practices Act (AOPA) (AARD 2009-b). In addition, the 2008 Reference Guide to the AOPA simplifies the Act to help producers understand the regulations and obligations (AARD 2009-b). For on-farm manure application, the Guide lists the detailed regulations including manure incorporation requirements, setback distances, soil nitrogen and salinity limits, record keeping, and soil testing (AARD 2008-a).

The regulation requires that manure be incorporated within 48 hours of application. The exceptions are cases where manure is applied on forages, frozen or snow-covered land, or crops with direct seeding, or if a permit for additional requirement has been obtained (AARD 2008-a). The setback distances are also specified to minimize the nuisance impact on residences, and runoffs into bodies of water (AARD 2008-a). The regulation establishes limitations on soil nitrate-nitrogen (NO_3-N) and salinity in manure application (AARD 2008-a). These limits can only be exceeded when the nutrient management plan is applied on farms (AARD 2008-a). On irrigated farms, the nitrate-nitrogen limits are

180 kg/ha, 225 kg/ha, and 270 kg/ha on sand soil (>45% sand and water table <4 meters), sand soil (>45% sand and water table >4 meters), and medium and fine textured soils, respectively (AARD 2008-a). If an operation applies less than 500 tonnes of manure annually, soil testing is not required (AARD 2008-a). However, operations applying more than 500 tonnes of manure a year must provide information about soil testing every three years (AARD 2008-a). Furthermore, any operation applying more than 500 tonnes of manure per year is required to keep records for a minimum of five years (AARD 2008-a).

2.1.5. Nutrient Management Planning

Nutrient management planning (NMP) is a means to optimize the on-farm available nutrients by matching the nutrient application to crop growth (Beegle et al. 2000). According to the Hilliard and Peedyk (2000), the principles of NMP are as follows: The amount of fertilizer application should be equal to the difference between crop demand based on target yield and available nutrient supply from the soil (Hilliard and Peedyk 2000). In addition, crops should be able to absorb the nutrients from fertilizer (Hilliard and Peedyk 2000). An appropriate NMP can contribute to reduced fertilizer use and mitigation of negative environmental impacts, while still maintaining soil productivity and crop yield (Beegle et al. 2000). NMP is usually associated with animal manure application to determine the right amount of manure to meet crop requirements and to prevent environmental pollution. Nutrient management planning is applicable to all fertility crop inputs such as organic matter, by-products from livestock production, and inorganic fertilizers (Oldham 2011).

2.1.5.1. Effects of Nutrient Management Planning on the Environment

Shepard (2005) studied the effects of NMP on the reduction of N and P application in two Wisconsin watersheds in the US. On average, farmers with NMPs applied less N and P fertilizer than farmers without NMPs. However, for farmers with NMPs, just 14% of the farms applied N within the recommended rate, while 37% of the farms over-applied and 49% of farms under applied. A similar phenomenon was found in P application on farms with NMPs. Of farmers with NMPs, 52% applied P at or below replacement rates, while 48% over applied P. Of farms with manure application, only 45% decreased the application of N fertilizer due to manure application. Based on results of the study, the author stated that implementing NMP did not necessarily lead to the eradication of over nutrient application or guarantee water quality improvement. According to a study conducted by Pease et al. (1998), the application of NMP on four livestock farms resulted in a 21 to 41 % reduction in N application. In addition, farms that adopted NMP significantly reduced potential N and P losses. The annual nutrient losses were reduced by 23-45% and 0-66% for N and P, respectively.

2.1.5.2. Effects of Nutrient Management Planning on Production

By using data from a survey of farmers in Maryland, US., Lawley et al. (2009) found that NMP was more widely adopted by larger grain or cattle operations, while it was not widely applied on the environmentally sensitive farms (e.g., high slopes farmland with large potential for nutrient runoff). They also found that fertilizer dealers and independent crop consultants tend to recommend increases in inorganic fertilizer rates. But when farmers conduct their own NMPs, the recommendation is to decrease fertilizer application.

To implement NMP, soil sampling is required. According to Kryzanowski (2005), this includes three processes: collecting samples, shipping samples, and analyzing samples. The best time to evaluate available soil nutrients is right before a crop is grown. In Alberta, spring and fall samplings are most widely applied. Spring sampling is conducted once the soil has thawed. Fall sampling usually happens after October 1st. Samples can be collected by producers or by fertilizer dealers. The tools of sampling can be either purchased or borrowed from fertilizer dealers, private soil analysis labs, or crop advisors. For each representative field, 15 to 20 samples are required. The samples then are sent to a soil testing laboratory for analyses.

Pease et al. (1998) found that farm incomes have increased when adopting NMP. That is because farmers can save money by applying less inorganic fertilizer when adopting NMP.

2.2. Empirical Economic Evaluations of BMPs or Farming Practices

This literature review discusses empirical methods used to evaluate the economics of BMPs and other farming practices. Generally, two types of approaches are commonly used: static and dynamic. A static model presents a system without time-variant behavior. A dynamic model can account for time-dependent changes in a system. In this study, some of the BMPs are considered as “dynamic” as they have impacts on the farm over a period of time. For example, adding alfalfa into a rotation will lead to crop rotation changes over a number of years. Therefore, a dynamic model is appropriate. The literature review focuses on studies that have applied a similar approach (i.e., dynamic modelling) to analyze the costs and benefits of BMPs and other farming practices.

Coiner et al. (2001) built field-level simulation models to assess the economic and environmental impacts of three different landscape scenarios in the Walnut Creek Watershed in Iowa. Each scenario had its own primary objective including increasing production, water quality, or biodiversity. Total return to land was used to measure the economic effect in each scenario. Environmental effects were indicated by four indexes: nitrate-N runoff, nitrate-N leaching, water erosion, and wind erosion. EPIC, a field-level simulation program, was utilized to determine the impacts of farm management on production, soil quality, and water quality. The simulated components from EPIC included weather, plant growth, nutrient cycling, hydrology, erosion, sedimentation, pesticide, soil temperature, tillage methods, fertilizer application, irrigation, and conservation practices. Coiner et al. found that only some changes in land use or agricultural practices could lead to both environmental and economic improvements, while a uniform environmental improvement was not found in most land use changes or agricultural practices.

The private-economic conditions of BMP adoption have also been evaluated. For instance, in a study conducted by Roebeling et al. (2004), a private-economic Farm Household Modelling approach was applied to each producer at the farm level. The agricultural producers in the study were classified based on their specific objectives (i.e., income and leisure), production choices, and agro-ecological and social-economic restrictions. Any changes in farm management and restrictions can lead to changes in land use, farming practices, income, and water quality. Gross income of a farm was evaluated based on the total value from agricultural production, employment (both on-farm and off-farm), and production costs. According to the simulation results of Roebeling et al. (2004), BMPs that reduced tillage, legume fallow, and nitrogen application in sugarcane production were economically viable for producers.

Matekole and Westra (2009) estimated and compared the net economic benefits of tillage and nutrient management practices, which were applied to reduce sediment and nutrients in Cabin-Teele Sub-watershed, Louisiana, US. Models were developed to simulate the quantities of surface water, nutrients, pesticides, and sediment runoff. Reduced tillage, nitrogen management, and conservation tillage were indicated to be cost-effective practices to reduce nutrient and sediment losses in the study area.

The economic and environmental effects of different irrigated potato rotations in southern Manitoba were studied by Khakbazan et al. (2009). A dynamic programming model was used to generate crop production and environmental inputs that linked an agro-environmental model with an economic model. The agro-environmental model included modules of irrigation, precipitation, soil characteristics, soil erosion, farming operations, soil water, phosphorus, nitrogen, soil organic matter, and crop yield. A crop yield function was estimated based on growing season precipitation, fertilizer application, and irrigation management. The economic model of potato rotation was constructed based on the crop yield, crop price, and production costs. Since the crop yield and production costs both depended on variables (e.g., irrigation, nutrients) from the agro-environmental model, a link existed between the economic model and the agro-environmental model.

Khakbazan and Hamilton (2012) studied the relationship between farm profitability and the implementation of reduced tillage BMPs in the South Tobacco Creek (STC) watershed, Manitoba. In the study, a tillage index was used to identify a field as conducting conventional, minimum or zero tillage. A tillage cost was evaluated based on the fixed, repair, fuel, oil and lube costs, and number of passes of tillage implement. Then, a tillage cost model was built to connect the relationship between the tillage index and the tillage cost function. In addition, a yield function was developed. It was based on fertilizer application rates, tillage index, ratio of growing season precipitation to growing degree days, manure application, rotation sequence, slope of field, and soil type. In the enterprise budget analysis, each annual net income was calculated by deducting production and input costs from the gross income. Lastly, crop simulations, developed in a Stella modelling framework, were applied to evaluate the differences between different tillage systems and their economic and environmental impacts. According to the study, when producing canola, the conventional tillage system had the largest net income because the tilled seedbed could increase crop yield. The net income from canola production decreased as the tillage intensity was reduced. For cereal production, the highest net income was from the minimum tillage because of less fuel costs and depreciation costs. The high equipment cost in zero tillage caused a low net income in cereal production. The authors indicated that additional incentives might be required to encourage the conservation tillage in the STC watershed.

Cortus (2005) used Monte Carlo simulation and NPV analysis methods to evaluate the on-farm costs and benefits of wetland drainage in Saskatchewan. In the study, weather variables, crop yields, commodity prices, and time available to conduct drainage were modelled as being stochastic. Input costs, machinery costs, drainage costs, crop insurance and Canadian Agricultural Income Stabilization Program were also evaluated. Results of scenario and sensitivity analyses indicated that conducting wetland drainage was an economically feasible practice for farmers. To arrest the wetland decline from drainage projects, potential incentive payment might be required.

Similar methods were applied by Koeckhoven (2008) in conducting the farm-level economic evaluation of BMP adoption in a representative cropping and cattle mixed farm in the Lower Little Bow Watershed, Alberta. The BMPs studied were off-stream watering, fencing riparian areas, installing buffer strips, and growing permanent cover. The representative farm included both the crop/forage production and cow/calf production enterprise. According to the results, the BMPs were costly for producers. Producers might require economic incentives to adopt these BMPs.

Trautman (2012) conducted a study on the farm-level costs and benefits of BMPs on five representative Alberta cropping farms. Four representative farms were in dryland production, while one was under irrigation in southern Alberta. The BMPs studied included shelterbelts, buffer strips, residue management, and adding alfalfa, field peas, legume green manure, or oats into rotation. Perennial forage and field peas BMPs were found to bring net on-farm benefits. Adopting shelterbelts, butter strips, and adding oat in rotation resulted in negative net on-farm benefits. Although a representative irrigated farm and BMPs of interest were studied by Trautman (2012), there are some limitations on the representative farm characteristics and BMP selection. The irrigated representative farm was assumed to produce only cereal, oilseeds and dry beans and no specialty crops such as potatoes or sugar beets, while in real farming in southern Alberta, high value crops such as potatoes and sugar beets are also grown on irrigated farms. The consequence of different irrigation rates and relevant costs in various weather conditions was not considered in the study. In addition, some BMPs such as applying cattle manure and nutrient management planning, were not included.

2.3. Chapter Summary

The BMPs of interest in this study are primarily aimed at improving soil and water quality. The BMPs of adding legumes into rotations can increase organic nitrogen in the soil since legumes can fix nitrogen from the air into the soil. The mineralized organic nitrogen provides a nitrogen source for crop growth. It reduces the application of inorganic nitrogen fertilizer as well as its runoff into bodies of water. In addition, adding legume crops can increase soil organic matter, create a better soil structure, and control diseases, leading to a yield increase for the following crops grown on the same land. The crop residue management BMP uses cereal residues to cover the fields after harvest. This BMP protects the land from soil erosion, thus reducing sediment in the water. Using cattle manure can replace part of inorganic fertilizer application, reducing inorganic fertilizer runoffs in the water. Moreover, farms with cattle manure application can have more organic matter and better growing conditions. Thus crops can have better yields. The nutrient management planning BMP takes into account residual fertilizer that was left from the previous growing season. As a result, less inorganic fertilizer application is required.

In sum, the BMPs of interest improve the water quality by using less inorganic fertilizer and fewer chemicals and pesticides, and by causing less soil erosion. The BMPs are considered to be beneficial to production since they can increase the crop yields through providing a better growing condition in some cases. The environmental benefits of BMPs are the reasons that these BMPs are selected for this study. The effects of BMPs on the crop production found in the literature are useful sources when building models to estimate the impacts of BMPs on production.

When evaluating the economics of BMPs, many previous studies utilized representative farms (or model farms) to represent the actual farms in the study area. That method will be considered in this study. The representative farm will be modelled based on statistical data and expert opinion in the study area. In addition, Monte Carlo simulation and NPV value methods have been applied in several similar studies. These two approaches will be used to determine the economics of BMPs in this study.

Chapter 3. The Study Area

The Watershed Evaluation of Beneficial Management Practices (WEBs) project is a nine-year national study, mainly funded by Agriculture and Agri-Food Canada (AAFC), to assess the environmental and economic performance of selected water quality-related agricultural BMPs at nine watersheds across Canada (AAFC 2013). The types of BMPs studied in the WEBs project can be classified into four groups: riparian BMPs (e.g., cattle exclusion fencing), in-field BMPs (e.g., manure management, crop rotation), runoff control BMPs (e.g., buffer strips, holding pond, or small reservoirs), and drainage BMP (i.e., controlled tile drainage). Each of the WEBs studies includes three components: biophysical evaluation, hydrologic modelling, and economic assessment. In Alberta, the selected site is the Lower Little Bow (LLB) Watershed. Five BMPs in the LLB watershed are studied including cattle exclusion fencing, off-stream watering without fencing, manure management, buffer strips, and the conversion of cropland to forage. These BMPs were examined in terms of biophysical/hydrological research, as well as economic analysis by Koeckhoven (2008).

This chapter presents an introduction to the LLB Watershed and the Oldman River Basin, and an overview of agriculture, mainly cropping production in the study area. This information provides a starting point to define the representative farm in the following chapter. It also discusses the environmental issues, especially water quality issues from irrigation production.

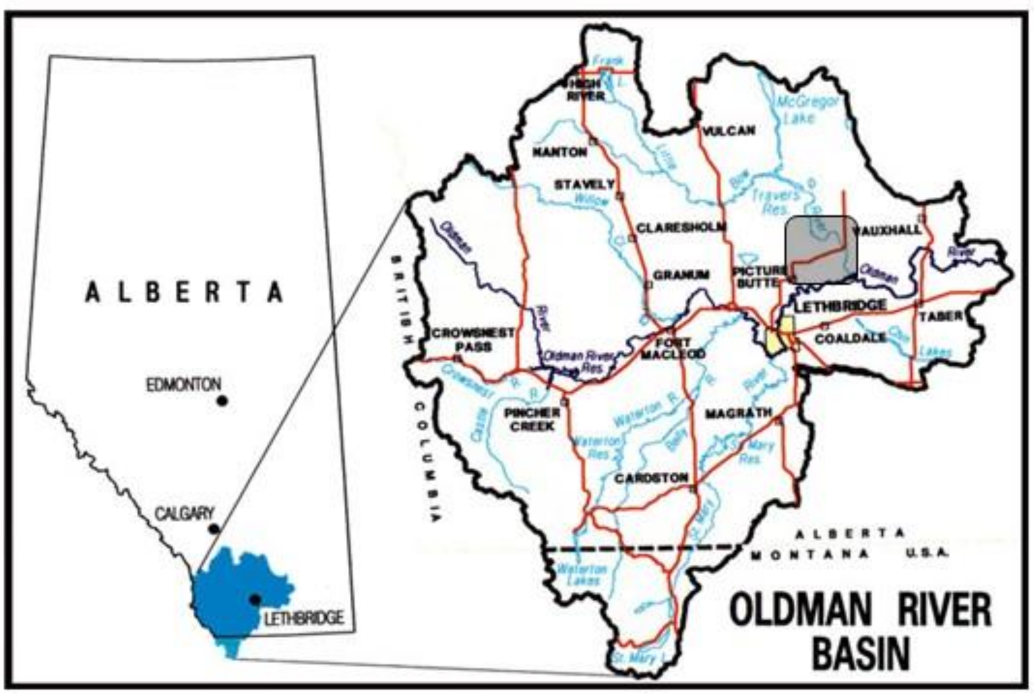
3.1. Oldman River Basin and LLB Watershed

The 26,000 square kilometres of the Oldman River Basin (Figure 3.1) constitutes one of the sub-basins of the South Saskatchewan River Basin. The LLB Watershed (Figure 3.2) is located within the Oldman River Basin in southwest Alberta and has a total area of 557 square kilometers. It has a semi-arid climate. Precipitation is approximately 386 millimetres per year, of which about one-third is snow. Diverse agricultural activities are conducted in the LLB Watershed, including cattle grazing on the native rangeland, dryland farming, and irrigated crop production (AAFC 2013).

The WEBs project in the LLB Watershed focuses on a 0.024 square kilometers micro-watershed (Figure 3.1 and Figure 3.2) north of Lethbridge (AAFC 2013). If this study is restricted in this micro-watershed or even in the LLB watershed, the study results might not be applicable to represent the typical BMP adoption on irrigated farms in southern Alberta. To conduct a more typical study, the study area in this project is not restricted to the LLB Watershed, but applied to a broader area within the Oldman River Basin.

The site of interest is selected in the area covering the County of Lethbridge and the Municipal District (M.D.) of Taber in the Oldman River Basin. The reasons for choosing this area are as follows: Firstly, the LLB Watershed is included within this area. Secondly, the area has a large proportion of farm area devoted to crops, as well as a high proportion of irrigated areas. According to the 2006 Census of Agriculture data, 70% of the land in Lethbridge is cropland, and 53% of the cropland is irrigated; 53% of agricultural land in Taber is devoted to crops, and 56% of cropland is irrigated. Lastly, Lethbridge and Taber are located in two different soil zones, the Dark Brown and Brown soil zones, respectively (Figure 3.3). These two soil zones represent the major soil zones in southern Alberta.

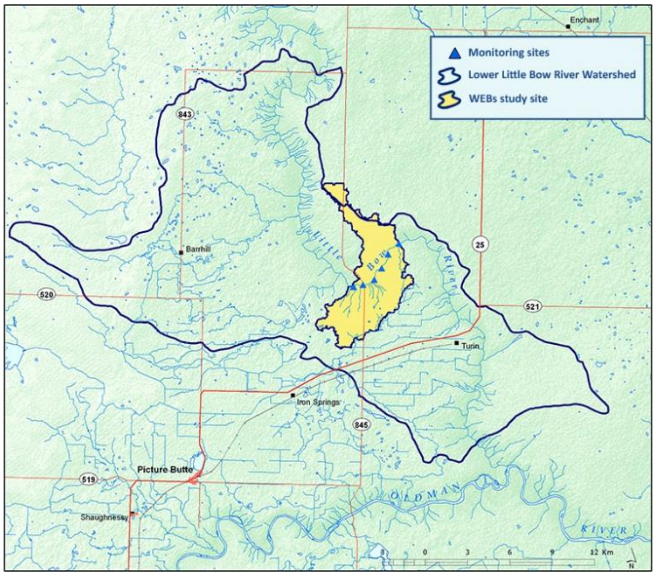
Figure 3.1 Map of Oldman River Basin



▢ - Approximate location of Lower Little Bow Watershed

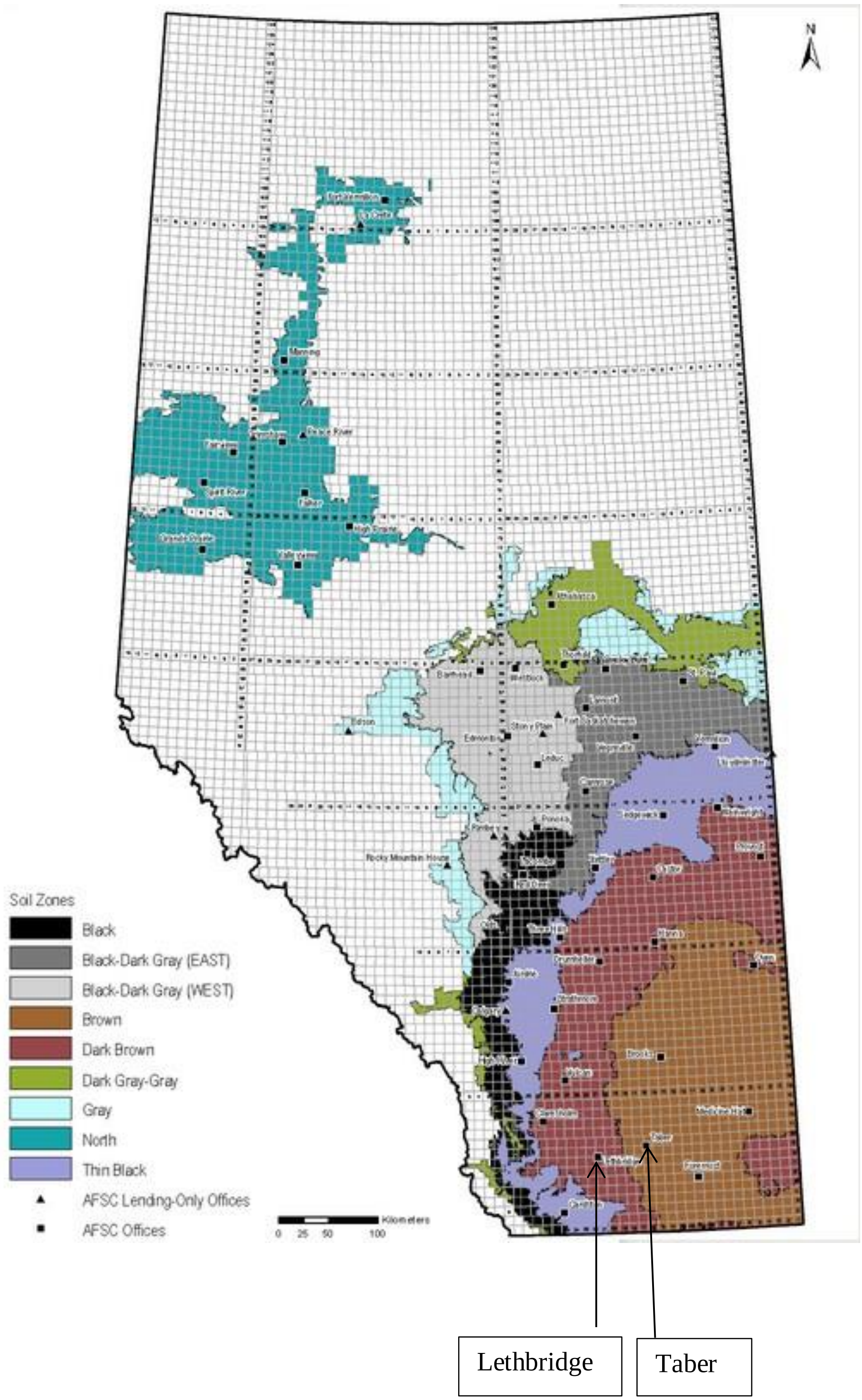
(Source: Oldman Watershed Council 2013)

Figure 3.2 The Lower Little Bow Watershed



Source: AAFC (2011-a).

Figure 3.3 Alberta Soil Zone Map



Source: AFSC (2011-a)

3.2. Agriculture in the County of Lethbridge and M.D. of Taber

According to 2011 statistics, the County of Lethbridge comprised 2,837.80 square kilometers with a population of 10,061 people; the total area of the M.D. of Taber was 4,203.79 square kilometers with a population of 6,851 people. The numbers and acreage of farms, crop farms, irrigated farms, cattle and calves farms, and poultry farms in those two areas are shown in Table 3.1.

According to Table 3.1, the County of Lethbridge has more farms than the M.D. of Taber, but the total acreage of farms in the County of Lethbridge is smaller than that in the County of Taber. Thus, the average farm size in Lethbridge is smaller than that in Taber. Approximately half of the farms include cattle and calf production both in Lethbridge and Taber. Poultry farms account for only 16% and 9% of the total farms in Lethbridge and Taber, respectively.

Table 3.1 Numbers and acreage of farms in the County of Lethbridge and the M.D. of Taber (2006)

		Lethbridge	Taber
Total farms[a]	Number of farms	1,058	768
	Acres	725,426	996,222
Land in crops[b]	Number of farms	907	661
	% of total farm number	86%	86%
	Acres	510,036	528,076
	% of total farm areas	70%	53%
Use of irrigation	Number of Farms	763	585
	% of farm in crop	84%	89%
	Acres	268,597	293,865
	% of land in crops	53%	56%
Cattle and calves farms	Number of Farms	544	410
	% of total farm number	51%	53%
Poultry farms	Number of Farms	166	70
	% of total farm number	16%	9%

[a] A census farm is defined as “an agricultural production that produces at least one of the following products intended for sale” (AARD 2008-b p.vi): crops, livestock, poultry, animal products or other agricultural products (AARD 2008). Thus, a farm might include crop and livestock production at the same time.

[b] Land in crops refers to “all areas reported for field crops, including grains and oilseed, fruits, vegetables, nursery, and sod” (AARD 2008-b p.viii).

Source: AARD (2008-b)

The distributions of farms by farm sizes in Lethbridge and Taber are shown in Table 3.2. According to AARD (1999), 1600 acres is the low bound when defining a "commercial production system." Thus, there are 111 and 149 commercial farms in Lethbridge and Taber respectively, accounting for approximately 10% and 19% of total farms in the area.

Table 3.2 Farms classified by total farm sizes, Lethbridge and Taber (2006)

Farm size (acre)	Number of farms	
	Lethbridge	Taber
Under 10	49	16
10-69	175	81
70-129	112	56
130-179	140	62
180-239	36	28
240-399	152	88
400-559	84	78
560-759	73	83
760-1119	73	75
1120-1599	53	52
1600-2339	43	54
2240-2879	26	24
2880-3519	15	14
3520 and over	27	57
Farms under 1600 acres	947	619
Farms over 1600 acres	111	149
Total farms	1,058	768

(Source: AARD 2008-b)

The total gross farm receipts in the County of Lethbridge and the M.D. of Taber were approximately $959 and $498 million in 2006. The distribution of farms by gross farm receipts in the County of Lethbridge and the M.D. of Taber is presented in Table 3.3. In comparison with the whole province, both Lethbridge and Taber have the lower percentage of farms with gross receipts under $100,000, and the higher percentage of farms with gross receipts over $500,000. The M.D. of Taber has a higher percentage than the County of Lethbridge of farms with gross receipts between $50,000 and $499,999. One reason may be that Taber has more commercial farmers than Lethbridge, as shown in Table 3.2.

Table 3.3 Distribution of farms by gross receipts, whole of Alberta, County of Lethbridge and M.D. of Taber (2006)

Gross farm receipts	Number of farms (% of total)		
	Alberta	Lethbridge	Taber
Under 10,000	9,791 (20%)	54 (7%)	127 (12%)
$10,000-24,999	8,720 (18%)	129 (12%)	86 (11%)
$25,000-49,999	7,170 (15%)	116 (11%)	68 (9%)
$50,000-99,999	7,448 (15%)	132 (12%)	105 (14%)
$100,000-249,999	8,805 (18%)	178 (17%)	182 (24%)
$250,000-499,999	4,333 (9%)	129 (12%)	129 (17%)
$500,000-999,999	1,871 (4%)	113 (11%)	68 (9%)
$1,000,000-1,999,999	688 (1%)	60 (6%)	37 (5%)
$2,000,000 and over	605 (1%)	74 (7%)	39 (5%)
Total	49,431	1,058	768

Source: AARD (2008-b)

The main types of soil conservation practices used in Lethbridge and Taber, as reported in census data, are shown in Table 3.4. The most commonly adopted conservation practice in these two areas is crop rotation, in which types of crops grown on the same field are periodically changed to control weeds, insects, and disease; balance soil nutrients; and/or reduce erosion (AARD 2008-b). Rotation grazing practice is alternating at least two pastures or setting temporary fences within one pasture, which can prevent overgrazing and allow grazed land to recover (AARD 2008-b). Winter cover crops (e.g., red clover) are crops seeded in the fall to cover the soil during the winter and spring. This can reduce erosion and runoff (AARD 2008-b). Establishing buffer zones around water bodies is retaining the natural vegetation in the riparian areas to prevent erosion and protect wildlife habitat and water quality (AARD 2008-b). Windbreaks or shelterbelts are natural or planted plantations that provide shelter from the wind, which can protect soil from erosion and trap snow to increase farmland moisture (AARD 2008-b). The green manure crops for plough down are young crops that are incorporated into soils before being harvested to improve soil quality (AARD 2008-b).

Table 3.4 Number of farms participating in soil conservation practices, County of Lethbridge and M.D. of Taber (2006)

	Lethbridge	Taber
Crop rotation	682 (64%)	575 (75%)
Rotational grazing	265 (25%)	200 (26%)
Winter cover crops	54 (5%)	78 (10%)
Buffer zones around water bodies	118 (11%)	86 (11%)
Windbreaks/shelterbelts	333 (31%)	203 (26%)
Green manure crops for plough-down	31 (3%)	25 (3%)
Total farms in the area	1058	768

Source: AARD (2008-b)

Table 3.5 shows the land preparation methods used in the County of Lethbridge and the M.D. of Taber. A farm might be divided into different fields with different tillage practices. That is why the sum of percentages of the number of farms in each column is greater than 100%. Zero tillage is most widely adopted in Lethbridge, accounting for 41% of total farmland prepared for seeding. In Taber, conventional tillage is the most popular method, accounting for 41% of total farmland prepared for seeding, followed by zero tillage, which accounts for 36%.

Table 3.5 Tillage practices for land seeding preparation, County of Lethbridge and M.D. of Taber (2006)

		Lethbridge	Taber
Conventional Tillage (incorporating most of the crop residue into soil)	Number of farms	432 (57%)	395 (65%)
	Acreage	157,085 (35%)	206,159 (41%)
Minimal-tillage (retaining most of the crop residue on the surface)	Number of farms	245 (32%)	205 (34%)
	Acreage	109,545 (24%)	113,463 (23%)
Zero tillage (directing seeding into stubble or sod)	Number of farms	193 (25%)	191 (32%)
	Acreage	182,881 (41%)	177,473 (36%)
Area prepared for seeding[a]	Number of farms	760	606
	Acreage	449,511	497,095

[a] Not all the cropland is prepared for seeding. That is why the number of farms prepared for seeding is smaller than the number of farms in crops in Table 3.1.

Source: AARD (2008-b)

In Alberta, information about irrigation is summarized and presented based on the irrigation districts[7]. Since the study area is located in part of the St. Mary River Irrigation District (SMID) and Taber Irrigation District (TID), the summarized irrigated crop production in the study area is based on the SMID and TID, respectively.

Table 3.6 provides a summary of major crops (by area) grown in these two irrigation districts in 2011. The top ten crops grown in the SMID, by area, are canola, hard spring wheat, alfalfa, dry beans, barley, corn silage, fresh corn, potatoes, durum wheat, and sugar beets. The top ten crops in the TID, by area, are hard spring wheat, alfalfa, potatoes, barley, canola, sugar beets, tame pasture, dry beans, corn silage, and fresh corn.

Table 3.6 Acreage of principal crops grown on irrigated farms in the SMID and TID (2011) (Acre)

	Crop	St. Mary River Irrigation District (SMID)	Taber Irrigation District (TID)
Cereals	Barley	24,598	7,617
	Hard spring wheat	55,100	13,353
	Durum wheat	14,015	537
	Soft wheat	7,152	547
Forages	Alfalfa[a]	32,287	9,063
	Corn silage	18,829	3,010
	Barley silage[b]	10,578	1,648
	Tame pasture	9,971	3,734
	Timothy hay	4,212	1,904
Oil seeds	Canola	57,079	6,628
Specialty crops	Dry bean	28,490	3,045
	Fresh corn	18,829	1,975
	Potato	14,969	8,827
	Sugar beet	11,115	5,128

[a] Alfalfa includes acres of alfalfa (two and three cuts), alfalfa hay, and alfalfa silage.
[b] Barley silage includes underseeded barley silage.
(Source: AARD 2012-b)

A summary of irrigation methods by area in the SMID and TID in 2011 is shown in Table 3.7. The low pressure pivot system is the most prevalent irrigation method in the study area, which is used by 69.6% of the irrigated area in the SMID and 47.4% in the TID. The

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[7] An irrigation district is “a corporation created according to the Irrigation Districts Act” (AARD 2012-a, p.1) and “acts similar to a municipality, with an elected board of directors responsible for managing the irrigation district” (AARD 2012-a, p1).

percentage of the low pressure pivot with the corner arm is 11.8% in the SMID and 15.4% in the TID.

The centre pivot, a sprinkler irrigation system, typically includes a pump, control panel, pivot pad, pipelines to conduct water to a field (including both the mainline and supply line), laterals (pipes to distribute water from the mainline to the sprinkler, and sprinkler heads (AARD 2003). The lateral is anchored to a pivot pad and applies a small amount of water at frequent intervals, creating a circle of irrigated crops (SMA 2012-a). The irrigation circle can vary from 100 acres to 495 acres, depending on the length of the lateral (AARD 2003). The most common coverage circle is 133 acres for a square quarter section (SMA 2012-a). If corner arms are installed, the coverage of irrigation can increase by up to 15% (AARD 2003; SMA 2012-a).

The low pressure center pivot system requires approximately 70 kPa of pressure (SMA 2012-a). The in-line pressure regular can keep water spraying in a constant rate regardless of the changing topography in a field (SMA 2012-a). The low pressure pivot can save energy costs and apply the water at a higher rate compared with other systems (SMA 2012-a). In addition, the efficiency of the low pressure center pivot system is designed at 84%, which is 11 percentage points higher than the high pressure center pivot system (AARD 2011-b). For a detailed discussion about the other irrigation methods mentioned in Table 3.7, see AARD (2011-b) and AARD (2013).

Table 3.7 On-farm irrigation method summary in the SMID and TID (2011)

	Irrigation Method	SMRID (acre)	TID (acre)
High pressure pivot sprinkler	Pivot high pressure	9,871	12,229
	Pivot high pressure - corner arm	1,408	1,016
	Linear - high pressure		109
	Percent	3.1%	16.7%
Low pressure pivot sprinkler	Pivot medium pressure	3,026	
	Pivot medium pressure - corner arm	288	
	Pivot low pressure	251,242	37,917
	Pivot low pressure - corner arm	42,423	12,305
	Linear - low pressure	931	249
	Percent	82.5%	63.0%
Wheel Move	Wheel move - two laterals	36,904	12,661
	Wheel move - four laterals	5,098	853
	Percent	11.6%	16.9%
Gravity	Gravity - developed - no control	1,526	1,450
	Gravity - undeveloped - Flood	6,557	1,105
	Percent	2.2%	3.2%
Others	Volume gun - stationary	151	10
	Volume gun - traveller	49	46
	Solid set (underground sprinkler)	254	
	Hand move (sprinkler above ground)	1,267	113
	Micro - spray - sprinkler	39	15
	Micro - drip - trickle	121	
	Other application use	6	
	Percent	0.5%	0.2%
	Total system acres	361,162	80,078

(Source: AARD 2012-b)

3.3. Water Quality Issues

Irrigation is the biggest water allocation sector in Alberta. In 2009, irrigation accounted for 42.5% of total water allocations in the province, while the non-irrigation agriculture accounted for only 1.8% (Alberta Environment 2010). In the South Saskatchewan River basin where most irrigated farms are located, irrigation accounted for 72% of the total water allocation in the area in 2009 (Alberta Environment 2010). Almost all of the irrigation water is from surface water sources (Alberta Environment 2010).

In Alberta, agriculture is regarded as one of major contributors to water degradation (SEAWA 2010). Irrigation production, representing the most intensive agricultural management in the province, causes water quality issues in the South Saskatchewan River basin (Little et al. 2010). Irrigation return flows can carry high levels of nutrients, bacteria, and pesticides, leading to water degradation in the receiving water bodies (SEAWA 2010). Nitrogen and phosphorus, which are essential nutrients for plant growth, are intensively applied on irrigated farms. For example, the amount of nitrogen application on the irrigated farm is 67% more than on dry land when growing red spring wheat (AARD 2011-c). The runoff of nitrogen and phosphorus into surface water can lead to excessive aquatic vegetation growth (SEAWA 2010). The growth of aquatic vegetation may cause oxygen depletion, water pH change, and reduction of biodiversity in water (SEAWA 2010). In addition, according to a study conducted by CAESA (1998-b), the amount of bacteria in all samples from irrigation return flows exceeded drinking water guidelines. Moreover, it has been indicated that there is a positive correlation between the level of pesticides in surface water in Alberta and agricultural intensity (Anderson et al. 1997). Anderson (2005) found a high frequency of pesticide detection and a large amount of pesticides in irrigation return flows during June and July. To address the issue of water degradation from crop production, especially from irrigation crop production systems, this study will consider BMPs that can reduce the amount of fertilizer application, pesticide application and total runoff.

3.4. Chapter Summary

The study area covers the County of Lethbridge and M.D. of Taber, parts of which are located in the Oldman River Basin. More than half of the cropland in Lethbridge and Taber is irrigated. The top five crops grown in the SMID, by area, are canola, hard spring wheat, alfalfa, dry beans, and barley. The top five crops in the TID, by area, are hard spring wheat, alfalfa, potatoes, barley, and canola. The low pressure pivot irrigation system is the most widely used both in the SMID and TID. According to studies, irrigation production brings about negative impacts to water quality. Implementing BMPs is a means to control and reduce the water degradation from intensive agricultural production such as irrigation.

Chapter 4. Net Present Value (NPV) and Simulation Analysis

Implementing a BMP on a farm can result in both biological and financial impacts over time. To evaluate the on-farm cost and benefit of the BMP, a tool must be able to measure the change of wealth (i.e., financial impacts) and take the dynamic implications (i.e., impacts over time) into account. This chapter discusses the Net Present Value (NPV) technique and modelling techniques for agricultural systems. It also outlines the methods of determining a discount rate for use in NPV analysis. Lastly, the specific model structure for the representative farm in this study is shown and discussed.

4.1. Net Present Value (NPV) Analysis

Adopting a BMP will impact on a farmer's wealth over an extended period of time. For example, when alfalfa is added into a rotation as a BMP, it will change the crop production sequence over time. With the change of rotation, the annual net cash flow generated from production will also change. Therefore, a method used to evaluate the economic impact of a BMP must allow for evaluating the changes of wealth and taking time into account. The tool that satisfies these two criteria is NPV analysis. According to Copeland et al. (2005), NPV analysis takes all cash flows into account and considers the cost of capital when discounting each cash flow.

NPV is defined as the present value of future cash flows (both incoming and outgoing) minus the present value of the cost of the project (Ross et al. 2003). To calculate the NPV of a project, all the cash flows are discounted back to the current values and summed, and then the initial cash outlay of the project is subtracted from the summed discounted cash flows. Using the NPV method allows one to incorporate all the cash flows that are generated by adopting a BMP. In addition, since the resulting cash flows for the BMP implementation usually occur over an extended period of time, the time value of money is taken into account. The function of NPV is written as follows:

$$NPV = \sum_{t=1}^{N} \frac{CF_t}{(1+r)^t} - I_0 \quad \cdots\cdots (4.1)$$

In Equation 4.1, CF_t is the net cash flow in time t, r is the discount rate, I_0 is the initial cash outlay. N is the number of years in the project.

4.1.1. Determine a Discount Rate for NPV Analysis

A discount rate is used to discount future cash flows to current values in the NPV analysis. To conform to the principle of wealth maximization, the capital rate should reflect the market-determined opportunity cost of capital (Copeland and Weston 1988). In the NPV analysis, the choice of discount rate is important because it is a key factor in causing an NPV to be positive or negative. When cash flows of a project are uncertain, the discount rate also incorporates the risk associated with the investment (Copeland and Weston 1988) through a risk premium added to the discount rate. Discount rates vary among investments depending on the project risk. To determine an appropriate discount rate, the simplest approach is seeking a discount rate from previous projects with the similar level of risk (e.g., Koeckhoven 2008; Trautman 2012). Another method is using the theory of capital market line (CML) to measure a unique risk to reflect the riskiness of an investment. By using the CML method (shown in Equation 4.2), the required expected return for an investment depends on risk-free rate of return, expected market return, and standard deviations of market portfolio and investment portfolio (Sharpe et al. 2000):

$$\overline{r_p} = r_f + \left(\frac{\overline{r_m} - r_f}{\sigma_m}\right) * \sigma_p \quad \cdots\cdots (4.2)$$

where $\overline{r_p}$ is the required expected return for an investment (i.e., the discount rate), r_f is the risk-free rate of return, $\overline{r_m}$ is the expected market return, σ_m is the standard deviation of the market portfolio, and σ_p is the standard deviation of returns for the investment.

Cortus (2005) considered grain production on a drained farm as an investment and used the CML approach to calculate the discount rate. Based on CML approach, the discount rate was 13.91%. Cortus (2005) considered this rate to be the maximum value for grain production in the project. He argued that crop production is less risky than livestock production because there is greater diversification (i.e., growing multiple crops in rotation versus a single livestock enterprise). His 2005 study also noted that discount rates used for previous related research were 10.21% (Miller 2002) and 12.34% (Bauer 1997) for cattle production, and 15% for pork production. Since the risk in grain production is less than that in livestock production, Cortus (2005) finally selected 10% as the discount rate for gain production on drained land. He found that previous research associated with drainage also used discount rates of around 10%.

Koeckhoven (2008) studied the crop and cattle operations in Southern Alberta and determined 7.5% as the discount rate by using the CML method. However, after consulting previous studies, he ultimately used a discount rate of 10%. Trautman (2012) studied the economics of BMPs adoption on representative crop farms in Alberta. A discount rate of 10% was used by seeking the projects with similar levels of risk (Cortus 2005; Koeckhoven 2008).

4.2. Agricultural Systems Modelling

This study utilizes discounted cash flows (NPV) analysis to estimate the change of producer's wealth when adopting BMPs. To estimate the cash flows, a modelling technique is required in order to build a representative production system. The process of agricultural production is dynamic and complex because physical and economic factors usually vary widely (Dent et al. 1986). For example, the weather which is stochastic can affect crop yield significantly. The prices of agricultural inputs and outputs are also frequently undergoing change. To build a model that is a close approximation to the real farming system, generally, three approaches are used: mathematical programing, simulation analysis and hybrid analysis.

4.2.1. Mathematical Programing

Mathematical programing is used to determine an optimal outcome (either minimum or maximum) under a set of requirements or constraints. Optimization problems are often mathematically expressed as identifying a minimum or maximum value of an objective mathematical function subject to a series of mathematical constraints. Mathematical programming can be linear or non-linear.

When applied in agriculture, mathematical programing models can be used to maximize the profit of a farming system or the economic efficiency of production system under resource and budget constraints, or to minimize the cost or energy subject to a set of target outcomes. For example, Grossmann and Martin (2011) used mathematical programming to achieve energy and water optimization for bioethanol production. Garrido (2000) used three interconnected mathematical programming models to simulate water use at the farm level and water market arrangement to increase water use efficiency in irrigation production.

Mathematical programing is widely used for agricultural planning because it can assess a large range of farming choices within a relatively short time (Beneke and Winterboer 1973). However, this technique has difficulty in incorporating complex relationships and multiple objectives.

4.2.2. Simulation Analysis

Maria (2007 p.1) defined simulation as “a tool to evaluate the performance of a system, existing or proposed, under different configurations of interest and over long periods of real time.” In simulation, sampling experiments on the model of the system are performed (Rubinstein 1981). The process of simulation includes three major steps: building a model of the system, experimenting with the model, and analyzing the results (Evans and Olson 2002). A simulation model may be static or dynamic, depending on whether it represents a system at a particular time or over time (Law and Kelton 2000). In addition, a simulation model may be deterministic or stochastic (Carson 2003). A model is stochastic if it includes at least one random variable; otherwise, it is deterministic.

The major advantage of simulation analysis in comparison with the mathematical modelling is its ability to integrate flexibility and risk (Evans and Olson 2002). The model in the simulation analysis is not necessary in a particular format, which might allow for a better representation of the system that is studied (Rubinstein 1981). When it is difficult to describe the observed systems in terms of a set of mathematical equations, simulation is an effective method of dealing with the situation (Rubinstein 1981). Simulation can be used to evaluate alternative hypotheses, which it is impossible or costly to conduct into mathematical models (Rubinstein 1981). By using simulation, the complex internal interactions of a system can be modelled and studied (Rubinstein 1981).

Simulation can evaluate the effect of changes on an operating system by making changes in the model (Rubinstein 1981). Thus, simulation can be regarded as a “pre-service test” before making changes on a real system, which can reduce the risk or cost of testing the changes on the real system directly (Rubinstein 1981). Therefore, simulation models are widely used in presenting agricultural systems when testing hypotheses and evaluating alternative farm planning scenarios (Bechini and Stockle 2007). The results of simulation may provide information for farmers to make decisions in choosing alternative farming practices or for policy makers to develop better policy programs. Examples of recent application where agricultural or bio-economic systems are modelled using simulation analysis include Gradiz et al. (2007) and Cortus et al. (2011). Gradiz et al. (2007) developed a simulation model to integrate a beef cow-calf production system and sugarcane production system on Tanegashima Island, Japan. Cortus et al. (2011) used a Monte Carlo simulation model to evaluate the on-farm costs and benefits associated with wetland drainage in Saskatchewan.

However, simulation analysis is an imprecise method (Rubinstein 1981). The results from simulation are statistical estimates, rather than exact results (Rubinstein 1981). Simulation allows researchers to compare the alternatives, but not to find the optimal solutions (Rubinstein 1981). In addition, conducting and simulating a model is often a complex and time-consuming process.

4.2.2.1. Monte Carlo Simulation

Monte Carlo simulation is a specific form of simulation. It is “basically a sampling experiment whose purpose is to estimate the distribution of an outcome variable that depends on several probabilistic input variables” (Evans and Olson 2002 p.6). In Monte Carlo simulation, stochastic sampling experiments are performed on the model of the system (Rubinstein 1981).

Monte Carlo simulation can take the risk into account in quantitative analysis or decision-making (Palisade Corporation 2010). It is highly flexible in accommodating different probabilistic information such as stochastic processes, multiple stochastic variables and correlations among these stochastic variables (Musshoff and Hirschauer 2009). In Monte Carlo simulation, inputs are randomly generated from the defined probability distributions, which can be Normal, Lognormal, Uniform, Triangular, and other distributions. Moreover, generally, there are interdependent relationships among input variables; if one price goes up, for example, other prices might go up or down accordingly. Monte Carlo simulation can build the correlation of inputs, which can enhance the accuracy of model.

In Monte Carlo simulation, a random input value is obtained from each defined distribution. Based on the built parametric model, an output value is calculated and recorded. This process is called an “iteration.” Then a new random input is generated, and a new output is calculated. The model keeps performing these recalculations until it completes the specified number of iterations. Results of Monte Carlo simulation present a distribution of possible outcome values. These probabilistic results show not only the possible outcomes, but also the likelihood of each outcome (Palisade Corporation 2010), which helps to make a better decision under uncertainty. Monte Carlo simulation is usually used to estimate the potential effects of risk in decision-making (Evans and Olson 2002).

4.2.3. Hybrid Analysis

The third method of modelling agricultural system is hybrid analysis. According to Mayer et al. (1998), hybrid analysis involves the use of simulation and optimization to analyze problems in agricultural and bio-systems. Hybrid analysis has been applied in many agricultural studies (Royce et al. 2001; Wilson and Dahl 2002; Kuo and Liu 2003; Srivastava et al. 2003; Musshoff and Hirschauer (2009). For example, Musshoff and Hirschauer (2009) applied a methodology which is a hybrid of simulation analysis and a genetic algorithm, in order to solve a production planning problem on a German crop farm. They found that simulation analysis made the representation of different stochastic processes and correlation easy during the modelling. Moreover, using a genetic algorithm allows identifying the optimized value when dealing with complex stochastic information.

The major advantage of hybrid analysis is using dynamic modelling to determine an optimal solution. Moreover, different mathematical programs and simulation methods can be selected and used in the hybrid analysis depending on characteristics of agricultural system studied (Mayer et al. 1998; Musshoff and Hirschauer 2009). However, challenges exist when using hybrid analysis: it is difficult to identify an appropriate variable to optimize, and to define the size of problem from a large set of possible management decisions (Mayer et al. 1998). When using stochastic simulation, the probability distribution of results makes stochastic optimization difficult (Mayer et al. 1998).

4.3. Representative Farm Model Structure

In this study, Monte Carlo simulation, rather than mathematical programing or hybrid analysis, is chosen to model the agriculture system. The reasons are as follows. Firstly, mathematical programing has limitations associated with model structure. It has difficulty in modelling the various relationships in a production system with BMP adoption. Thus, mathematical programing and hybrid analysis are excluded. Secondly, Monte Carlo simulation has the flexibility to incorporate stochastic elements (risks) and their complex relationships, such as stochastic crop yields, stochastic crop prices, stochastic and irrigation costs, when modelling the representative farm and the BMP implementation. Thirdly, the results of Monte Carlo simulation present all possible outcome values and their probabilities, which are useful for making decision under risks. Lastly, it is feasible to conduct sensitivity analysis in a Monte Carlo simulation.

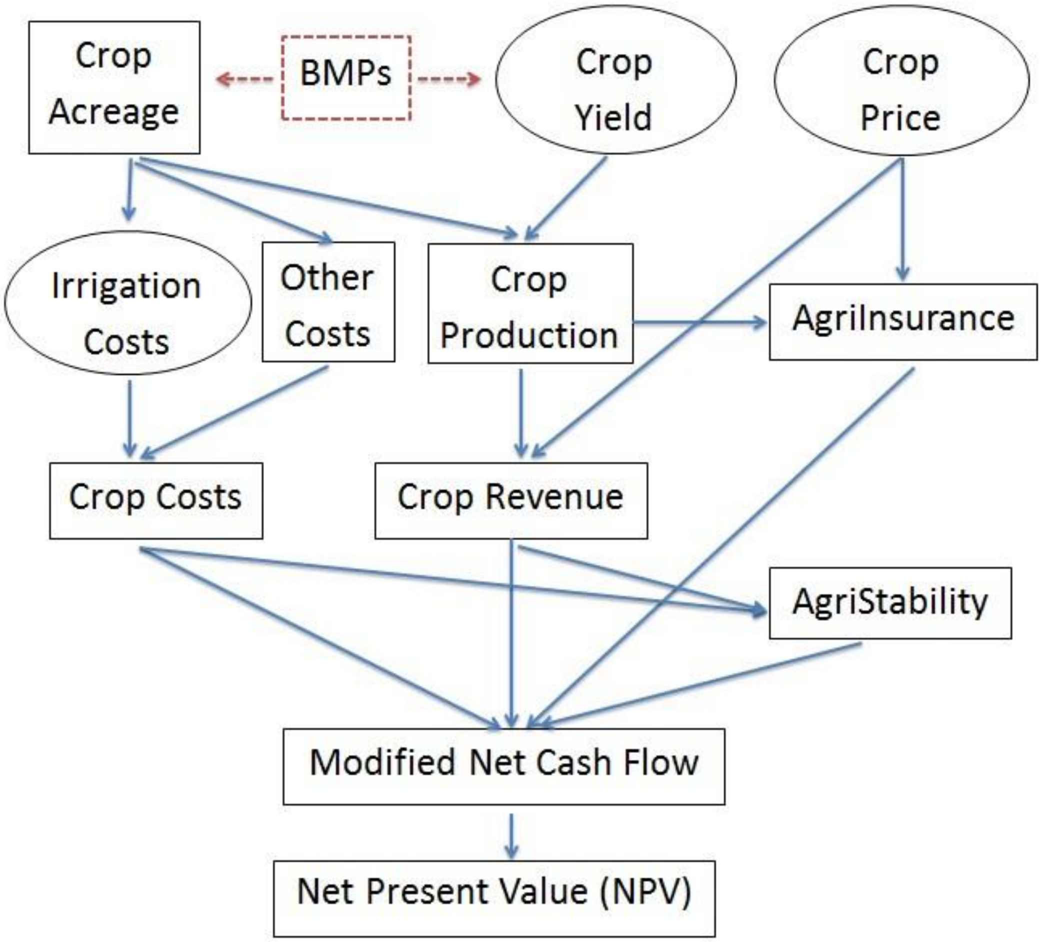
This study applies the Microsoft Excel add-in program, @RISK, to Monte Carlo simulation. An uncertain cell value in Excel can be defined as a probability distribution using a function in @RISK (Palisade Corporation 2010). The risk is summarized as a probability distribution including the determined outcomes and the probabilities of occurrence (Palisade Corporation 2010). For this study, the crop prices, crop yields, and irrigation costs are modelled stochastically. The change in NPVs before and after adopting BMP is measured as a distribution of performance which includes a mean and standard deviation.

To understand the economic impact of BMP adoption in an irrigated crop production system in southern Alberta, it is necessary to build a working simulation model. Firstly, the characteristics of the representative farm are determined, including the farm size, location, crop choice, rotation, and irrigation method. Input costs such as fertilizer, seeds and seeding, and labour costs are then incorporated into the representative farm model depending on the choice of crop grown on the farm. Thirdly, risks associated with farming, including uncertain irrigation costs, crop prices, and crop yields, are modelled stochastically and incorporated into the farm-level simulation. Another risk in agricultural production is the time value of money. In the NPV analysis, the time value of money is incorporated into the simulation in terms of discount rate.

When the representative farm adopts a BMP, the amount of land used for cash crop production might change. In addition, implementing a BMP might affect the crop yields. The crop yield effect is modelled stochastically. The crop acreage change, stochastic crop yield effect, and costs associated with BMP implementation are incorporated into the baseline model to calculate the change in NPVs. If the change in NPVs due to BMP adoption is positive, it is more likely that the producer will adopt this BMP voluntarily. If the change is negative, it is unlikely that the producer will implement the BMP without any other economic incentives.

Figure 4.1 is a schematic diagram of the representative farm model. In this model, crop yield, crop prices, and irrigation costs are stochastic variables, denoted by the circle "boxes" in Figure 4.1. The solid arrows (in blue) indicate the relationship between the connected variables in the baseline model. The dashed arrows (in red) show the factors that are directly affected by the BMP adoption.

Figure 4.1 Diagram of Modelled Farm Relationship



4.4. Chapter Summary

This chapter discusses the different techniques used in farm-level economic analysis of BMP adoption. According to the study, NPV analysis is a suitable capital budgeting method to determine whether or not implementing BMP is an economically feasible investment. Simulation analysis, especially Monte Carlo simulation, is used to generate NPVs. The Monte Carlo simulation model can present both biophysical and economic relationships at the farm level. The combination of Monte Carlo simulation and NPV analysis allows for a decision about BMP adoption based on the calculated risks. The whole model is built in Microsoft Excel using @RISK software.

Chapter 5. The Representative Farm and Empirical Simulation Model

This chapter discusses the procedures used to identify the representative farm characteristics and build the stochastic crop price, yield, and irrigation cost variables. It also outlines the methods for evaluating farm revenue, production cost, and agricultural insurance by using the estimated crop price, yield and irrigation cost models. All of the models are incorporated into the @RISK program for Monte Carlo simulation analysis. In addition, the effects of BMPs on the representative farm are evaluated and quantified. As discussed in Chapter 4, the difference in NPVs between a rotation with and without BMP adoption is regarded as the economic benefit or cost of the BMPs.

5.1. Representative Farm Characteristics

This section discusses the characteristics of the representative commercial farm in this study. It shows how farm location, size, crop rotations, irrigation considerations, and machinery are determined based on the statistics and/or expert opinion.

5.1.1. Location

As mentioned in Chapter 3, the study area includes the County of Lethbridge and M.D. of Taber, which are located in the Dark Brown soil zone and Brown soil zone respectively. According to crop economists and crop specialists in AARD, there are no differences in crop returns and costs in irrigation production between the Dark Brown soil zone and Brown soil zone in Alberta. Lethbridge and Taber are very close geographically, and similar crops are grown in these two areas. Taber receives a few more heat units than Lethbridge on average, but this does not make a difference to irrigated crop returns and costs within the two regions. After expert opinions and the availability of data sources are jointly considered, it is decided that the representative farm in this study should be located in the M.D. of Taber.

5.1.2. Farm Size

According to AARD (1999), 1600 acres is the lower boundary when defining a “commercial production system”. The distribution of farms by size in Taber is shown in Table 3.2. However, the farms in Table 3.2 include both irrigated and dryland production operations. To have a better understanding of the typical size of irrigated farms in the study area, expert opinion is also used (Dunn 2011). Expert opinion indicates that the average size of irrigated farms in the study area is smaller than that of dryland operations. In the study area, 1600 acres represents a typical commercial irrigated operation. Thus, this study assumes that the size of the representative farm is 1600 acres.

5.1.3. Irrigated Crop Production and Rotations

The crops and rotation sequences assumed to be in place on the representative farm are decided based on a combination of statistics and expert opinion. This study focuses on a commercial crop farm production under irrigation. Regarding forage, experts suggested that much of the irrigated forage production is associated with livestock operations (Dunn 2011; Smith 2011). For example, producers grow silage primarily for their own use in dairy or beef production. An exception to this rule might occur where an irrigated farm is located next to a feedlot; in such cases, silage may be grown and sold to the feedlot. Tame pasture is used for cow-calf and dairy operations. If alfalfa (or other hay) is not grown on livestock operations for the farms' own use, it can be sold to other farms, or into the export market. However, the consensus is that irrigated forage production is largely grown by livestock producers for use in their own livestock enterprises. Therefore, irrigated forage production is not considered in the baseline consideration. Based on Table 3.6, the irrigated crops that are considered for the representative farm rotations are barley, canola, dry beans, durum wheat, potatoes, red spring wheat, and sugar beets.

Determining a representative crop rotation is complicated because of existing diverse irrigated crop rotations; it also depends on whether "specialty crops" such as sugar beets and/or potatoes are grown (Dunn 2011; Smith 2011). For example, a field used to grow canola is not suitable to grow sugar beets due to disease issues (Dunn 2011; Smith 2011). In other words, sugar beets and canola should not be in a rotation sequence. As well, the overall diversity in crops grown suggests the need for more than one representative rotation in the study area. Expert opinion is used to establish multiple potential rotations for the representative farm. The basic crop rotations on the representative farm were generated based on including either sugar beets or canola.

One "sugar beet" rotation is modeled as follows (Dunn 2011):

> Potato – Cereal (Red spring wheat) – Sugar beet – Dry bean (Acronym: **PWSbDb**)

Two “canola” rotations are modeled, with and without potatoes (Dunn 2011):

> Cereal (Red spring wheat) – Canola – Cereal (Red spring wheat, durum wheat or barley) – Dry bean (Acronym: **WCaCeDb**)
>
> Potato – Cereal (Red spring wheat) – Canola – Cereal (Red spring wheat, durum wheat or barley) (Acronym: **PWCaCe**)

The “cereal” in the rotations can be red spring wheat, durum wheat, or barley. According to Table 3.6, red spring wheat is the most popular irrigated crop in the TID, by seeded area. Therefore, this study assumes that if just one cereal is included in a rotation, the cereal is red spring wheat. If two cereals are included in a rotation, one is red spring wheat, while the other is chosen depending on the highest expected gross margin. The expected gross margin of a cereal is determined based on the expected prices from estimated price model, mean of historical detrended yield, and mean of input costs.

5.1.4. Irrigation Production Characteristics

The irrigation method adopted on the representative farm is determined based on statistics for irrigation methods in the study area. As shown in Table 3.7, the low-pressure pivot system is the most prevalent irrigation method in the TID, used in 47.4% of irrigated area in the TID. The percentage using a low-pressure pivot with corner arm is 15.4% in the TID. The representative farm in this study produces high-value crops such as potatoes and sugar beets. Using a low pressure-pivot with corner arms can enlarge the irrigated area and increase the revenue. Thus, the study assumes that a low-pressure center pivot system with corner arm is used on the representative farm.

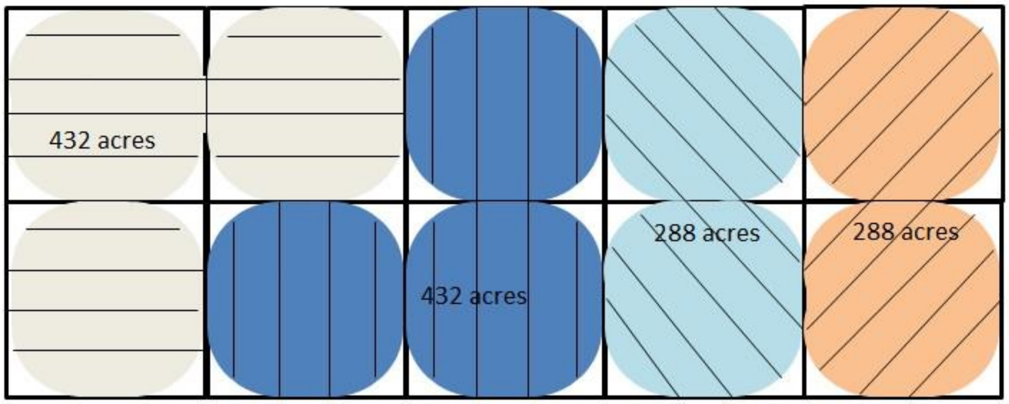
This study assumes that each quarter section (160 acres) of the representative farm is square, and is covered by a pivot system. The total acreage of the representative farm is 1600 acres. Therefore, there are 10 center pivot systems on the representative farm. Due to the installation of corner arms, the size of non-irrigation corners is reduced. However, 10% of the representative farm still cannot be irrigated (Woods 2012).

The non-irrigated corners on the representative farm are assumed to be seeded with alfalfa-grass because it is tolerant of dry conditions. The total area of alfalfa-grass is 160 acres on the representative farm. Alfalfa is a perennial legume. Its stand can keep on producing for many years before it needs to be reseeded. The main reason for reseeding is decreased alfalfa yields in old stands, which occurs due to autotoxicity, seeding disease and pests (Bagg 2001). Entz et al. (1995-a) stated that the average forage stand length in Saskatchewan was 6.5 years. This study assumes the non-irrigated alfalfa-grass lasts five years before reseeding. Every year, alfalfa-grass hay is harvested and sold to the market.

5.1.5. Summary of Crop and Hay Production on the Representative Farm

Due to farm size and the nature of center pivot irrigation system, this study assumes that the representative farm includes 10 square quarter sections. Each quarter section (160 acres) within the farm contains 144 acres of irrigated farmland and 16 acres of non-irrigated corners. Figure 5.1 shows the map of the representative farm. Areas with the same color and sharp fill in the map are used for the same crop in a particular year. The areas without sharp fill are the non-irrigated corners.

Figure 5.1 Map of the representative farm



Since the base rotations are all four-year rotations, the representative farm is divided into four parts and grown with specific irrigated crops in rotation. The non-irrigated corner areas are grown with alfalfa-grass hay. The total area for each irrigated crop on the representative farm will vary each year. The area allocated annually for each crop and hay for base rotation is shown in Table 5.1.

Table 5.1 Annual crop production (in acres) for base crop rotations, by rotation (acre)

Rotation and Crop[a]	Year 1	Year 2	Year 3	Year 4
Rotation WCaCeDb				
W (Irrigated)	432	432	288	288
Ca (Irrigated)	432	288	288	432
Ce (Irrigated)	288	288	432	432
Db (Irrigated)	288	432	432	288
Alfalfa-grass hay (dryland)	160	160	160	160
Total	1,600	1,600	1,600	1,600
Rotation PWSbDb				
W (Irrigated)	432	432	288	288
Sb (Irrigated)	432	288	288	432
Db (Irrigated)	288	288	432	432
P (Irrigated)	288	432	432	288
Alfalfa-grass hay (dryland)	160	160	160	160
Total	1,600	1,600	1,600	1,600
Rotation PWCaCe				
W (Irrigated)	432	432	288	288
Ca (Irrigated)	432	288	288	432
Ce (Irrigated)	288	288	432	432
P (Irrigated)	288	432	432	288
Alfalfa-grass hay (Dryland)	160	160	160	160
Total	1,600	1,600	1,600	1,600

[a] W, Ca, Ce, Db, Sb, and P represent red spring wheat, canola, cereal, dry bean, sugar beet, and potato.

5.1.6. Machinery Complements

Machinery complements are required to complete the cropping operations in a production system. The presence of machinery results in cash-flow implications for fuel and repair costs (discussed later in this chapter) and replacement decisions. On commercial farm operations, machinery replacement occurs at irregular intervals. Typically, each replacement decision results in a significant cash outflow. Moreover, the timing of a decision on replacing machinery may be affected by economic feasibility, a fact which makes it more complicated to model the replacement decision. This study uses a constant annual cash flow as a proxy for machinery replacement expenditures, with the assumption that this cash flow represents the expenditure required to maintain the machinery replacement at its initial asset value. This method has been applied in previous studies using cash flow modelling structures (e.g., Cortus 2005; Koechoven 2008; Trautman 2012).

The first step in estimating machinery cost is to identify the required machinery on the representative farm, including the types and sizes. Generally, three different methods can be used to define the machinery: optimization method, selection algorithm, and expert opinion of farmers. Each method has advantages and limitations, which are summarized by Trautman (2012). In this study, the machinery complements used for grain, oilseed and dry bean production are based Trautman (2012). The specialty machinery required for irrigation, and for potato and sugar beet production, are determined based on expert opinion.

5.1.6.1. Machinery Complements for Crop Production

According to Trautman (2012), the total annual machinery replacement cost, excluding irrigation equipment, is $22.01 per acre for an irrigated farm that grows cereal, canola and dry beans within the Brown soil zone. To estimate this value, Trautman (2012) developed a machinery complement for a representative irrigated production cropping farm. An initial book value for this complement was calculated based on market values for machinery consistent with the assumed initial average machinery age of five years. An annual depreciation value for this machinery complement was then calculated, representing the annual machinery replacement expenditure required to maintain the initial book value. This was converted to a cost per acre for the representative farm.

Trautman’s (2012) value of $22.01 per acre includes the annual cost for special machinery required for dry bean production, which is $1.53 per acre. Subtracting this amount from the total cost per acre results in a machinery replacement expenditure of $20.48. This value is used as the basis for determining the annual machinery replacement cost in the three representative rotations in this study (discussed later). This is done by adding on the annual cost per acre of specialized machinery cost associated with other crops modeled in the current study.

Potatoes and sugar beets, which are included in this study but not that of Trautman (2012), require specialized machinery for planting/seeding, cultivating, and harvesting. The types of specialized machinery needed for those two crops are obtained from communication with experts (Smith 2012; Konschuh 2012). The sizes of machinery for potatoes and sugar beets are based on farmer and expert opinion (Camps 2012; Konschuh 2012).

The annual machinery replacement cost for specialized potato and sugar beet machinery is evaluated using the same method as that applied in Trautman (2012). The new machinery values for equipment are obtained from Lazarus (2009). These new machinery values are depreciated to an age of five years using a depreciation rate of 7.5%. The discounted value represents the machinery value required to be maintained through the simulation. For potato hillers and potato seed cutters, the prices for used machinery posted by Tractors Search.com (2012) and Big Iron Equipment Inc.com (2012) are consulted. These two prices are regarded as the values of five-year old machinery. New and five-year old estimated machinery for potato and sugar beet production are shown in Table 5.2.

Table 5.2 New and initial values of machinery complement required for potato and sugar beet production ($)

Machinery	Size	New value	5 year-old estimated economic values
Potato hiller	8 Row	-	4,500
Potato row cultivator	6 Row, 19 ft.	13,000	8,803
Potato seed cutter	36"	-	2,000
Potato planter	8 Row, 25.3 ft.	86,000	58,238
Potato harvester	4 Row, 12.6 ft.	147,000	99,546
Sugar beet row cultivator	12 Row, 22ft.	16,000	10,835
sugar beet planter	12 Row, 22 ft.	39,000	26,410
Sugar beet topper/defoliator	12 Row, 22 ft.	48,000	32,505
Sugar beet lifter (Digger)	6 Row, 11 ft.	82,000	55,529
Potato and Sugar beet wagon	20 tonne	56,000	33,067

Source: Lazarus (2009), Tractors Search.com (2012), Big Iron Equipment Inc.com (2012)

5.1.6.2. Irrigation Equipment

Since the representative farm is irrigated, the installation of irrigation equipment is a significant start-up cost. The average center-pivot sprinkler installation cost is $607-647/acre (AARD 2000) or $112,000/quarter section[8] (SIPA 2012). The value of $112,000/quarter section estimated by SIPA includes main lines and pivots. This capital cost may vary depending on the topography and water source (Bathgate 2012). In this study, the installation cost of a low-pressure center pivot system with arms is set at $700/acre; thus the total new value of irrigation equipment for the representative farm is $1,120,000. Consistent with Trautman (2012), the annual reduction in economic value for irrigation system is set at 10% (MSUE 2009). As a result, the five-year old value of irrigation equipment on the representative farm is $661,348.80.

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[8] Generally, a quarter section (160 acres) of an irrigated farm has a center pivot irrigation system.

5.1.6.3. Machinery Complements for Each Rotation

Once the total value of machinery is available, it is divided by total farm acreage. Then the annual replacement cost per acre is estimated using the 8% depreciation rate used by Trautman (2012). The summary of annual machinery replacement costs for different usages is shown in Table 5.3.

Table 5.3 Summary of annual machinery replacement costs for different crops ($/acre)

Usage	Annual machinery replacement cost per acre
Whole farm equipment for growing cereals and oilseeds	20.48
Special equipment for growing dry beans	1.53
Special equipment for growing potatoes	8.65
Special equipment for growing sugar beets	6.26
Wagon for sugar beets and potatoes	1.65
Irrigation equipment	33.07

This study includes three rotations. Each rotation requires a different combination of machinery because they include different crops. As a result, the machinery complements for each rotation are calculated by using $20.48 as a basis and adding the cost of other equipment[9]. For example, Rotation PWSbDb includes red spring wheat, sugar beets, dry beans and potatoes. The machinery replacement cost including irrigation is $71.65/acre -- the sum of $20.48/acre, $6.26/acre, $1.65/acre, $1.53/acre, $8.65/acre and $33.07/acre. The summarized annual machinery replacement cost including irrigation machinery for each rotation is shown in Table 5.4.

Table 5.4 Total annual machinery (including irrigation) replacement cost by rotation ($/acre)

Rotation	Annual machinery replacement cost per acre
WCaCeDb	55.08
PWSbDb	71.65
PWCaCe	63.85

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[9] Based on communication with farmers, the machinery required for producing canola is the same as the machinery used in cereal production. Therefore, the machinery cost of canola is not specified in this study.

5.2. Stochastic Simulation Model Parameters

This section discusses the methods of establishing the stochastic models for crop yields, crop prices, and irrigation costs based on the historical data. The estimated stochastic models are set in @RISK program for Monte Carlo simulation. By doing this, the risk in agricultural production and prices is taken into consideration and modelled.

5.2.1. Crop and Forage Yield Models

5.2.1.1. Crop Yield Model

One method for crop yield estimation used in previous studies (Cortus 2005; Koeckhoven 2008) is to build a function associating crop yield with temperature and precipitation. Stochastic crop yield is based on draws from weather variable distributions. This approach was tried and shown to be problematic in this study because of low statistical significance and poor predictive power. One possible reason is that irrigation can provide water as a supplement to precipitation in crop growth, making crop growth as well as resulting yield less dependent on precipitation. This assumption is confirmed by results of a correlation test in which low correlation is found between precipitation and crop yield, and between temperature and crop yield.

An alternative method is to identify the distribution of historical crop yield data directly. Each stochastic crop yield in the simulation is a draw from the estimated crop yield distribution. This method has been used by Trautman (2012) and is applied in this study. The data on crop yields used in this study were provided by the Agriculture Financial Services Cooperation (AFSC). These are county-level annual crop yields on irrigated farms in Taber from 1986 to 2008. A summary of the historical yield data is presented in Table 5.5.

Table 5.5 A summary of historical crop yield data (1986-2008) (kg/acre)

Crop	Mean	St. Dev.	Minimum	Maximum
Barley	1,805	256	1,360	2,321
Canola	885	130	618	1,079
Dry bean[a]	792	218	200	1,131
Durum wheat	1,725	331	1,091	2,302
Potato	13,663	1,397	11,276	15,721
Red spring wheat	1,618	306	1,076	2,149
Sugar beet	20,146	2633	14,804	25,651

[a] According to AFSC records, 2.2 kg of bean can be dehydrated into 1kg of dry bean. To make the yield of dry bean consistent (in dry matter terms) with its prices in this study, the crop yields of "dry bean" were obtained by dividing the crop yields of "bean" by 2.2.

5.2.1.1.1. **Detrending Crop Yield Data**

Before estimating a probability distribution for each crop yield series, the data need to be detrended to eliminate technology bias (Swinton and King 1991). The first step in detrending is to determine the type of trend in the data. Generally, there are two types of trend models: a deterministic model and a stochastic trend model. The deterministic model is based on a time function and assumes that the trend is not affected by random effects from year to year. For example, if the trend is upward, it suggests that the crop yields increase at a constant rate from year to year. The stochastic trend model assumes that each previous shock has a permanent effect on trend (Sherrick et al.2004). The crop yield series could have a trend with unpredictable slope and direction changes.

Just and Weninger (1999) suggested using an approximation of a deterministic component to model a yield distribution, if the economic variables change slowly through time. To determine whether the historical data satisfy the precondition of a deterministic component, a Philips-Perron (PP) test is conducted on each yield series. The null hypothesis of the PP test is that there is a unit root in a univariate time series. A PP test is considered to be appropriate to assess the possibility of trend stationarity (Enders 2004). As shown in Table 5.6, the yield series for all of the crops are found to be trend-stationary.

Table 5.6 Results of Philips-Perron (PP) test of historical yield data (prior to detrending)

Crop	Newey -West Lags	Test Statistic of Z(rho)	Test Statistic of Z(t)	Mackinnon Approximate p-value for Z(t)
Barley	2	-21.527	-3.974	0.0096
Canola	2	-16.806	-3.962	0.0099
Dry bean	2	-24.286	-5.055	0.0002
Durum wheat	2	-24.471	-6.056	0.0000
Potato	2	-24.037	-4.573	0.0011
Red spring wheat	2	-20.728	-4.178	0.0048
Sugar beet	2	-20.412	-4.663	0.0008
1% Critical Value		-22.50	-4.38	
5% Critical Value		-17.90	-3.60	
10% Critical Value		-15.60	-3.24	

In addition, according to previous studies (Just and Weninger 1999; Enders 2004; Maradiaga 2010), the deterministic and polynomial trend is more widely employed in agricultural risk analysis and production economics. The deterministic trend of a time series is specified as a polynomial function as shown below in Equation 5.1.

$$Y_t = Y_0 + \alpha_1 t + \alpha_2 t^2 + \cdots, \ldots \qquad (5.1)$$

where $\alpha_1, \alpha_2, \ldots$ are estimated parameters; Y_t is the observed crop yield in year t.

The yield data for each crop were fitted to a polynomial of arbitrarily large degree, which is set at five in this study. The optimal degree of polynomial function for each series is chosen by jointly considering the t-test, F-test, and AIC and BIC. In this study, the degree of polynomial for each crop is chosen as one, with the exception of barley, which is assigned a degree of two.

Once the degrees of polynomial have been chosen, the historical data on yields are detrended. The detrended yield series are generated by adding the residual (observed values minus predicted values from the regression) to predicted values of the base year (2008). A summary of detrended yield data is shown in Table 5.7.

Table 5.7 Summary of detrended historical yields of crops (1986-2008) (kg/acre)

Crop	Mean	St.Dev.	Minimum	Maximum
Barley	1,826	201	1,416	2,249
Canola	1,020	999	824	1,227
Dry bean	980	181	474	1,219
Durum Wheat	2,187	1,699	1,763	2,470
Potato	15,234	1,006	12,133	17,055
Red spring wheat	2,054	1,477	1,802	2,307
Sugar beet	22,151	2,325	15,897	26,015

5.2.1.1.2. **Goodness-of-fit Distribution**

To select a best fit distribution for each crop yield series, the detrended data are fitted to distributions through using the “Fit Distributions” option in @RISK. The “Fit Distribution” displays the historical detrended data in representative distributions by estimating the parameters and shape of the data as well as suggesting which distribution best replicates the data set. The types of distributions selected to test in this study are Beta distribution, Exponential distribution, Gamma distribution, Lognormal distribution, Triangular distribution, Uniform distribution, and Weibull distribution. These distributions are all truncated at zero, allowing the model to exclude the possibility of negative yields. In addition, these distributions allow for the possibility of skewness and/or kurtosis in crop yield data which have been discussed in previous studies (Gallagher 1987; Moss and Shonkwiler 1993).

In this study, the goodness-of-fit is determined by using three test statistics in @RISK. These are Chi-Squared, Anderson-Darling, and Kolmogorov-Smirnov (K-S) statistics, which represent how well a certain distribution fits the historical input data. A smaller fit statistic indicates a better fit between the distribution and the data. Appendix A shows the test statistics of distribution for the detrended historical crop yield data.

According to the fit statistics, the Gamma distribution is best for most cereal crops (barley, red spring wheat, and durum wheat), and the Weibull distribution was best for most non-cereal crops (canola, dry bean, potato, and sugar beet). The Gamma distribution is characterized by the probability density function, as shown in Equation 5.2:

$$f(x) = \frac{1}{\beta\Gamma(\alpha)}\left(\frac{x}{\beta}\right)^{\alpha-1} e^{-x/\beta}, \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (5.2)$$

where α is the continuous shape parameter and β is the continuous scale parameter; both α and β must be greater than zero (Palisade Corporation 2010). Given the density function, the distribution mean is $\beta\alpha$, and the variance is $\beta^2\alpha$ (Palisade Corporation 2010).

The Weibull distribution is characterized by the probability density function, as shown in Equation 5.3:

$$f(x) = \frac{\alpha x^{\alpha-1}}{\beta^{\alpha}} e^{-(x/\beta)^{\alpha}}, \quad \cdots\cdots (5.3)$$

where α is the continuous shape parameter and β is the continuous scale parameter; both α and β must be greater than zero (Palisade Corporation 2010). Given the density function, the distribution mean is $\beta\Gamma(1+\frac{1}{\alpha})$, and the variance is $\beta^2\left[\Gamma\left(1+\frac{2}{\alpha}\right) - \Gamma^2\left(1+\frac{1}{\alpha}\right)\right]$ (Palisade Corporation 2010). The estimated distribution for each detrended historical yield series is presented in Table 5.8.

Table 5.8 Estimated distribution parameters for each detrended historical crop yield series

Crop	Distribution	Mean (kg/acre)	St. Dev.	α	β
Barley	Gamma	1,826	201	85.115	21.456
Canola	Weibull	1,020	99	11.642	1,064.200
Dry bean	Weibull	983	162	7.160	1,049.800
Durum wheat	Gamma	2,187	169	170.390	12.835
Potato	Weibull	15,234	1,006	19.729	15,647.000
Red spring wheat	Gamma	2,054	147	204.400	10.049
Sugar beet	Weibull	22,151	2,325	12.031	23,121.000

5.2.1.1.3. **Correlation of Crop Yields**

To model the stochastic crop yields in simulation analysis, it is necessary to consider the correlations of yields among crops. Since crops in the same area are affected in similar ways by environmental conditions (e.g., weather), it is likely that yields are positively correlated. In this study, the correlation matrix was provided by the AARD. The correlation matrix represents the field-level correlation coefficients, based on 2004-2006 field level data on irrigated farms in Risk Area 3 in Alberta, which includes the M.D. of Taber. Table 5.9 shows the correlation coefficients of crop yields on irrigated farms in Alberta.

Table 5.9 Correlation coefficient of crop yields on irrigated farm in Alberta

Crop	Barley	Canola	Dry bean	Durum wheat	Potato	Red spring wheat	Sugar beet
Barley	1						
Canola	0.4194	1					
Dry bean	0.2087	0.2000	1				
Durum wheat	0.4491	0.4633	0.2710	1			
Potato	0.2000	0.2755	0.2000	0.3307	1		
Red spring wheat	0.4491	0.4633	0.2710	0.4869	0.2000	1	
Sugar beet	0.3030	0.2000	0.4316	0.3307	0.3144	0.3307	1

Source: AARD (2007)

5.2.1.1.4. Validation and Adjustment

5.2.1.1.4.1. Marra-Schurle (M-S) Adjustment

This study uses the historical county-level yield data to represent the yield at the farm level. This causes an issue of aggregation bias. The county-level yield data do not accurately represent the variability conditions of farm-level data (Rudstrom et al. 2002). Marra and Schurle (1994) suggested that the variability of farm-level yields must be greater than that emerging from a more aggregated level. By comparing the farm-level and county-level data for wheat yields in Kansas, they found that the variability of county-level yields should be revised upwards by 0.1% for each percentage difference between county acreage and farm acreage within the county. This finding was used by Cortus (2005), Koeckhoven (2008), and Trautman (2012). Based on this information, the standard deviations of each detrended crop series are adjusted. In this study, total county acreage of a crop and total farm acreage for each crop are used to replace the total county farm acreage and total farm acreage respectively, which are mentioned in Marra and Schurle (1994). The procedure is shown is Table 5.10.

Table 5.10 Marra-Schurle adjustment of standard deviation of crop yields (after detrended)

	Barley	Dry bean	Sugar beet	Durum wheat	Canola	Potato	Red spring wheat
Farm grown acreage[a] of crop (acre)	400	400	400	400	400	400	400
County grown acreage (2008) (acre)	10,968	7,039	15,377	22,642	22,730	40,251	9,593
Difference between farm and county acreage (%)	2,642	1,660	3,744	5,561	5,582	9,963	2,298
M-S adjustment coefficient	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Change of St. Dev. (%)	264	166	374	556	558	996	230
County-level St. Dev.	201	99	185	169	1,006	147	2,325
Farm-level St. Dev.	732	265	877	1,107	6,623	1,611	7,669

[a] In real production on the representative farm, the acreage of crop grown in each year could either be 432 or 288. For the sake of simplicity, a quarter of the representative farm (400 acres) is used.

Once the revised standard deviations of crops are available, the estimated distributions of crops are adjusted. The procedure is changing the continuous shape parameter (α) and the continuous scale parameter (β) to match the revised standard deviation without changing the mean. The revised α and β are recalculated by solving equations for the mean and variance of the distribution. Table 5.11 outlines the characteristics of crop distributions after adjustment.

Table 5.11 Crop yield distribution parameter estimates (after M-S Standard deviation adjustment)

Crop	Distribution	Mean (kg/acre)	St. Dev.	α	β
Barley	Gamma	1,826	732	6.219	293.673
Canola	Weibull	1,020	265	4.364	1,120.109
Dry bean	Weibull	2,156	1,929	1.120	2,247.505
Durum wheat	Gamma	2187	1,107	3.901	560.642
Potato	Weibull	15,234	6,623	2.456	17,176.730
Red spring wheat	Gamma	2,054	1,611	1.625	1,264.216
Sugar beet	Weibull	22,151	7,669	3.167	24,743.737

5.2.1.1.4.2. Maximum Restrictions on Crop Yields[10]

In this study, the crop yields in the simulation are stochastic draws from the estimated distributions. By using this procedure, it is possible to get yields that are unrealistically high. To account and correct for this possibility, maximum restrictions are applied on final simulated crop yields. The maximum crop yields were obtained by consulting with Smith (2012), while the estimates were derived from an analysis by Bennett and Harms (2011). The maximum crop yield restrictions are displayed in Table 5.12.

Table 5.12 Maximum restrictions for irrigated crop yield in southern Alberta (kg/acre)

Crop	Maximum restriction of crop yield
Barley	2,954
Canola	1,578
Dry bean	1,457
Durum wheat	3,157
Potato	27,195
Red spring wheat	3,157
Sugar beet	32,982

5.2.1.1.4.3. Validation

Based on the estimated distributions with adjusted standard deviations and the maximum restrictions, the model of crop yields is run for 5,000 iterations. The mean of detrended crop yields and simulated mean of Year 20 are compared.[11] The percentage of simulated values truncated by the maximum restriction for each crop is also reviewed. This process is used to make sure that each yield distribution does not generate too many values exceeding the maximum restriction. The results of simulation are shown in Table 5.13.

The simulated means for dry bean, durum wheat, and red spring wheat in Year 20 are much smaller than those within the historical detrended data, which are 18.79%, 7.85% and 14.84% respectively (Table 5.13). The differences between the historical and simulated means for the other crops are not greater than 1.8%. In addition, a large percentage of the simulated values for dry bean, durum wheat and red spring wheat

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[10] A minimum crop yield of zero is implied by the choice of distributions used to model crop yields.

[11] Year 20 is used in the yield validation exercise because the time horizon for the simulation analysis is 20 years. This is discussed in more detail in section 5.5.3.

(22.5%, 16.3%, and 20.0% respectively) are truncated by the maximum restrictions. The percentages for the other crops are smaller than 10%.

Table 5.13 Comparison of mean of historical yield (detrended) and simulated values in Year 20, percentage of simulated values truncated by maximum restrictions in Year 20

Crop	Historical mean (kg/acre)	Simulated mean in Year 20 (kg/acre)	Difference between means	Percentage of simulated values being truncated
Barley	1,826	1,793	-1.84%	7.2%
Canola	1,020	1,018	-0.19%	1.1%
Dry bean	980	796	-18.79%	22.5%
Durum wheat	2,187	2,015	-7.85%	16.3%
Potato	15,234	15,037	-1.30%	4.5%
Red spring wheat	2,054	1,749	-14.84%	20.0%
Sugar beet	22,151	22,029	-0.55%	8.9%

The problems of having smaller simulated means and a larger percentage of simulated values truncated by the maximum restrictions are related. The procedure of truncation makes the exceeded values equal the maximum value. As more values are truncated in a distribution, the mean of the distribution tends to be smaller than the mean without truncation. To account and correct for the above-mentioned problems on dry bean, durum wheat and red spring wheat, the distributions of those crops are adjusted by revising their variability of distribution without changing the means for each distribution. The adjustment continues until the differences between the simulated mean and historical detrended mean do not exceed 5%, and the percentages of truncated values are all smaller than 10%. The revised parameters and standard deviations of crop distributions after the second adjustment are shown in Table 5.14.

Table 5.14 Estimated crop yield distributions (after the second adjustment of standard deviation)

Crop	Distribution	Mean (kg/acre)	2nd Adjustment of St. Dev.	α	β
Barley	Gamma	1,826	732	6.219	293.674
Canola	Weibull	1,020	265	4.365	1,120.109
Dry bean	Weibull	980	350	3.059	1,096.570
Durum wheat	Gamma	2,187	550	15.811	138.319
Potato	Weibull	15,234	6,623	2.456	17,176.730
Red spring wheat	Gamma	2,054	550	13.947	147.271
Sugar beet	Weibull	22,151	7,669	3.167	24,743.737

Since yields among crops are correlated, the whole yield model is run again for 5,000 iterations. As shown in Table 5.18, the differences of simulated mean and historical detrended mean do not exceed 2.5%. The percentages of truncated values are all smaller than 10%. The problems inherent in having a smaller simulated mean and a large percentage of truncated values have been eliminated after the second adjustment. Therefore, estimated crop yield distributions shown in Table 5.15 are used in this study's analysis.

Table 5.15 Comparison of means of historical yield (detrended) and simulated values in year 20, percentage of simulated values truncated by maximum restrictions in Year 20

Crop	Historical mean (kg/acre)	Simulated mean in year 20 (kg/acre)	Difference between means	Percentage of simulated values being truncated
Barley	1,826	1,780	-2.53%	7.1%
Canola	1,020	1,027	0.63%	1.1%
Dry bean	980	962	-1.83%	9.3%
Durum wheat	2,187	2,173	-0.62%	5.0%
Potato	15,234	15,294	0.39%	5.0%
Red spring wheat	2,054	2,050	-0.18%	3.5%
Sugar beet	22,151	21,849	-1.36%	8.3%

5.2.1.2. Yields of Irrigated Alfalfa Hay[12] and Dryland Alfalfa-grass Hay

The historical yield data for irrigated alfalfa and dryland alfalfa-grass hay are not available in the study area. As per previous studies, the stochastic irrigated alfalfa hay and dryland alfalfa-grass hay yields are modelled using the correlation between its yield and a reference crop (Koechhoven 2008; Trautman 2012). This method is used in this study as well, where barley is chosen as a reference crop. One of the reasons for choosing barley is to maintain consistency with the use of barley as a reference crop when calculating irrigated alfalfa insurance, a process that is discussed later in the chapter. The equation to estimate the hay yield is shown in Equation 5.4:

$$\mathrm{Y_{hay,t}} = \mathrm{E}\left[\mathrm{Y_{hay}}\right] * \left[1 + \left(\Delta\mathrm{Y_{barley}} * \rho_{\mathrm{barley,hay}}\right)\right] \ldots\ldots \quad (5.4)$$

where $\mathrm{E}\left[\mathrm{Y_{hay}}\right]$ is the average hay yield, which can be dryland alfalfa-grass hay or irrigated alfalfa hay; $\Delta\mathrm{Y}_{barley}$ is the change of barley yield from previous year to current year; and $\rho_{\mathrm{barley,hay}}$ is the AARD correlation coefficient between barley and hay. Based on consultations with an expert (Dunn 2011), the estimated average yield of irrigated alfalfa is set at 4,451 kg/acre. The average yield of non-irrigated alfalfa-grass is set at 1,600 kg/acre, a figure chosen on the basis of expert opinion. This value is also consistent with Koeckhoven (2008). Because the alfalfa-grass is grown in the non-irrigated corners on the representative farm, Koechoven's (2008) value is appropriate in this study.

5.2.1.2.1. Yield Adjustment based on Stand Year for Dryland Alfalfa

There is a yield change pattern over the stand length in forage production. The annual yields of forage increase for a certain number of years after establishment and then decrease again (Koeckhoven 2008). The percentages of dryland alfalfa/grass yield differential relative to the five-year mean (Leyshon et al.1981; Koeckhoven 2008) are shown in Table 5.16. This study uses the results in Table 5.16 to adjust the yield trend of dryland alfalfa-grass. The initial hay yield obtained from Equation 5.4 is adjusted by multiplying the percentage of yield differential depending on its stand year.

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[12] Irrigated alfalfa is not included in the baseline rotations on the representative farm, but it is considered as a BMP in this study. In the BMP, alfalfa will be added into the rotation. This is discussed in detail later in this chapter.

Table 5.16 Alfalfa/grass variation by year of stand

Year	% yield differential relative to the 5 year mean
1	10.00%
2	34.20%
3	20.38%
4	-14.98%
5	-53.88%

Source: Leyshon et al. (1981), as cited by Koeckhoven (2008).

5.2.1.2.2. Yield Adjustment based on Stand Year for Irrigated Alfalfa

In this study, the stand of irrigated alfalfa is kept on the farm for three years. According to AARD (2011-a), in the establishment year, there is only one cut in the first or second week of August, if alfalfa is seeded in spring. In the production years, alfalfa can be harvested three times, which are in late June, early August, and late September respectively in southern Alberta. The stochastic alfalfa yields from Equation 5.4 are estimated based on historical data. This study initially assumes that these stochastic yields are for alfalfa production involving three harvests per year. To address the issue of only having one cut in the establishment year, the stochastic yield is multiplied by 1/3.

5.2.2. Crop and Forage Price Models

In this study, the crop and forage prices are modelled as stochastic parameters, since farmers face price risk in production. The price data in the study area were collected and used to estimate a stochastic price model from which annual crop prices were determined. Historical crop prices from 1984 to 2010 were used in estimation of price models. Price data for red spring wheat and durum wheat were based on prices for No.1 Canadian Western Red Spring Wheat (12.5%) and No.1 Canadian Western Amber Durum (12.5%), obtained from the Canadian Wheat Board. Price data for barley, dry beans, potatoes, and sugar beets were obtained from the Agricultural Statistics Yearbooks published by AARD[13]. Price data for alfalfa hay, obtained from the AFSC, were based on the quarterly price for good quality baled hay in the fourth quarter each year. The reason for choosing the fourth quarterly price of alfalfa hay as the yearly prices is that most hay transactions in Alberta take place in the fall, while the market for hay is thin in the other seasons.

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[13] There are no price data for sugar beets in 1985, since sugar beets were not grown in that year (AARD 2013).

Before statistical analysis was undertaken, the price data were adjusted for inflation by using the Consumer Price Index (CPI) for all items from Statistics Canada. All the prices were set in 2008 Canadian dollars. The summary price statistics after adjustment for inflation are presented in Table 5.17.

Table 5.17 Summary prices statistics (2008$/1000kg)

Crop	Mean	Standard Deviation	Maximum	Minimum
Alfalfa	97	28	177	61
Barley	147	35	234	102
Canola	410	86	662	279
Dry bean	726	190	1,196	461
Durum wheat	293	76	522	182
Potato	220	30	267	133
Red spring wheat	256	51	377	185
Sugar beet	50	8	69	38

5.2.2.1. Test for Stationarity

Crop and forage prices are assumed to be stochastic in this study. Before estimating the price model, the price series are tested for stationarity. A time series, y_t, is defined as being stationary, if for all values and every time period it is true that there is a constant mean and variance (Hill et al.2008), and that “the covariance between two values from the series depends only on the length of the time separating the two values, and not on the actual times which the variables are observed” (Hill et al.2008 p: 326-327). In a stationary time series, for example, shock from drought weather only temporarily influences the underlying price trend. When using a time series model in which current price is a function of previous prices, the price series must be stationary. If the price series is non-stationary, a random walk process should be applied to model prices. The Augmented Dickey-Fuller (ADF) test and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test are most widely used for testing stationarity.

5.2.2.1.1. Augmented Dickey-Fuller (ADF) Test

The null hypothesis of the ADF test is that the time series has a unit root. Three versions of the ADF tests were run: one assuming no time trend, one assuming a time trend, and one assuming a drift (Stock and Waston 2006). Table 5.18 shows the results of ADF test. Price data for barley, dry bean, potato, sugar beet, and alfalfa are stationary for all three tests under the assumptions of no trend, trend, and drift. Red spring wheat and canola prices are stationary only when we assume a drift. Durum wheat prices are stationary for tests when either no trend or a drift are assumed.

Table 5.18 ADF/DF unit root test for crop price data

Crop	Lag	Test Statistics[a] Non-trend	Trend	Drift
Alfalfa	1	-4.213***	-3.876**	-4.213***
Barley	2	-3.598***	-3.582**	-3.598***
Canola	2	-2.069	-2.134	-2.069**
Dry bean	4	-4.087***	-4.288***	-4.087***
Durum wheat	2	-2.758*	-2.844	-2.758***
Potato	0	-3.926***	-3.847**	-3.926***
Red spring wheat	2	-2.474	-2.534	-2.474**
Sugar beet	1	-2.616*	-3.899**	-2.616***
Critical Value for ADF test:	1%	-3.750	-4.380	-2.528
	5%	-3.000	-3.600	-1.725
	10%	-2.630*	-3.240	-1.325
Critical Value for DF test:	1%	-3.743	-4.371	-2.492
	5%	-2.997	-3.596	-1.711
	10%	-2.629	-3.238	-1.318

[a] *, **, and *** represent statistical significance at the 10%, 5%, and 1% level, respectively.

5.2.2.1.2. **Kwiatkowski-Phillips-Schmidt-Shin (KPSS) Test**

The null hypothesis of the KPSS test is that the time series are stationary, which is the opposite of the null hypothesis of the ADF test. If the results of these two tests are consistent in terms of the conclusion, the conclusion is more reliable. The KPSS test was performed in STATA using automatic lag length selection, and the Quadratic Spectral (QS) kernel. The automatic lag length selection in STATA can automatically identify the maximum lag order of a lagged equation (Hobijin et al. 2004). The QS kernel can make more accurate estimates on finite samples (Hobijin et al. 2004). The results of the KPSS test (shown in Table 5.19) suggest that all crop prices fail to reject the null hypothesis of stationarity, except for the price of potatoes, in which case the null hypothesis is rejected at a 10% confidence level.

Table 5.19 KPSS test results for stationarity of crop price data

Crop	Test Statistics
Alfalfa	0.0989
Barley	0.0832
Canola	0.0701
Dry bean	0.0910
Durum wheat	0.0478
Potato	0.1280*
Red spring wheat	0.0754
Sugar beet[a]	0.0629
Critical Value:1%***	0.216
5%**	0.146
10%*	0.119

[a] In the KPSS test, all of the data are from 1984 to 2010 except the sugar beet data, which are from 1986 to 2010. That is because no sugar beets were grown in Alberta in 1985 and the KPSS test could not be performed on data with a gap.

The results of both the ADF and KPPS tests indicate that the prices series are stationary in most cases. Therefore, the requirement to model current price being a function of previous prices is fulfilled.

5.2.2.2. Estimation of Price Model

5.2.2.2.1. **Length of Lag in Price Model**

This study assumes that the current price of a crop is a function of its own lagged prices. The AIC (Akaike Information Criterion) is used to determine the number of lags in the price function. The values of the AIC were obtained by running an Ordinary Least Squares (OLS) regression of the current price with one to five lagged prices in SHAZAM. As shown in Table 5.20, the optimal lag length for red spring wheat, durum wheat, and alfalfa is determined to be 2. The optimal lag length for canola and sugar beets is 4. The optimal lag length for barley, dry beans and potatoes is 5.

Table 5.20 AIC values for lagged price equations[a]

Crop	1 Lag	2 Lags	3 Lags	4 Lags	5 Lags
Alfalfa	497.40	381.34*	428.91	482.05	513.12
Barley	910.73	740.31	830.12	955.48	661.80*
Canola	3662.9	3042.1	3151.7	2753*	3030.4
Dry bean	25247	26071	27531	26683	12207*
Durum wheat	5665.9	5344.1*	6073.8	6305.6	7009.6
Potato	996.46	1075.7	1213.1	787.01	592.77*
Red spring wheat	2411.8	2324*	2605.6	2753.3	2485.8
Sugar beet[b]	54.165	60.341	58.511	52.284*	55.829

[a] * identifies the minimum value of AIC.

[b] Since there is a missing value in 1985 for sugar beets, the price series was set from 1986 to 2008 when estimating the AIC.

The resulting price equations for Seeming Unrelated Regression (SUR) analysis are as follows (Equation 5.5 to Equation 5.12):

$P_t^a = \beta_0^a + \beta_1^a P_{t-1}^a + \beta_2^a P_{t-2}^a + \epsilon_t^a$ .... (5.5)

$P_t^b = \beta_0^b + \beta_1^b P_{t-1}^b + \beta_2^b P_{t-2}^b + \beta_3^b P_{t-3}^b + \beta_4^b P_{t-4}^b + \beta_5^b P_{t-5}^b + \epsilon_t^b$ .... (5.6)

$P_t^c = \beta_0^c + \beta_1^c P_{t-1}^c + \beta_2^c P_{t-2}^c + \beta_3^c P_{t-3}^c + \beta_4^c P_{t-4}^c + \epsilon_t^c$ .... (5.7)

$P_t^{db} = \beta_0^{db} + \beta_1^{db} P_{t-1}^{db} + \beta_2^{db} P_{t-2}^{db} + \beta_3^{db} P_{t-3}^{db} + \beta_4^{db} P_{t-4}^{db} + \beta_5^{db} P_{t-5}^{db} + \epsilon_t^{db}$ .... (5.8)

$P_t^{dw} = \beta_0^{dw} + \beta_1^{dw} P_{t-1}^{dw} + \beta_2^{dw} P_{t-2}^{dw} + \epsilon_t^{dw}$ .... (5.9)

$P_t^p = \beta_0^p + \beta_1^p P_{t-1}^p + \beta_2^p P_{t-2}^p + \beta_3^p P_{t-3}^p + \beta_4^p P_{t-4}^p + \beta_5^p P_{t-5}^p + \epsilon_t^p$ .... (5.10)

$P_t^{rsw} = \beta_0^{rsw} + \beta_1^{rsw} P_{t-1}^{rsw} + \beta_2^{rsw} P_{t-2}^{rsw} + \epsilon_t^{rsw}$ ....(5.11)

$P_t^{sb} = \beta_0^{sb} + \beta_1^{sb} P_{t-1}^{sb} + \beta_2^{sb} P_{t-2}^{sb} + \beta_2^{sb} P_{t-2}^{sb} + \beta_3^{sb} P_{t-3}^{sb} + \beta_4^{sb} P_{t-4}^{sb} + \epsilon_t^{sb}$ .... (5.12)

where:

P^a, P^b, P^c, P^{db}, P^{dw}, P^p, P^{rsw} and P^{sb}, are prices for alfalfa, barley, canola, dry beans, durum wheat, potatoes, red spring wheat, and sugar beets respectively. P_{t-n}^i is the price of the i^th crop in period t-n. ε_t^i is the error term for crop i in time t. β_0^i to β_n^i are the coefficients on the lagged price variables, to be estimated.

5.2.2.2.2. **Crop Price Model Results and Incorporation**

The price model is estimated using SUR in SHAZAM. The SUR equations model is a linear regression model which consists of a series of regression equations. When the error terms are correlated across equations, the SUR produces more efficient estimates than using Ordinary Least Squares (OLS) to estimate equation by equation. Since the prices of crops can be affected by exogenous variables (e.g., financial crisis, drought, or flood) in a similar way, SUR was applied in this study. The results of SUR estimation are shown in Table 5.21. The overall model R-squared is 0.9882. The statistic for the overall significance is 93.196. The Log of Likelihood Function (LLF) is -737.97.

Table 5.21 SUR model estimated coefficients for price models[a]

Variable	Alfalfa	Barley	Canola	Dry bean	Durum wheat	Potato	Red spring wheat	Sugar beet
lag1	0.6946***	0.2898	0.7539***	0.5932***	0.3203*	0.7167***	0.1796	0.1894
	(-0.196)	(-0.1843)	(-0.1409)	(-0.1713)	(-0.1569)	(-0.1869)	(-0.1617)	(-0.1793)
lag2	-0.2782	-0.3826**	-0.0639	-0.3846***	-0.5323***	-0.2833	-0.3017*	0.0854
	(-0.2)	(-0.1646)	(-0.185)	(-0.1228)	(-0.1625)	(-0.1795)	(-0.1585)	(-0.1771)
lag3		-0.316*	-0.6973***	0.0381		0.0582		-0.2248
		(-0.1781)	(-0.1919)	(-0.111)		(-0.1326)		0.183
lag4		-0.1733	0.5048***	0.082		0.2428*		0.212
		(-0.1586)	(-0.1346)	(-0.0928)		(-0.1317)		(-0.1709)
lag5		-0.1742		-0.1129		-0.233*		
		(-0.1575)		-0.0842		(-0.1308)		
Constant	51.926***	246.41***	198.43***	524.59***	353.28***	111.56	281.36***	35.984**
($/1000kg)	(-17.6)	(-57.34)	(-67.53)	(-135.3)	(-59.27)	(-54.46)	(-50.98)	(-13.25)
Standard Error ($/1000kg)	19.715	24.252	48.261	100.58	76.647	22.174	48.828	6.6997
R-squared	0.2674	0.5355	0.6287	0.4054	0.2148	0.4219	0.1464	0.1253

[a] *, **, and *** represent statistical significance at the 10%, 5%, and 1% level, respectively.

In this study, annual crop and forage prices used in the simulation are determined based on the estimated price equations from the SUR, in which the price is a function of its own lagged prices. The stochastic element of the price in the simulation is introduced by the error term in each price equation. This study uses @Risk to generate a standard normal distribution N (0,1). Since the error terms in the equations are correlated, they should be adjusted and scaled using the standard deviation (Hull 2003). According to Hull (2003), the error correlations are calculated using the following formulae:

$$\varepsilon_m = \sum_{k=1}^{k=m} \alpha_{mk} \ x_k$$

$$\sum_k \alpha_{mk}^2 = 1$$

$$\textstyle\sum_k \alpha_{mk} \, \alpha_{jk} = \rho_{m,j} \quad \text{.........(5.13)}$$

where ε_m is the correlated error term for the price of crop m, x_k is the error draw scaled to the standard deviation of the corresponding crop price, $\rho_{m,j}$ is the correlation between the errors for crop prices m and j, and α_{mk} are the terms estimated from the constraints.

By solving the α_{mk} terms, the equations for the corrected error terms are as follows:

$$\boldsymbol{\varepsilon_1} = x_1 \quad \text{.........(5.14)}$$

$$\boldsymbol{\varepsilon_2} = \rho_{2,1} \, x_1 + \left(\sqrt{1-\rho_{2,1}^2}\right) x_2 \quad \text{.........(5.15)}$$

$$\boldsymbol{\varepsilon_3} = \rho_{3,1} \, x_1 + \left(\frac{\rho_{3,2}-\rho_{2,1}\rho_{3,1}}{\sqrt{1-\rho_{2,1}^2}}\right) \quad x_2 + \left[\sqrt{1-\rho_{3,1}{}^2-\left(\frac{\rho_{3,2}-\rho_{2,1}\rho_{3,1}}{\sqrt{1-\rho_{2,1}^2}}\right)^2}\right] x_3 \quad \text{.........(5.16)}$$

$$\boldsymbol{\varepsilon_4} = \rho_{4,1}\, x_1 + \left(\frac{\rho_{4,2} - \rho_{4,1}\rho_{2,1}}{\sqrt{1-\rho_{2,1}^2}}\right) \quad x_2 + \frac{\rho_{4,3-}\rho_{4,1}\ \rho_{3,1-}\left(\frac{\rho_{3,2} - \rho_{2,1}\rho_{3,1}}{\sqrt{1-\rho_{2,1}^2}}\right)\left(\frac{\rho_{4,2} - \rho_{4,1}\rho_{2,1}}{\sqrt{1-\rho_{2,1}^2}}\right)}{\sqrt{1-{\rho_{3,1}}^2 - \left(\frac{\rho_{3,2} - \rho_{2,1}\rho_{3,1}}{\sqrt{1-\rho_{2,1}^2}}\right)^2}}\ x_3$$

$$+ \left[\sqrt{1-{\rho_{4,1}}^2 - \left(\frac{\rho_{4,2} - \rho_{2,1}\rho_{4,1}}{\sqrt{1-\rho_{2,1}^2}}\right)^2 - \left[\frac{\rho_{4,3-}\rho_{4,1}\ \rho_{3,1-}\left(\frac{\rho_{3,2} - \rho_{2,1}\rho_{3,1}}{\sqrt{1-\rho_{2,1}^2}}\right)\left(\frac{\rho_{4,2} - \rho_{4,1}\rho_{2,1}}{\sqrt{1-\rho_{2,1}^2}}\right)}{\sqrt{1-{\rho_{3,1}}^2 - \left(\frac{\rho_{3,2} - \rho_{2,1}\rho_{3,1}}{\sqrt{1-\rho_{2,1}^2}}\right)^2}}\right]^2}\,\right]$$

……………………………………………………………………………………………… (5.17)

When more than four prices series are considered as being correlated, calculating the correlated error equation becomes more complicated. Therefore, crops are divided into groups, and the maximum number of crops in each group is four. The decision to group crops in a particular way is based on the SUR-estimated error correlations shown in Table 5.22. Prices of red spring wheat are strongly correlated with barley, canola, and durum wheat. Therefore, those four crops are grouped together. The rest of crops (dry bean, potato, sugar beet and alfalfa) are also grouped together.

Table 5.22 SUR-estimated error correlations for price equations

	Alfalfa	Barley	Canola	Dry bean	Durum wheat	Potato	Red spring wheat	Sugar beet
Alfalfa	1							
Barley	0.2536	1						
Canola	-0.0727	0.2024	1					
Dry bean	0.4782	0.0274	0.5944	1				
Durum wheat	0.0763	0.5062	0.5156	0.2678	1			
Potato	0.2737	-0.0218	-0.1923	0.2568	-0.2584	1		
Red spring wheat	0.0189	0.7112	0.6134	0.2565	0.8707	-0.1251	1	
Sugar beet	-0.0794	0.0183	0.5906	0.0913	0.1914	-0.0942	0.2044	1

5.2.2.3. Adjustment and Validation of Crop Price Model

In order to determine whether the simulated prices are reasonable over time, the historical, inflation adjusted means of crop prices are compared with the mean of the simulated results in Year 20. The simulated means are smaller than the historical means for alfalfa, barley, canola, red spring wheat, and sugar beets. The simulated mean for durum wheat is the same as the historical mean. For potatoes, the simulated means are greater than the historical mean. To correct for those differences, the constants in price equations are adjusted until the simulated means are approximately equal to the historical means by using the Goal Seek function in @RISK. Table 5.23 outlines the means in this adjustment. The estimated crop price equations following the adjustment are shown in Table 5.24.

Table 5.23 Means of historical price data, and simulated prices both pre-adjustment and post-adjustment in Year 20 (Unit: 2008$/1000kg)

Crop	Historical Mean	Simulated Mean Pre-adjustment	Simulated Mean Post-adjustment
Alfalfa	97	88	97
Barley	147	141	147
Canola	410	397	410
Dry bean	726	670	726
Durum wheat	293	293	293
Potato	220	223	220
Red spring wheat	256	251	256
Sugar beet	50	49	50

Table 5.24 Estimated crop price equations (after adjustment)

Crop	Constant	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5
Alfalfa	57.12	0.6946	-0.2782	-	-	-
Barley	255.65	0.2898	-0.3826	-0.3160	-0.1733	-0.1742
Canola	205.30	0.7539	-0.0639	-0.6973	0.5048	-
Dry bean	568.10	0.5932	-0.3846	0.0381	0.0820	-0.1129
Durum wheat	353.28	0.3203	-0.5323	-	-	-
Potato	110.22	0.7167	-0.2833	0.0582	0.2428	-0.2330
Red spring wheat	287.49	0.1796	-0.3017	-	-	-
Sugar beet	37.03	0.1894	0.0854	-0.2248	0.2120	-

5.2.3. Stochastic Irrigation Cost Model

On an irrigated farm, direct irrigation costs come from the fuel and/or electricity used in pumping water, moving the arm of center pivot system and controlling the pressure of irrigation water. Thus, irrigation costs will vary depending on the amount of irrigation water used. According to expert opinion (Smith 2011), farmers apply irrigation water according to the net irrigation requirement for the crop, which is calculated by subtracting the total precipitation from the total crop water requirement. Given the fact that the amount of irrigation water use depends on precipitation, and the precipitation is stochastic, the irrigation costs are also stochastic.

This study uses annual growing season precipitation in Taber and annual depth of irrigation application in the TID to estimate the relationship between the amount of irrigation water applied and the total precipitation that fell during the growing season. The daily weather data, including precipitation, from the period 1976 to 2010 were obtained from the Weather Station in Taber. In the study area, the growing season is from May 1st to October 31st (Smith 2012). The daily precipitation levels during the growing season were summed to represent the annual growing season precipitation. The annual depth of irrigation application is the annual gross diversion of water divided by the total area actually irrigated (AARD 2012-b). The data for the annual gross diversion of water and annual area of actual irrigated in the TID from 1976 to 2010 were obtained from AARD (2012-b). Not all of the water measured by annual depth of irrigation application is used for irrigation. It can be used for industrial and recreational purposes, and in reservoir storage. However, the annual depth of irrigation application is the closest available data to represent the amount of irrigation water used in study area.

Once the data are available, a regression was run as shown in Equation 5.18, which connects the depth of irrigation application to a function of precipitation and time trend. The results of the regression are shown in Table 5.25.

$$Y_t = \alpha + \beta X_t + \gamma t + \varepsilon_t \quad (5.18)$$

where Y_t is the annual depth of irrigation application in year t, and X_t is the growing season precipitation in year t. The reason for adding the time trend is that variability in irrigation application may change because of improvements in irrigation technology and types of crops grown in an irrigated area.

Table 5.25 Results of depth of irrigation application regression

Variable	Coefficient[a]
Precipitation	-0.677***
(St.Er)	(0.111)
time	-1.661
(St. Er)	(1.074)
Constant	612.177***
(St.Er)	(31.800)
R-squared= 0.6276	Standard Error= 59.88

[a] *, **, and *** represent statistical significance at the 10%, 5%, and 1% level, respectively

The negative coefficient for the time trend (Table 5.28) indicates that the amount of irrigation application decreases over the time period. One possible explanation is the increasing adoption of more water efficient irrigation methods. The use of low-pressure center pivot equipment on the representative farm is an example of one such method. The irrigation equipment and type of crop grown on the representative farm are constant in the simulation. Thus, there is no significant change in the overall water usage during the simulation.

To better use the historical data to predict the current usage of irrigation water, historical data for the depth of irrigation application are detrended using 2010 as the base year. There is a correlation between growing season precipitation and application levels for irrigation water. Due to the stochastic nature of precipitation, a random draw from historical annual growing season percipitation is used to represent the stochastic growing season precipitation in the simulation. Once the annual growing season precipitation is available, the corresponding detrended historical depth of irrigation application could be found. The detrended depths of irrigation application and growing season precipitation from 1976 to 2010 are shown in Appendix B.

This study makes an assumption about the relationship between irrigation cost and irrigation application: the percentage change in irrigation cost from its mean equals the percentage change in depth of irrigation application from its mean. Each year in the simulation, a precipitation draw refers to a corresponding depth of irrigation application from the historical data. This historical depth of irrigation application is compared with its mean to obtain the percentage change in irrigation application. The annual stochastic irrigation cost for a crop in the simulation is determined by multiplying its average irrigation cost, as provided by AARD (2012-c) by (1+ percentage change of irrigation cost), where the percentage change of irrigation cost is equal to the percentage change of irrigation. Table 5.26 shows the average irrigation costs used in this study.

Table 5.26 Average of irrigation cost in southern Alberta (2012$/acre)

Crop	Irrigation Fuel & Electricity Cost
Alfalfa	29.70
Barley-Feed	21.15
Canola-Argentine	29.15
Dry bean	23.30
Durum wheat	18.65
Potato	64.10
Red spring wheat	17.50
Sugar beet	34.95

Source: AARD (2012-c)

5.3. Economic Relationships

This section provides information about how the stochastic price, yield and irrigation cost variables are used to determine the production revenue, production costs, and agriculture insurance program payment in calculating farm cash flows. The connection of variables is shown as follows.

5.3.1. Revenues

The main revenues for representative farm come from the sale of irrigated crops and hay from non-irrigated field corners. Crop revenues (including hay) in each year are generated by multiplying the simulated crop yield by the simulated annual price and their corresponding acreage. Other potential revenues are payments from the sale of crop residues, crop insurance, and AgriStability, which are discussed later in this section.

5.3.2. Input Costs

Input costs are costs for any inputs used in crop production on the representative farm. In this study, irrigation application costs (discussed earlier), fertilizer costs, licence costs for potatoes and sugar beets, and labour costs for potatoes, sugar beets and dry beans, and potato storage costs, require special attention and are discussed separately. Other input costs, including seed, chemical, trucking and marketing, fuel, oil and lube, machinery repairs, building repairs, and utilities and miscellaneous costs, are taken directly from the CropChoice$ Computer Software Program, Version 3.60 (AARD 2012-c).

5.3.2.1. Fertilizer Costs

In the CropChoice$ program, fertilizer costs are quantified based on generic application, in which the nutrient composition used for each crop is unknown (Kaliel 2012). The aim of this study is to analyze the costs and benefits of BMP adoption. In some cases, the adoption of BMPs will change fertilizer/nutrient application (e.g., adding alfalfa into rotations, green manuring, and adding cattle manure). If the actual amounts of fertilizers/nutrients are unknown, it will be problematic for BMP analysis.

To address this problem, the fertilizer cost for each crop is recalculated. The fertilizer cost for a crop equals the total cost of four macronutrients: nitrogen (N), phosphorus (P), potassium (K), and sulphur (S). The amounts of N, P, K, and S for each crop are based on 2011 AgriProfit$ Cropping Alternatives (AARD 2011-c). The prices of fertilizers were provided by AARD (2012-c) and a fertilizer dealer (McEwen's Fuels & Fertilizers 2012). Prices were then broken down from fertilizers to nutrients using the procedure introduced by AARD (2002). In this study, prices are $1.80/kg, $1.19/kg, $1.18/kg, and $0.69/kg for N, P, K, and S, respectively. The details of fertilizer inputs are shown in Table 5.27.

Table 5.27 Nutrient requirement for crops on the representative farm

Crop	N (kg/acre)	P (kg/acre)	K (kg/acre)	S (kg/acre)	Total Cost ($/acre)
alfalfa (irrigated)	2.3	18.1	0	0	25.7
alfalfa-grass (dryland)	4.5	4.5	0	0	13.6
Barley	45.4	18.1	2.3	0	106.1
Canola	49.9	22.7	2.3	9.1	126.0
Dry bean	36.3	22.7	0	4.5	95.6
Durum wheat	45.4	18.1	2.3	0	106.1
Potato	99.8	63.5	49.9	9.1	321.0
Red spring wheat	45.4	18.1	2.3	0	106.1
Sugar beet	45.4	22.7	4.5	0	114.2

Source: AARD (2011)

5.3.2.2. Potato and Sugar Beet Licence Charge

In Alberta, growing potatoes and sugar beets requires licences. A potato licence is needed for a farm growing more than 5 acres of potatoes, or a greenhouse or laboratory generating more than $10,000 in annual gross income and sales arising from potatoes (AARD 2012-d). To grow sugar beets, producers must have a licence under the Alberta Sugar Beet Production and Marketing Regulation (AARD 2012-e). According to the Potato Growers of Alberta Marketing Regulation (GOA 2011) and Sugar Beet Production and Marketing Regulation (GOA 2009), the charges for licenses are $1.323 per 1000 kg and $0.45 per 1000 kg for potatoes and sugar beets, respectively. However, the charge for a sugar beet license is deducted directly from the payment (GOA 2009). In this study, the price of sugar beets is assumed to be the actual payment that farmers receive after deducting the license charge. Therefore, the deduction of sugar beet costs is not considered in this study. The cost of potato licences is calculated at a rate of $1.323 per 1000 kg.

5.3.2.3. Labour Costs in Potato, Sugar Beet, and Dry Bean Production

In the CropChoice$ program, the cost of labour is divided into two parts: paid labour and unpaid labour (as shown in Table 5.28). Potatoes, sugar beets, and dry beans have significantly higher labour costs (both paid and unpaid) than other crops (cereals and oilseed). This is because cereal and oilseed are common crops that do not require much specialized labour (Kaliel 2012). Potato, sugar beet and dry bean require more labour-intensive management and labour activities (Kaliel 2012; Konschuh 2012; Smith 2012; Reid 2012).

Table 5.28 Labour costs in 2012 CropChoice$ Program (Brown soil zone) (Unit: $/acre)

Labour costs	Irrigated or dryland	Paid labour	Unpaid labour
Alfalfa	Irrigated	16.1	10
Alfalfa	Dryland	5.35	5
Barley	Irrigated	10.2	10
Canola	Irrigated	10.2	10
Dry bean	Irrigated	48.3	40
Durum wheat	Irrigated	10.2	10
Red spring wheat	Irrigated	10.2	10
Potato	Irrigated	214.7	150
Sugar beet	Irrigated	53.65	45

Source: AARD (2012-b)

Potato production requires more labour for seeding, harvesting, storage, and hauling (Smith 2012; Konschuh 2012). Seed potatoes must be cut and treated before seeding

(Konschuh 2012). In the potato growing season, more intensive management is required; this includes more field passes, scouting, and pesticide application (Konschuh 2012). Once potatoes are harvested, they are typically graded before being stored (Konschuh 2012). More labour is needed to remove stems, seed pieces, rotten tubers, and rocks to maintain the quality of storage (Konschuh 2012). In addition, Konschuh (2012) indicated that before being processed, potatoes are typically stored by producers until being delivered to processing facilities. To supply potatoes year-round to processers, potato growers need to keep the potatoes from one to ten month(s) per year (Konschuh 2012). Unlike other crops, potatoes cannot be stored in unheated facilities and require a temperature-controlled and ventilated environment (Konschuh 2012). More labour is required to monitor the potatoes throughout the storage season (Konschuh 2012). Sometimes, in order to improve their quality, potatoes are graded a second time when coming out of storage (Konschuh 2012).

Sugar beet production requires more labour during the harvest, when beets are hauled from the field to the storage piles (Smith 2012). In dry bean production, seeding, handling, chemistry or fungicide application, and harvest require more labour (Kaliel 2012; Reid 2012). Dry bean growers usually require six passes over the field to deal with land preparation, fertilizer and herbicide application, while a non-tillage cereal production just requires two passes (Reid 2012). When beans are growing, producers need to take four trips over the land to spray herbicide for weed control and inter-row cultivation (Reid 2012). By contrast, cereal production requires a maximum of only three trips in a bad year with heavy weed population (Reid 2012). During harvesting, bean production requires at least two trips (Reid 2012). Therefore, dry bean producers need more time to travel over the field than do farmers producing no-tillage cereal.

In the previous studies on cereal and/or oilseed farms (Cortus 2005; Koeckhoven 2008; Trautman 2012), the labour costs (hired and owned farm labour) were not included when assessing farm cash flows. This is based on the assumption that the availability of family members can satisfy labour requirements for production. For the sake of simplicity, all the labour was assumed to be unpaid. However, in this study, high labour-intensive crops (potato, sugar beet, and/or dry bean) are included in the three different farm rotations. Konschuh (2012) indicated that potato farms usually have a similar number of managers to other farm types. The additional labour during production, especially during harvesting, comes from temporary foreign workers.

To address the issue of labour costs, and especially that of hired labour, assumptions in labour availability on the representative farm are made as follows. The number of managers/owners for each rotation is equal. The large amount of unpaid labour required in potato production primarily involves monitoring storage after the growing season. The significant amount of hired labour is involved in harvesting potatoes. The unpaid labour in sugar beet and dry bean production involves maintaining the crop growth, while the paid labour is involved in harvesting. For cereal and oilseed production, the farm labour already on the representative farm can provide the entire labour requirement during and post production.

Based on these assumptions, a modified paid labour cost is added to the total cost of potato, sugar beet, dry bean, and irrigated alfalfa production, respectively. The modified paid labour cost for a crop (e.g., potato, sugar beet, dry beet, or irrigated alfalfa) is calculated by subtracting the paid labour cost for cereal/oilseed from the paid labour for the evaluated crop (e.g., potato, sugar beet, dry beet, or irrigated alfalfa) shown in Table 5.28. For example, as Table 5.31 shows, the paid labour costs for cereal/oilseed and potatoes are \$10.2/acre and \$214.7/acre, respectively. The modified paid labour cost for potato is obtained by subtracting \$10.20/acre from \$214.70, resulting in a cost of \$204.5/acre. As a result, the modified paid labour costs are \$204.5/acre, \$43.45/acre, \$38.1/acre, and \$5.9/acre for potatoes, sugar beets, dry beans, and irrigated alfalfa, respectively. In addition, there is no hired labour cost for cereal, oilseed and dryland alfalfa production.

5.3.2.4. Potato Storage Cost

As discussed earlier, potato growers will store the potatoes for one to ten month(s) after harvesting them. Since potato storage requires temperature-controlled and well-ventilated facilities, there is a cost associated with storage. According to 2011 Crop Alternatives (AARD 2011-c), the annual cost of potato storage is set at \$160/acre.

5.3.2.5. Custom Cost of Hay Harvesting

Additional costs for hay production include cutting, conditioning, baling, and removal of hay. These costs are quantified using custom rates. Therefore, it is not necessary to consider additional machinery costs. The custom rates were obtained from AARD (2012-f) and shown in Table 5.29. The average values of minimum and maximum custom rates are used in this study. Therefore, the custom rate of cutting and conditioning is set at

$18.5/acre. The custom rate for baling and hauling is set at $18.5/bale. The total custom rate for baling and hauling per acre depends on the yield of hay.

Table 5.29 Custom rates for hay harvesting in (South) Alberta in 2012

Operation	Custom Rate		
	Minimum[a]	Maximum[a]	Average[b]
cutting and conditioning hay ($/acre)	17	20	18.5
baling-large round ($/bale)	11	14	12.5
hauling-large round ($/bale)	4	8	6

[a] Source: AARD (2012-f)

[b] The average values are used in the analysis.

5.3.2.6. Summary of Input Costs

Based on the above-mentioned information, the input costs for each crop are shown in Table 5.30.

Table 5.30 Input costs on the representative farm ($/acre)

	Alfalfa (Irrigated)	Alfalfa (dryland)	Barley	Canola	Dry bean	Durum wheat	Red spring wheat	Potato	Sugar beet
Seed	12.5	2.8	24.1	41.85	53.4	31.6	36.2	362.7	125
Fertilizer	25.71	13.59	106.14	126.01	95.63	106.14	106.14	321.02	114.23
Chemicals	2.65	1.3	33.6	48.45	79.55	33.6	33.6	390.15	33.65
Trucking & Marketing	18.3	6.85	16.45	9.35	14.35	18.7	16.8	164.9	125.95
Fuel, Oil & Lube	45.4	9.7	30.25	30.25	43.6	29.6	28.9	121.05	93.5
Repairs - Machinery	25.15	7.55	21.15	19.6	36.25	20.65	20.2	100.65	54.85
Repairs - Buildings	1	0.5	2	2	3	2	2	20.15	6.55
Utilities & Misc. Expenses	34.6	6.5	16.2	16.2	21.6	16.2	16.2	129.7	28.65
Custom work	6.25	3.4	14.8	11.4	34.2	14.8	14.8	136.75	25.65
Paid Labour	5.9	0	0	0	38.1	0	0	204.5	43.45
Storage Cost	0	0	0	0	0	0	0	150[a]	0
Water Rate[b]	8	0	8	8	8	8	8	8	8

Source: AARD (2012-c), except for [a] AARD (2011-c), and [b] AARD (2012-b).

5.3.3. Crop Residues

After harvesting, crop residues, including stems (e.g., stubble, straw), leaves, and/or chaff[14], are left in the field. These crop residues may be left on, incorporated into, or removed from the farm.

Leaving crop residues on the field can decrease the potential risk of wind and water erosion and add organic matter and nutrients into the soil (AARD 2008-c). For crops (i.e., sugar beets, beans, and potatoes) that produce a small amount of residues, the residues are usually incorporated into the soil (AARD 2005-a). This practice can increase soil organic matter (AARD 2005-a). An alternative is to bale and sell the residues of some crops (e.g., wheat, and barley) as by-products from crop production (AARD 2008-c). This can help farmers to obtain extra revenue from farming. But removing residues can lead to soil erosion and to a reduction in organic matter (AARD 2008-c). Farmers need to make a decision between selling straw to get a short run economic benefit and maintaining the residues to achieve sustainable long run production (AARD 2008-c). Management decisions related to crop residue vary by producer and by crop. For example, cereals (e.g., wheat and barley) can produce a large quality of straw but very little chaff (SSCA 2008). Conversely, oilseeds produce less straw but more chaff than cereals (SSCA 2008). Dry beans, potatoes, and sugar beets are all low-residue crops (Dunn 2008). The baseline scenario in this study assumes that each year, the straw from wheat (red spring wheat and durum wheat) and barley are moved from the field by baling, and residues of dry bean, potato, sugar beet and canola are left on the field.

The amount of crop residues (straw) was measured by using a constant grain-to-straw ratio for each crop. The ratios were obtained from AARD (2008-c). They are 0.833 for wheat (including red spring wheat and durum wheat) and 0.625 for barley. For example, when producing 1 kilogram of wheat, there is 0.833 kilogram of wheat residues.

The custom rate of baling including the cost of twine is set at $10.34 per large round bale (5ft by 6ft) (SAF 2011). The cost of hauling large round bales from field to yard is set at $5.6 per large round bale (SAF 2011). Therefore, the total cost of baling and removing residue is charged at custom rate of $15.94 per large round bale. The price of baled residues is set at $25 per large bale (500kg) (AARD 2011-d).

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[14] Chaff is the outer seed covers (i.e., seed pods) that are separated from grain before it is used as food.

5.3.4. Business Risk Management Programs

The federal-provincial-territorial Growing Forward Framework Agreement offers a series of Business Risk Management (BRM) programs in Alberta, including AgriInsurance, AgriStability, AgriInvest, and AgriRecovery. In Alberta these BRM programs are administered by the Agricultural Financial Services Corporation (AFSC), which is a provincial Crown corporation (AFSC 2011-b).

In Alberta, 73% of all annual crop acres in 2010 were insured by the AFSC. Payments from crop insurance in Alberta play an important role in the province's farm cash receipts. It was $468,533 million in 2010, accounting for 5.2% of the province's farm cash receipts and 40.5% of total crop insurance payments in Canada (AARD 2011-e). Crop insurance payments are a significant source of income for producers, especially when unexpected natural perils cause losses in crop production.

This study assumes that the representative farm participates in the AgriInsurance and AgriStability programs. Thus, these two programs are included in the simulation analysis. The models of those two programs are built based on the AFSC AgriInsurance and AgriStability programs. Since the structures for crop and hay insurance have some similarities as well as differences, this study models them separately.

5.3.4.1. Crop AgriInsurance Model

The AgriInsurance program from the AFSC offers coverage for the insured annual crops to offset the losses caused by designated natural perils. Producers can select a percentage of the "the long term average yield" for insured crops, which could be 50%, 60%, 70%, 80% or 90%[15] of normal yield. The selected percentage is called the coverage rate in crop insurance. The insurance provides a yield guarantee and guarantees a price for yield losses. When the actual yield is lower than the coverage yield (i.e., shortfall occurs), there is an insurance payout via the insurance company. The level of payout is determined by using by using spring insurance price (SIP), fall market price, risk area average yield, courage rate, and actual yield (AFSC 2012-a).

According to the AFSC (2012-a), the Spring Insurance Price (SIP) is a predicted fall market crop price in spring based on analysis of historical and current prices and information/expectations regarding trends in future prices. In this study, the SIP is set to

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[15] The 90% coverage level is only available for sugar beet production.

equal the expected price from the estimated price model and varies from year to year. The expected price is based on the estimated price equations from the SUR, the price of which is a function of its lagged prices. Compared with the actual price used in the simulation, it does not include the stochastic element (i.e., error term in the price equation). The fall market price is the actual price of the insured crop after harvesting. In this study, the stochastic price generated from the estimated price model is the fall market price.

Actual crop yield is based upon the estimated crop yield model. It is stochastic in the analysis. The “normal” yield (or risk area average yield) in each year is set to equal the average between the historical average and all the simulated yields in the previous years. Therefore, the simulated yields get more weight in the calculation as more yields are simulated in the analysis. A shortfall occurs if the actual yield is less than the insured yield (risk area average yield times coverage level). When a shortfall occurs, the payout for crop insurance is equal to the shortfall multiplied by the SIP. The equation to calculate the payout is as follows:

Payout per acre

= (Risk Area Average Yield * Coverage Level – Actual Yield) * SIP ·················(5.19)

where the calculation in parentheses is the yield loss. This assumes that the actual yield is less than the insured yield (i.e., a payout is triggered).

The AgriInsurance program also includes a Variable Price Benefit (VPB) for most crops in this study, except potatoes and sugar beets. The VPB insures against situations in which the SIP is significantly lower than actual fall price and a yield loss occurs in production. Payout of the VPB is provided for an insured crop when shortfall occurs and the fall market price of insured crop is at least 10% greater than the SIP. The VPB is limited to no more than a 50% price increase over the SIP (AFSC 2012-a). Payout of the VPB for eligible crop equals the shortfall times the difference between the SIP and fall market price. The equation to calculate the payout for the VPB is as follows:

VPB per acre

= (Risk Area Average Yield * Coverage Level – Actual Yield) * (Fall Market Price – SIP) ··(5.20) where the calculation in parentheses is the yield loss. This assumes that the actual yield is less than the insured yield, and the fall price is not less than (1.1*SIP) and not greater than (1.5*SIP).

Spring Price Endorsement (SPE) can be also purchased as an additional protection against price declines of 10% or more (limited to 50%) below the SIP for most crops, except potatoes and sugar beets in this study (AFSC 2012-a). Payout for the SPE is equal to the difference between the SIP and the fall market price multiplied by the minimum of the actual yield and insured yield, and is shown in Equation 5.21.

SPE per acre
= Min (Actual Yield, Insured Yield Coverage)* (SIP – Fall Market Price) ··········(5.21)
This assumes that the actual fall market price is not less than (0.5*SIP) and not greater than (0.9*SIP).

The insurance premium for each crop is equal to the dollar value of the coverage level multiplied by a premium rate. According to AFSC (2011-b), premiums for crop insurance are jointly paid by producer, the Government of Canada and the Government of Alberta at the ratio of 40:36:24. As a result, this study assumes that 40% of insurance premium is paid by producer.

In Alberta, premium rates are determined based on type and species of the insured crop and location of the farm. The province is divided into several Crop Risk Areas for the purposes of setting insurance premiums. In this study, the representative farm is located in Taber, which is in Risk Area 3. It is assumed that the representative farm selects an 80% coverage rate. Premium rates at 80% coverage for irrigated crops in the Risk Area 3 from 2010 to 2012 were obtained from the AFSC. The average of 3-year premium rates was used for each crop on the representative farm. The premium rate for a crop varies depending on its varieties/species or usage. For example, the AFSC classifies types of potato as seed, chip, fry, table-other, and table-Russet. According to experts (Konschuh 2012; Roessel 2012), the most commonly grown potato in the southern Alberta is the processing potato for French fries. As a result, the premium rates for fry potato are used in this study. Dry beans include several varieties including Black, Great Northern, Pink, Pinto, and Small Red. The premium rates for different types of dry bean are not significantly different, except for that of Black/Other, which is much higher than the rates for other types of beans. In this study, the average premium rate for Great Northern, Pink, Pinto and Small Red was used. For canola, the AFSC classified the crop into two species: Polish and Argentine. The Polish canola is better suited to the more northern production areas in Alberta (AARD 2008-d). The premium rate for Argentine canola was used in this study. The total premium rates used in this model are shown in Table 5.31. The producer is assumed to pay 40% of this amount. For example, if the coverage for an acre of barley is $250, the producer crop insurance premium per acre would be $7.83 (i.e., 40% of $250*0.0783).

Table 5.31 Total premium rates at 80% coverage for irrigated crops on the representative farm (%)

Crop	Total Premium Rate
Barley-commercial	7.83
Canola-argentine	10.53
Dry bean	15.74
Durum wheat	10.40
Irrigated Alfalfa	9.61
Potato- fry	3.10
Red spring wheat	6.19
Sugar beet	3.72

Source: AFSC (2012-b)

5.3.4.2. Hay Insurance Model

Hay, which is mechanically harvested for use as livestock feed, is eligible for the AFSC hay insurance (AFSC 2012-c). On an irrigated farm, the eligible hay is alfalfa hay (>50% alfalfa), but quality loss in hay is not compensated by hay insurance (AFSC 2012-c). The hay insurance is a "production guarantee" program: a claim is triggered once the actual yield falls below the coverage level (AFSC 2012-c). Irrigated alfalfa, which is considered as a BMP in this study, is eligible for the AFSC hay insurance[16]. As a result, the hay insurance model is estimated based on the AFSC program.

The insurance coverage of alfalfa hay for a farm is initially based on a "risk area normal", which is the expected hay yield in a normal year (AFSC 2010). Thus, if a farm is new to hay insurance, the AFSC uses four years of risk area average yields as the farm's actual yield history. As the new farm's annual yields become available, they are used as the individual average yield to replace the risk area average yield (AFSC 2010).

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[16] This study assumes that dryland alfalfa grown in the non-irrigated corners on the representative farm is not included in the insurance program.

The normal yield of a farm is adjusted over time to have a stable coverage (AFSC 2010). The adjustments are applied when an extremely high or low crop yield occurs. Each annual yield is capped at (1.8 * the risk area average * coverage adjustment in previous year). If the actual yield of a farm is less than (70% * risk average yield for the same year* coverage adjustment in previous year), the yield is cushioned using a progressive formula (AFSC 2012-c). For the sake of simplicity, the progressive formula is not used in this study. The yield is capped at (70% * risk average yield * coverage adjustment in previous year).

In this study, the coverage rate for hay insurance is set at 80%, which is same as for crop insurance. The "risk area normal" was estimated in an *ad hoc* manner: it was determined based on the mean of historical yields obtained in communications with an expert (Dunn 2012). It was then adjusted to make sure the insurance payment does not occur too frequently or too infrequently in the 20-year study period of the simulation. The frequency of payout is assumed to be 15-20%. In the end, the "risk area normal" is set to equal 4896 kg per acre, which is 110% of the mean of historical yields.

The payment of hay insurance is generated when the actual production is lower than the coverage. The payout of insurance equals the shortfall multiplied by the selected price option (i.e., Spring Insurance Price) on hay contract (AFSC 2012-c). In this study, the selected price option for a hay contract was set to equal the expected hay price each year based on the estimated price model.

VPB is included in AFSC alfalfa hay insurance. VPB provides support when there is a shortfall in hay production and the price of 1CW barley increases at least 10% during the growing season (AFSC 2012-c). The reason for using 1CW barley in VPB is that hay is a difficult commodity to price accurately (AFSC 2012-c). For simplicity, this study uses the expected barley price and simulated stochastic barley price from the estimated price model as the SIP and fall market price of 1CW, respectively. As a result, if there is a shortfall and a more than 10% increase in the barley price, the payout of the VPB occurs, which equals the shortfall times percentage increase (50% maximum) times the selected alfalfa hay price in the contract.

The premium rates for irrigated alfalfa hay in Risk Areas 2 and 3 were obtained from the AFSC. There is no difference in the annual premium rates between these two Risk Areas. The total premium rate of irrigated alfalfa hay on the representative farm is set at 9.61%, which is the average of premium rates from 2010 to 2012. Since hay insurance is included in the AgriInsurance program, the federal and provincial governments pay all of the administration expenses and share premium cost with producers (AFSC 2012-c). This study assumes that 40% of the hay premium rate is paid by producers.

5.3.4.3. AgriStability

The AgriStability program provides protection for a farm when having a large margin decline due to low prices and/or increased input costs (AAFC 2008). Government and producers share the risk of lost income (AFSC 2008). As of April 2013, Growing Forward 2 is the federal-provincial agricultural policy framework in place. Thus, the version of AgriStability modeled in this study is consistent with the provisions in the Growing Forward 2 (AAFC 2012).

According to the Growing Forward 2 AgriStability framework, a producer will receive an AgriStability payment once the Production Margin (PM) is below 70% of the historical Reference Margin (RM). The PM is the difference between Allowable Income (AI) and Allowable Expenses (AE) (AAFC 2011-b). In this study, AI is assumed to be the revenue from the sale of agricultural commodities including crops, hay and residues. The AE is assumed to be the total input costs (excluding machinery replacement expenditure) for crop production. The RM is determined as one of two values. Specifically, it is the minimum of the five year Olympic average of historical PMs[17] and the AE reported in the previous year (AAFC 2012).

For the Growing Forward 2 version of AgriStability modeled in this analysis, the AgriStability payout for a participating producer is calculated as follows (AAFC 2012):

$$AgriStability\ Payment = \begin{cases} 0,\ if\ PM \geq 70\%\ RM \\ 70\% * (70\%RM - PM),\ if\ PM < 70\%RM \end{cases} ,\text{..........}(5.22)$$

There is an AgriStability participation fee paid by producers (AAFC 2012). However, at the time the modeling was done, the fee for the Growing Forwarding 2 version of AgriStability was not known. As a result, this study uses the fee for the version of the program in place before 2013. The fee for participating in the AgriStability is $0.0045 per

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[17] The Olympic average is calculated using three of the previous five years, excluding the highest and lowest PMs (AAFC 2011-b).

$1 of the RM[18], multiplied by 85% (AFSC 2008). The minimum fee is $45 (AFSC 2008). The annual Administrative Cost Share (ACS) fee is an additional $55 (AFSC 2008). Therefore, the minimum payment for participating in the AgriStability Program is $100.

5.4. Beneficial Management Practices (BMPs)

The objective of this study is to evaluate the on-farm benefits and costs of the adoption of BMPs on the representative farm in southern Alberta. This section discusses how the BMPs are implemented and modelled on the representative farm.

5.4.1. Adding Alfalfa into Rotation

Adding alfalfa into rotations is considered to be a BMP because of the potential for improved soil quality, controlled disease and insects, and reduced inorganic nitrogen fertilizer application. The strategy related to this BMP, as well as its benefits and costs, is discussed in the following section.

5.4.1.1. BMP Strategy

When alfalfa is added into a rotation, the producer’s first decisions relate to (a) how many years the stand will remained in a rotation, and (b) between which two crops the alfalfa will be added. According to Aasen and Bjorge (2009) and SMA (n.d.), the stand may typically be productive for three to five years. The highest productivity occurs during the second and third years (SMA n.d.). This study assumes that three-year alfalfa is added into the baseline rotation. Keeping an alfalfa stand for three years has been recommended by Entz et al. (1995) and used by Trautman (2012).

The sequence of Rotation WCaCeDb with alfalfa BMP was determined based on a previous study (Trautman 2012). The sequences of Rotations PWSbDb and PWCaCe were generated based on farmer practices (Roessel 2012). According to Roessel (2012), when alfalfa is added into a potato rotation, there is usually a cereal grown between alfalfa and potatoes. There are two agronomic reasons for adding one more year of cereal into the rotation after alfalfa. The alfalfa sod is very compacted after three or more years of harvest traffic, making the soil conditions unfavourable for growing potatoes directly (Roessel 2012). In addition, there is a significant amount of alfalfa root mass after alfalfa,

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[18] In 2013 program year, the actual fee for participant is $0.00315 per $1 of the RM (AAFC 2013).

which becomes more manageable after one year of decomposition (Roessel 2012). The rotations without and with BMP are as follows:

Basic Rotation WCaCeDb: Red spring wheat – Canola – Cereal – Dry bean

BMP Rotation WCaCeDb-Alf: Red spring wheat – Canola – Cereal – Dry bean – Alfalfa – Alfalfa – Alfalfa

Basic Rotation PWSbDb: Potato – Red spring wheat – Sugar beet – Dry bean

BMP Rotation PWSbDb-Alf: Potato – Red spring wheat – Sugar beet – Dry bean – Alfalfa – Alfalfa – Alfalfa – Cereal

Basic Rotation PWCaCe: Potato – Red spring wheat – Canola – Cereal

BMP Rotation PWCaCe-Alf: Potato – Red spring wheat – Canola – Alfalfa – Alfalfa – Alfalfa– Cereal

When deciding the area on the representative farm to be allocated to alfalfa, the characteristics of irrigated farm and rotation sequence, and stable cash flow were all taken into consideration. In the baseline scenario, the representative farm is divided into four partitions for the crop rotation. To avoid a large decrease in cash flow due to the production of alfalfa, this study assumes that only one partition is grown with alfalfa each year. This means that one of the annual crops in the rotations will not be grown on the representative farm every four years. This might not be an issue for a farm producing only cereals, oilseeds and dry beans. It is unlikely that a potato or sugar beet farm would not produce potatoes or sugar beets in a particular year, however.

To address this issue, the representative farm is divided into five partitions when adopting the alfalfa BMP. As discussed earlier in this chapter, the representative farm contains ten equal-sized fields. Each field is 160 acres and includes 144 acres under irrigation. By dividing the farm into five partitions, each part has two fields and is used to grow 288 acres of irrigated crop. The missing annual crop in the first four parts due to adding alfalfa is grown in the fifth part. The areas on the representative farm allocated for crops are shown in Appendix C.

5.4.1.2. Economic Impacts of Alfalfa BMP

Once alfalfa is grown as the cash crop in rotation, income will be generated from the sale of the baled alfalfa hay. As discussed earlier, the price and yield of alfalfa are estimated as being stochastic in the simulation. Insurance for irrigated alfalfa is also included. Moreover, growing alfalfa will bring two extra benefits: saving of nitrogen fertilizer and gains in yields of the subsequent crops.

5.4.1.2.1. Economic Evaluation of Saving of Nitrogen (N) Fertilizer

One benefit of adding alfalfa into the crop rotation is saving of N fertilizer because alfalfa can fix nitrogen. In Rotation WCaCeDb, the saving of N fertilizer for crops following alfalfa is determined based on previous studies (MAFRI 2010; Trautman 2012). Therefore, the amount of N fertilizer applied is 25%, 50%, and 80% of the baseline amount in the first, second, and third year crop following alfalfa, respectively.

In Rotations PWSbDb-Alf and PWCaCe-Alf, potato is included in the rotations. The reduction of N fertilizer application is recalculated. According to MAFRI (2010), the N level in the soil could increase by a total of 59 kg per acre after growing two years of alfalfa and taking two cuts of alfalfa every year. This study assumes that the total accumulated N from three years of alfalfa in soil is 90 kg per acre.

In the first crop (red spring wheat) succeeding alfalfa, just 25% of regular amount of N fertilizer is applied, and the remaining 75% of the required N has been fixed in the soil previously by alfalfa. As discussed early in this chapter, the quantities of N required for cereals and potatoes are 45.36 kg and 99.79 kg per acre, respectively. Based on this information, the total available alfalfa-fixed N after the first year crop is 55.98 kg per acre (90kg/acre – 45.36kg/acre*75%). If the rest of alfalfa-fixed N is totally absorbed by the potato crop, the amount of N fertilizer required for potato crop is about 44% of its normal requirement (i.e., (99.79kg/acre – 55.98 kg/acre)/99.79 kg/acre). However, it is not realistic to expect that the alfalfa-fixed N is totally absorbed by the potato crop, due to the run-off from water or snow and the process of decomposing organic matter from alfalfa residues.

In addition, Zebarth and Rosen (2007) indicated that potato famers always face two economic risks when applying N fertilizer: loss of yield and tuber size, which is associated with insufficient N fertilizer; and low specific gravity, which is associated with excessive N fertilizer. Since the value of the loss of yield and tuber size is greater than the loss of low specific gravity, potato producers always apply fertilizer at a rate which can satisfy the potato N demand in most years (Zebarth and Rosen 2007). Therefore, N fertilizer applied to potato farms is about 65% of its regular level.

For the third crop (red spring wheat) following alfalfa, the N fertilizer applied is set at 85% of its regular level. It is 5 percentage points higher than the one in the rotation without potatoes. That is because potato production may consume more alfalfa-fixed N in comparison with canola in the rotation without potato.

Once the amount of N fertilizer application in each year has been determined, the saving of N fertilizer is calculated by multiplying the quantity of N fertilizer saving by the N price. The summarized nitrogen benefits are shown in Table 5.32.

Table 5.32 Nitrogen saving benefit for crops following alfalfa, by rotation

Subsequent Year		N Fertilizer Saving		
		Rotation WCaCeDb-Alf	Rotation PWSbDb-Alf	Rotation PWCaCe-Alf
Year 1	Crop	W	W	Ce
	N application (as % of normal)	25%[a]	25%[a]	25%[a]
	Saving of Fertilizer Value ($/acre)	61.24	61.24	61.24
Year 2	Crop	Ca	P	P
	N application (as % of normal)	50%[a]	65%	65%
	Saving of Fertilizer Value ($/acre)	44.91	34.93	34.93
Year 3	Crop	Ce	W	W
	N application (as % of normal)	80%[a]	85%	85%
	Saving of Fertilizer Value ($/acre)	16.33	12.25	12.25

[a] Source: Trautman (2012)

5.4.1.2.2. **Yield Benefit Following Alfalfa**

Based on the literature on alfalfa studies in southern Alberta (Hoyt 1990; Hoyt and Henning 1971), Trautman (2012) assumed that the yield benefit of three-year alfalfa could be observed in the next three crops succeeding alfalfa. The yield increases for the cereal/oilseed following alfalfa on the irrigated farm are 10%- 80%, 4%-70%, and 4%-70% for the first, second, and third subsequent year, respectively. For the effect of alfalfa on potato yield, Wheeler (1946) showed a 46% increase in potato yield after a three-year stand of alfalfa compared with yield from continuous potato rotation. In a two-year alfalfa rotation, the yield of potato was found to increase by 23.4% (Emmond and Ledingham 1972) and 19.8% (Boring 2005), in comparison with the continuous potato production. Generally, each crop has a maximum potential yield. The increased crop yield due to alfalfa BMP should not be greater than maximum yield. Table 5.33 shows that information of crop yield restrictions in this study.

Table 5.33 Maximum yield restriction, by crop

Crop	Average Yield (kg/acre)	Max Restriction on Yield[a] (kg/acre)	% of increase from mean to max
Barley	1,826	2,954	61.75%
Canola	1,020	1,578	54.65%
Dry bean	980	1,457	48.65%
Durum wheat	2,187	3,157	44.35%
Potato	15,234	27,195	78.52%
Red spring wheat	2,054	3,157	53.70%
Sugar beet	22,151	32,982	48.90%

[a] Source: Dunn (2012); Bennett and Harms (2011)

Based on the above-mentioned information, the increase in cereal yield in the first year following alfalfa is set between 10% and 50%. The ranges of yield increase in the second year succeeding alfalfa are 5% -55% and 5%-50% for canola and potatoes, respectively. In the third subsequent year following alfalfa, the range of yield increase is 5%-40%. The annual yield increases from growing alfalfa are assumed to be stochastic and change from year to year. The yield change is modelled using a uniform distribution. A draw is obtained between the maximum and minimum values in Table 5.34.

Table 5.34 Yield increases (%) following alfalfa

Subsequent Year		Yield Increases		
		Rotation WCaCeDb-Alf	Rotation PWSbDb-Alf	Rotation PWCaCe-Alf
	Crop	W	W	Ce
Year 1	Minimum	10%	10%	10%
	Maximum	50%	50%	50%
	Crop	Ca	P	P
Year 2	Minimum	5%	5%	5%
	Maximum	55%	50%	50%
	Crop	Ce	W	W
Year 3	Minimum	5%	5%	5%
	Maximum	40%	40%	40%

5.4.1.3. Costs of BMP Adoption

The input costs for alfalfa production were estimated earlier in this chapter. Since alfalfa is a perennial legume and its stand is kept on the representative farm for three years in each BMP rotation, there is a one time seed cost in the cycle of a rotation. The costs of baling and removing irrigated alfalfa hay are the same as the value for dryland alfalfa production in the non-irrigated corners. The custom rate of cutting and conditioning is set at $18.5/acre. The custom rate for baling and hauling is set at $18.5/bale, where the size of bale is 5ft. by 6ft. After the growing season in the third year, the alfalfa stand will be terminated to prepare for annual crop production. The alfalfa stand is terminated by using tillage, herbicides, or a combination of both (SMA n.d.). The custom rate of breaking with two operations (tillage and glyphosate herbicide) is $14.48 per acre (GOS 2006).

5.4.2. Adding Green Manure into Rotation

Green manuring is considered as a BMP because of its ability to improve soil quality and increase the levels of organic nitrogen and organic matter in the soil. The type of green legume crop used for manuring in this study is determined based on expert opinion and similar studies. Two green manure crops/approaches used in this study are: vetch under-seeded with barley, and fababean. The strategy and economic impacts of each green manuring method are discussed below.

5.4.2.1. Strategies of Adding Green Manure into Rotation

5.4.2.1.1. Growing Vetch Under-seeded with Barley as Green Manure

Growing vetch under-seeded with barley as green manure was suggested by Konschuh (2012). It is an approach that a potato farmer would adopt when considering green manure (Konschuh 2012). In the potato rotation, vetch is grown after barley harvest, and then plowed in the soil[19]. For the potato rotation including sugar beets (Rotation PWSbDb), one year of vetch under-seeded with barley is added between potatoes and dry beans in the rotation. Thus, the new BMP rotation cycle is five years in length. For the potato rotation including canola (Rotation PWCaCe), given that a cereal crop is produced

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[19] Konschuh (2012) also suggested planting green peas for processing or barley for silage. Growing green peas is not considered in this study as the crop is not included in the baseline model. In addition, because this study focuses on crop-only production, barley for silage is excluded.

before the potato crop in the basic rotation, the cereal in the basic rotation is changed to barley under-seeded to vetch in the green manure rotation. The new BMP rotation cycle is still four years in length. In the rotation without potatoes (Rotation WCaCeDb), growing vetch as green manure is conducted by converting the cereal production between dry bean and canola to barley under-seeded to vetch. The sequences of rotations are as follows.

Basic Rotation WCaCeDb: Red spring wheat – Canola – Cereal – Dry bean

BMP Rotation WCaCeDb-BV: Barley under-seeded to vetch – Canola – Red spring wheat – Dry bean

Basic Rotation PWSbDb: Potato – Red spring wheat – Sugar beet – Dry bean

BMP Rotation PWSbDb-BV: Potato – Red spring wheat – Sugar beet – Dry bean – Barley under-seeded to vetch

Basic Rotation PWCaCe: Potato – Red spring wheat – Canola – Cereal

BMP Rotation PWCaCe-BV: Potato – Red spring wheat – Canola – Barley under-seeded to vetch

5.4.2.1.2. Growing Fababean as Green Manuring

An alternative green manuring practice is growing a green manure crop for one year in a rotation. This practice was used by Trautman (2012) to replace summer fallow with a legume green manure in the Brown and Dark Brow soil zones in dryland production in Alberta. There are diverse legumes that can be used as green manure crops. In this study, since the legume is grown for just one year, the options are narrowed down to annual legumes: field pea, lentil, chickling vetch, and fababean. Each of these crops has its benefits and drawbacks.

Field peas can be grown under a large range of growing conditions. Their residues can break down quickly (AARD 2004-a; GOS 2008). As regards lentils, their residue can break down quickly, but their N fixation is smaller than that of field peas and seed is relatively expensive (AARD 2004-a). As regards vetch, it is good when grown in dry conditions and has good capacity for nitrogen fixation. Its residues can also breakdown as quickly as those of lentils. There is limited availability of vetch seed (AARD 2004-b;

GOS 2008). Fababeans can fix nitrogen during the whole growing season. If the water supply is sufficient, fababeans can produce a large amount of dry matter and fix the highest level of nitrogen among the annual legume green manure crops. However, fababeans are more reliant on soil moisture (AARD 2004-b; GOS 2008).

Since the representative farm is under irrigation and the requirement of sufficient water for crop growth is more likely be satisfied, fababean crop is chosen as the green manure crop. In this case, the green manure is grown individually instead of being under-seeding with other crops. One more year is added into the cycle of rotation to grow fababean. The sequences of rotations with fababean are as follows.

Basic Rotation WCaCeDb: Red spring wheat – Canola – Cereal – Dry bean

BMP Rotation WCaCeDb-Fa: Red spring wheat – Fababean – Canola – Cereal – Dry bean

Basic Rotation PWSbDb: Potato – Red spring wheat – Sugar beet – Dry bean

BMP Rotation PWSbDb-Fa: Potato – Red spring wheat – Sugar beet – Dry bean – Fababean

Basic Rotation PWCaCe: Potato – Red spring wheat – Canola – Cereal

BMP Rotation PWCaCe-Fa: Potato – Red spring wheat – Canola – Cereal – Fababean

5.4.2.2. Economic Impacts of Adding Green Manure BMPs

5.4.2.2.1. Positive Effects on the Subsequent Crop

As discussed in Chapter 2, adopting green manure BMPs can reduce inorganic fertilizer application and increase the yields of subsequent crops and. These two benefits are quantified and modelled based on recommendations in the literature and on expert opinion.

The most widely recognized benefit of adding green manure is nitrogen fixation ability. The organic nitrogen provides a nitrogen source for crops following green manure and decreases the demand for inorganic nitrogen fertilizer. Moreover, the direct benefits to potato yield following the application of green manure has been demonstrated by Sincik et al. (2008) and Konschuh (2012). There is little literature supporting canola yield increase when it is grown following green manure, however. This study estimates both yield and nitrogen saving benefits for rotations.

According to AARD (1993), approximately 10% to 20% of the total annual nitrogen fixed by legumes is available for the first subsequent crop when the legumes are incorporated as green manure. This study assumes 15% of nitrogen fixed by legumes is available for the first subsequent crop. As shown in Table 5.37, the nitrogen fixation of vetch and fababean are 63.64 kg/acre and 121.36 kg/acre respectively. Thus, 9.55 kg/acre (140*15%) and 18.20 kg/acre (121.36*0.15) of nitrogen from vetch and fababean respectively are available for the following crops. The nitrogen fertilizer demand for potatoes and canola are 99.79 kg/acre and 49.90 kg/acre, respectively. The price of nitrogen nutrient is $1.80/kg. Therefore, the inorganic nitrogen fertilizer savings are $17.19/acre and $32.76/acre following vetch and fababean, respectively.

Table 5.35 Nitrogen fixation by annual legume under irrigation (kg/acre)

Crop	N fixed symbiotically
Vetch	63.64[b]
Fababean	121.36[a]
Field Pea	80.91[a]
Chickpea	40.09[a]

[a] Source: AARD (2004-a)

[b] The nitrogen fixation of vetch is not available in AARD (2004-a). However, in GOS (2007) report, the range of N fixation of vetch is greater than chickpea and smaller than field pea. According to this information, the N fixation by vetch is estimated at 63.64kg/acre.

Based on Sincik et al.(2008) and Boydston and Hang (1995), the increase in yield when potatoes are grown after green manure (either vetch or fababean), compared with being grown in the basic rotation, is modelled assuming a uniform distribution with a minimum 5% and maximum 20%. The increase of canola yield following green manure is assumed to have a uniform distribution where a draw is taken from the minimum of 0% and the maximum of 10%.

5.4.2.2.2. **Negative Effect on Barley Yield**

When barley is under-seeded with vetch, regular herbicides used in barley production may not be applied. For example, 2-4-D and dicamba are widely used in weed control in barley production (SMA 2012-b). However, these two herbicides can also control the growth of vetch (Verhallen 2012). Therefore, when growing vetch under-seeded with barley for green manure, the application of these two herbicides is avoided, which might lead to a reduction in barley yield. According to AARD (2011), crop yield could reduce 15% to 20% in Alberta due to the competition from weeds. This study assumes that the yield of barley will decrease 15% when under-seeded with vetch. Therefore, each stochastic yield drawn from the distribution is multiplied by 85%.

5.4.2.2.3. **Cost of Green Manure BMP**

There are three types of costs associated with green manuring: seed and seeding, inoculant to maximize nitrogen fixation, and termination. The seeding rate is 41 kg/acre for vetch (AARD 1993) and 69kg/acre for fababean (GOS 2005). The costs of seed are \$1.76/kg (Green Cover Seed Corp 2012) and \$0.36/kg (SCIC 2012) for vetch and fababeans, respectively. Since vetch is under-seeded with barley, there is no extra seeding cost beyond the cost of seed itself. For fababean, the seeding cost is set at \$18/acre (AARD 1993)[20]. According to AARD (1993), the inoculant cost is \$1.17 per 25 kg of seeds. Therefore, the inoculant costs are \$2.0/acre and \$3.2/acre for vetch and fababean, respectively. Once the green manure crops are at full bloom, it is the best time to terminate the crops (AARD 1993). To terminate the green manure crops, the use of either chemicals or tillage can be effective (GOS 2008). Chemical termination will leave more residues on the field than using tillage, which can help to reduce soil erosion and maintain the moisture in the soil (GOS 2008). Since there are no available data on termination costs, this study uses the same termination cost as that used for alfalfa stand termination, which is \$14.48/acre.

5.4.3. Crop Residue Management BMP

In this study, leaving crop residues in the field is considered as a BMP. This is because it can increase soil moisture in the in the short-turn, and reduce soil erosion during the non-growing season and increase soil organic matter in the long run (Korol 2004).

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[20] There is no information about cost of fababean seeding in AARD (1993). Since the seeding rates for fababeans and field peas are similar, this study assumes that the seeding cost of fababeans is the same as field peas, which is \$18/acre.

5.4.3.1. Strategy of Crop Residue Management BMPs

The baseline scenario in this study assumes that residues of cereals are removed by baling and selling in the market and residues of the rest of the crops (canola, dry beans, sugar beets, and potatoes) are left on the field. For a residue management BMP, there is no change in crop rotation. The residues of cereals are also removed and baled. But these baled residues are chopped and spread on the fields grown with sugar beets, potatoes, or dry beans. The reason for applying residues on the potato, sugar beet and dry bean fields is that there is a small amount of easily decomposable residues left in the fields after harvesting. By doing so, producers can reduce soil erosion and increase the quantity of farm organic matter. Since canola can produce a large quality of chaff to cover the field, no additional residue management is used in canola fields.

According to AARD (2005-a), spreading one to three tonnes of cereal straws on each acre field by using a round bale shredder can generate a ground cover that is sufficient to prevent erosion. This study assumes that each acre of potatoes, sugar beets and dry beans is broadcasted with three tonnes of cereal straws. The shortage or surplus of baled cereal residues will come from or go to the market[21].

5.4.3.2. Economic Impacts of BMP Adoption

When producers adopt the crop residue management BMP, the crop residues which are sold in the baseline scenario are used on the fields grown with potatoes, sugar beets and dry beans. Thus, the representative farm has less cash flow compared with the baseline model. Moreover, if crop residues produced on the representative farm are not enough to cover the fields, additional residue will be bought from the market at $25 per large bale (500kg). The custom rate of chopping and spreading residue is set at $11.20 per acre (SMA 2012-c).

The short-run effect of leaving/applying crop residues in the field is to increase soil moisture. Trautman (2012) assumed that increasing soil moisture might have different effects on crop yield depending on whether the year is “dry” or “wet”. However, the representative farm is under irrigation in this study. Water requirements in addition to rainfall are supplied by irrigation. Therefore, this study does not assess the short-run

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[21] In practice, producers may just use the cereal residues produced by their own farms to cover potatoes, sugar beets, and dry beans fields and not buy extra residues when there is shortage. However, this study models the “ideal” situation, in which all the potato, sugar beet and dry bean fields have enough residue cover.

effect. In addition, the benefits from increasing soil organic matter and reducing soil erosion are more likely to be found in the long-run. As a result, they are not evaluated in this study.

5.4.4. Applying Cattle Manure BMP

Applying cattle manure is considered as a BMP in this study. That is because it can reduce the use of inorganic fertilizer and increase soil organic matter. There is also a non-nutrient benefit on crop yield when manure is applied. The method, benefits and costs of applying cattle manure are discussed in this section.

5.4.4.1. Strategy of Cattle Manure Application BMP

According to AARD (2009-b), manure application in Alberta can be determined based on soil nitrogen limits, the nitrogen requirements of intended crops, or the phosphorus requirements in one or more years of crop production. Smith (2012) suggested that the strategy of manure application should be P-based in order to reduce the environmental problems related to manure application (e.g. runoff of excess nitrogen from manure to water). Manure should be applied at three times the annual rate of P once every three years (Smith 2012). By doing so, the amount of N required for one year can be satisfied. However, modelling this strategy is problematic in this study. The reasons are as follows.

In this study, there are yield differences between crops depending on whether or not the farm has manure application. The yield differences are based on a non-nutrient effect of manure, which is discussed later in this chapter. In order to estimate the non-nutrient effect, the nutrients provided by manure must be the same as nutrients from the baseline model (which involves the application of only inorganic fertilizer). According to the Liebig's Law of the Minimum, the growth of a plant is controlled by its scarcest resource (nutrient) instead of the total available resource (nutrients) (Barak 2000). Thus, if the levels of some of the nutrients (N, K, P or S), supplied by manure application, but not all of them, are higher than those of the baseline model, the effect of these additional nutrients on yield can be considered as zero.

However, when manure is applied based on three-times the annual rate of P in this study, it cannot satisfy this condition. The quantities of available N, K and S in first year from manure application based on three-times P are not equal to those of the baseline application. For crops that have more N, P, S and K than the baseline level in the first year because of applying manure, the increases in yields could result from both nutrient and non-nutrient effects. For crops that have insufficient N, K or S in the first year due to manure application, the non-nutrient effect of manure on yield increases might be cancelled by yield decreases due to insufficient N, K or S provided by manure. Therefore, a change in crop yield might result not only from the non-beneficial effect, but also from the availability of additional nutrients from manure application.

In addition, it is not common to apply manure in the production of some crops, such as sugar beets, potatoes and dry beans. Sugar beet's root yield and sucrose content are sensitive to available N in soil: too much N will increase root yield, while the sucrose content will be lower and impurities in concentration will be higher; a lower level of N will cause an increase in sucrose yield and quality, with decreased root yield (Carlson and Bauder 2005). If manure is applied at three times the annual rate of P, the available N for sugar beet in the first year is much higher than its requirement, which may affect the root yield. Moreover, producers who grow a high-value crop (e.g., potatoes) rarely apply manure, due to disease issues (Smith 2012). Producing potatoes and dry beans requires much higher levels of N and P than producing other crops. If manure is applied at a rate based on triple the annual P requirement, a much larger amount of manure application is required. Thus N and P mineralized from manure in the second and third years may be too much for later crops, causing environmental issues (e.g., nutrient runoff).

To solve the above-mentioned issues, the strategy of manure application is modified to apply manure based on the one-year N requirement of crops. According to Smith (2012), manure is most commonly applied to farmland at approximately three to four times the annual rate of P once every three years. The three-four times rate may provide roughly the correct amount of N required for the first year. Thus no additional inorganic fertilizer is required in the first year. An alternative way to think about Smith's suggestion (2012) is that manure is applied based on the annual N requirement of the crop. In addition, because it is not suitable or common to use manure application for potato, sugar beet and dry bean crops, this study assumes that manure is just applied on cereals. As red spring wheat is grown in each rotation, an additional assumption is made: manure is only applied in red spring wheat production every four years.

In sum, the strategy of manure BMP in this study involves applying manure on the fields growing red spring wheat. Since spring wheat is grown on some of the fields each year, manure is applied by the producer in each year of the simulation. Given the nature of the base rotations, manure is applied on any particular field once every four years. The amount of manure is based on the one-year N requirement of red spring wheat.

5.4.4.2. Economic Impacts of Manure BMPs

5.4.4.2.1. **Inorganic Fertilizer Savings from Manure Application**

Generally, the amount of manure application is based on a combination of the results of soil tests, the nutrient requirement of crops, and the results of manure sampling. However, the information provided by soil tests and manure sampling are not available in this study. The nutrient requirement for crop growth is assumed to be constant in each year and is based on the fertilizer rate listed in the 2011 AgriProfit$ Cropping Alternatives (AARD 2011-c) (shown in Table 5.36). "Book values" of nutrient content from AARD (2009-b) are used in this study, and are presented in Table 5.37. In addition, the mineralizing rate of organic nutrients[22] in manure is shown in Table 5.38.

Table 5.36 Annual nutrient requirements for irrigated crops in southern Alberta (Unit: kg/acre)

Crop	N	P_2O_5	K_20	S
Cereal (barley, wheat)	45.4	18.1	2.3	0
Dry bean	36.3	22.7	0	4.5
Sugar beet	45.4	22.7	4.5	0.0
Canola	49.9	22.7	2.3	9.1
Potato	99.8	63.5	49.9	9.1

Source: AARD (2011-c)

Table 5.37 Nutrient content of manure

Total N	NH_4-N	P	K	S	Moisture	Loss of NH_4-N in 48 hours
Kg/tonne						
9	2.3	2.2	6.1	0	50%	15%

Source: AARD (2009-b)

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[22] Mineralizing rate of organic nutrient is the rate at which the nutrient in organic form transforms into its mineral form. The mineral form can be absorbed by plants.

Table 5.38 Mineralizing rate of organic nutrients

	N	P	K	S
1st year	25%	70%	90%	0%
2nd year	12%	20%	0	0
3rd year	6%	6%	0	0
Total	43%	96%	90%	0%

Source: AARD (2008-a)

In this study, manure is applied to red spring wheat based on its annual N requirement. The amount of manure application is estimated by dividing the annual N requirement by available N in the first year from manure. The process and calculation are shown as follows:

Total organic N after manure application per tonne of manure
= Total N – NH_4-N
= 9kg/tonne – 2.3kg/tonne
= 6.7 kg/tonne

Mineralized N from organic N in the first year per tonne of manure
= Mineralizing rate of N in the first year* Total organic N after manure after manure application per tonne
=25%*6.7 kg/tonne
= 1.68 kg/tonne

Available N from NH_4-N per tonne of manure
= Total NH4-N – Loss of NH4-N
= 2.3kg/tonne*(1-15%)
= 1.96 kg/tonne

Total available N in the first year per tonne of manure
= Mineralized N from organic N in the first year per tonne+ Available N from NH_4-N per tonne
= 1.675kg/tonne + 1.955kg/tonne
= 3.63 kg/tonne

Manure applied to red spring wheat per acre
= Annual N needs of red spring wheat per acre/Total available N in the first year from manure per tonne

= (45.4kg/acre) / (3.63kg/tonne)
= 12.51 tonne / acre

The available P in the first year per acre when manure application rate is 12.51 tonne/acre
= Total manure per acre * Total P content of manure per tonne * Mineralizing rate of P in the first year
= (12.51 tonne/acre) * (2.2 kg/tonne) * 70%
= 19.27 kg/acre

The available K in the first year per acre when manure application rate is 12.51 tonne/acre
= Total manure per acre*Total K content of manure per tonne * Mineralizing rate of K in the first year
= 12.51 tonne/acre * (6.1kg/tonne) * 90%
= 68.74 kg/acre

The nutrient requirements for P and K are reported in kg of P_20_5 and K_20. To be consistent, the available P and K content of manure must be converted into forms of P_20_5 and K_20 by using factors of 2.29 and 1.2, respectively (AARD 2008-b).

The available P_20_5 in the first year per acre when manure application rate is 12.51 tonne/acre
= 19.27kg/acre*2.29
= 44.13 kg/acre

The available K_20 in the first year per acre when manure application rate is 12.51 tonne/acre
= 68.74 kg/acre * 1.2
= 82.49 kg/acre

The residual P_20_5 from the first year per acre when manure application rate is 12.51 tonne/acre
= The available P_20_5 in the first year – Crop requirement P_20_5 in the first year
= 44.13 kg/acre – 18.1kg/acre
= 26.03 kg/acre

The residual K_20 from the first year per acre when manure application rate is 12.51 tonne/acre

= The available K_20 in the first year per acre – Crop requirement K_20 in the first year per acre

= 82.49 kg/acre – 2.3kg/acre

= 80.19 kg/acre

This study assumes that the runoff rate for P_20_5 and K_20 between two growing seasons is set at 17.18% (as discussed in Section 5.4.5).

The carryover P_20_5 in the second year per acre when manure application rate is 12.51 tonne/acre

= The residual P_20_5 from the first year per acre * (1-17.18%)

= 26.03 kg/acre * (1-17.18%)

= 21.56 kg/acre

The carryover K_20 in the second year per acre when manure application rate is 12.51 tonne/acre

= The residual K_20 from the first year per acre* (1-17.18%)

= 80.19 kg/acre * (1-17.18%)

= 66.41 kg/acre

In the second and third year after manure application, nutrients are derived from both (a) mineralizing organic matter from manure and (b) inorganic fertilizer. The total saving of inorganic fertilizer results from mineralized and/or carryover nutrients if possible. In the fourth year, there are no mineralized nutrients from manure. But the carryover K can still be used by crops. The summarized inorganic fertilizer savings from manure application in each of four years is shown in Table 5.39[23].

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[23] In some cases, the nutrients derived from manure might exceed the crop requirement. If that happens, the fertilizer saving is determined by the amount of nutrient required rather than the total available nutrients.

Table 5.39 Summarized inorganic fertilizer saving from manure application in each of four years, by rotation (kg/acre)

	Year 1	Year 2	Year 3	Year 4
Rotation WCaCeDb	W	Ca	Ce	Db
N	45.4	11.12	5.03	0
P (in form of P_20_5)	18.1	22.6	13.23	0
K (in form of K_20)	2.3	2.3	2.3	0.00
Rotation PWSbDb	W	Sb	Db	P
N	45.4	10.07	5.03	0.00
P (in form of P_20_5)	18.1	22.6	13.23	0.00
K (in form of K_20)	2.3	4.5	0.00	42.45
Rotation PWCaCe	W	Ca	Ce	P
N	45.4	11.12	5.03	0
P (in form of P_20_5)	18.1	22.6	13.23	0
K (in form of K_20)	2.3	2.3	2.3	42.13

Once the amount of inorganic fertilizer saving is established, the economic benefit is calculated by multiplying the amount of nutrient saved by nutrient prices. Table 5.40 presents the reduced fertilizer costs from manure application in each manure application cycle.

Table 5.40 Economic values from reduced fertilizer inputs from manure application, by rotation (excluding costs of manure application, soil test, and manure test) ($/acre)

	Year 1	Year 2	Year 3	Year 4
Rotation WCaCeDb	W	Ca	Ce	Db
	106.36	49.83	27.53	0.00
Rotation PWSbDb	W	Sb	Db	P
	106.36	50.62	24.84	50.24
Rotation PWCaCe	W	Ca	Ce	P
	106.36	49.83	27.53	49.85

5.4.4.2.2. **Non-nutrient Benefit of Manure Application BMP**

According to the literature (Lupwayi et al. 2005; Ghanbari et al. 2012; Mallory and Porter 2007; Nitschelm and Regitnig 2005; Lentz and Lehrsch 2012) (summarized in Table 5.41), manure application offers a non-nutrient benefit. Applying a certain amount of manure alone or in combination with inorganic fertilizer can result in a higher yield of crop, in comparison with just applying the same level of nutrients in a form of inorganic fertilizer. Black and White (1973) speculated that the non-nutrient benefits resulting from the application of manure include a better growing environment for crops, such as increased soil organic matter, better soil structure and moisture-holding capacity, and improved cation-exchange capacity[24].

In this study, the application of cattle manure in combination with inorganic fertilizer is considered as a BMP to replace inorganic fertilizer application alone. The non-nutrient benefit and fertilizer savings associated with this BMP are determined.

The findings from previous studies shown in Table 5.41 include some projects that examine sites outside of Alberta; some focus on irrigated land, and some on dryland. The non-nutrient benefit on crop yield found by these studies might not be the same as the effects on crop yields on an irrigated farm in Southern Alberta. The gains in crop yields because of applying cattlemanure are assumed to be within a range of 1% to 5% determined by drawing from a uniform distribution.

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[24] Cation-exchange capacity is a soil science terminology. It refers to the maximum quantity of total cations capable being held by a soil. One of its usages is to measure soil fertility.

Table 5.41 Non-nutrient benefit of manure

Crop	Nutrient Source	Level of Nutrient	Yield Increase[a]	Location/ Farm Type/ Source
Canola	cattle manure	N requirement	+24%	Falher and Fairview, Alberta, Canada; (dryland); (Lupewayi et al. 2005)
Canola	hog manure	N requirement	+46%	
Barley	cattle manure	N requirement	+18%	
Barley	hog manure	N requirement	0	
Wheat	cattle manure	N requirement	+13%	
Wheat	hog manure	N requirement	-1%	
Barley	50% manure + 50% fertilizer	Equal to fertilizer. application	+1.6%	Zabol, Sistan and Baluchestan, Iran; (Irrigated farm) (Ghanbari et al. 2012)
Potato	amended soil	Equal to non-amended soil (manure, compost, green manure and supplement fertilizer)	+(4-54)%	Maine, United States; (Dryland) (Mallory and Porter 2007)
Sugar beet	composted manure + fertilizer (N+P)	Depends on soil test	-(5.16-12.35)%	Taber, Alberta, Canada; (Irrigated farm) (Nischelm and Regitnig 2005)
Sugar beet	composted manure + urea fertilizer	Depends on soil test	+20%	Idaho, United States; (Irrigated farm); (Lentz and Lehrsch 2012)

[a] The yield increase is calculated by in comparison with yield from application of inorganic fertilizer.

5.4.4.2.3. Cost of Cattle Manure Application BMP

Regarding the cost of manure application, it is estimated based on expert opinion. According to Smith (2012), there is no market for manure, but there might be a small market for compost. If crop producers do not have livestock, they might purchase manure from their neighbour, but the prices of manure are not always available. Smith (2012) made an assumption that crop producers could pay to have manure delivered and applied at about break-even with the cost of inorganic fertilizer N and P_20_5 [25]. Based on a two-mile hauling distance, the total cost of manure transportation and application is set at $8/tonne. In this study, the manure application rate is 12.51 tonnes per acre. As a result, the total cost of manure application is $100.16/acre every four years.

The amount of manure applied on the representative farm each year is either 5,409 tonnes (12.51tonne/acre*432 acres) or 3,606 tonnes (12.51tonne/acre*288 acres). Both of these figures exceed the limit of 500 tonnes for no soil test (as discussed earlier). Therefore, a soil test is required on the representative farm in preparation for manure application. According to AARD (2004-c), there are two steps involved in such a test: soil sampling and soil testing. Soil sampling is conducted by farmers, fertilizer dealers or crop advisors (AARD 2004-c). Fields with different crops and management histories must be sampled separately (AARD 2004-c). Generally, 15 to 20 samples must be obtained from a representative portion of a farm (AARD 2004-c). The samples are then submitted to a laboratory (AARD 2004-c). This study assumes that 15 samples and 20 samples are obtained from fields of 432 acres and 288 acres, respectively. According to Soil Foodweb Canada Ltd. (2012), the cost of soil testing is set at $50 per sample.

In addition, although this study uses the “book value” of nutrient content in manure when determining the manure application, the cost of manure testing is considered. It assumes five samples are taken and tested each time when applying manure. The cost of manure testing is $55 per sample (Soil Foodweb Canada Ltd. 2012).

5.4.4.3. Manure BMP versus Regulations

As discussed in Chapter 2, there are regulations on manure application in Alberta. The practice of manure BMP must not violate the regulations before being adopted by a farm. According to the Reference Guide to AOPA (AARD 2008-a), the requirements for on-farm manure application include manure incorporation requirements, prescribed setback distances, soil nitrogen and salinity limits, record keeping, and soil testing. In this model, there is no information on soil salinity or on the slope of the land on the representative farm. Therefore, this study assumes that the representative farm meets the requirements for setback distance and salinity limits. In addition, the nutrients from manure in this

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[25] Smith (2012) also suggested that most crop producers are not willing to pay an inorganic fertilizer equivalent price for manure.

study are calculated on the assumption that they are incorporated within 48 hours, which does not violate the regulations. There is a soil test on the farm with manure application in this study, as required by regulations. Furthermore, the regulations require that the level of nitrate-nitrogen (NO_3-N) should not be higher than 72.84 kg/acre, 91.05 kg/acre, and 109.27 kg/acre on sandy soil (>45% sand and water table <4 meters), sandy soil (>45% sand and water table >4 meters), and medium and fine textured soils, respectively (AARD 2008-a). In manure application, nitrate is derived from the nitrification of ammonium, while ammonium is derived from manure itself and from the mineralization of organic nitrogen in manure (UCCE 2009). Therefore, the total amount of nitrate-nitrogen from manure application is approximately equal to the total amount of crop-available nitrogen from manure. In this study, the highest total amount of crop-available nitrogen from manure, which is 45.4kg/acre (3.630kg/tonne*12.51 tonnes), is available in the first year that manure is applied. The level of nitrate-nitrogen is lower than the limit in the regulations. As a result, the practice of manure BMP assumed in this study does not violate the regulations in Alberta.

5.4.5. Nutrient Management Planning (NMP) BMP

In the baseline scenario, a constant rate of fertilizer is applied for a crop each year based on its target yield. When the farm adopts the NMP BMP, the residual fertilizer from the previous growing season is taken into account when considering the fertilizer application in the current growing season.

5.4.5.1. Strategy of Nutrient Management Planning (NMP) BMP

The baseline scenario assumes that a constant amount of fertilizer is applied to a crop each year based on its target yield. In this study, the target yield is assumed to be the average historical yield (detrended) plus one standard deviation. The reason that the target yield is higher than the average yield is because the study assumes that a rational farmer always applies the fertilizer based on a higher-than-average yield expectation. However, when unfavourable weather, various soil physical and chemical factors, and/or crop diseases occur in the growing season, crop growth will be impeded, thus reducing the nutrient uptake and crop yield (Jong et al. 2009). In other words, if the actual crop yield is lower than the farmer's target yield, nutrients from fertilizer are not totally absorbed by crops[26].

With the adoption of NMP, soil tests are conducted on the representative farm to assess the nutrients available in the soil for the current growing season, which are left over from the previous year's fertilizer application. In this study, the result of the soil test is not available. To model the amount of available nutrients from the soil test, a series of assumptions are made as follows.

In the growing season, nutrients removed from the farm equal the nutrients absorbed by crops. In addition, this study assumes that a linear relationship exists between crop yield and crop nutrient uptake. Once the stochastic yield is lower than its target yield, there are residual soil nutrients at the end of growing season. The percentage of difference between the stochastic yield and the target yield equals the percentage of difference between actual nutrient removed by crops and total nutrient application (Equation 5.23):

$$\frac{Stochastic\ yield - Target\ yield}{Target\ yield} * 100\% = \frac{Actual\ nutrients\ removed\ by\ crops - Nutrient\ application}{Nutrient\ applicaiton} * 100\% \quad \cdots\cdots(5.23)$$

where the stochastic yield is less than the target yield.

The term for residual soil nutrients refers to the amount of nutrients from fertilizer being left in the soil at the end of the growing season. By transforming Equation 5.23, the total amount of residual nutrients, which is equal to subtracting actual nutrients removed by the crop from the amount of nutrients applied in forms of fertilizer, can be expressed as Equation 5.24:

$$Residual\ nutrient = \left[\left(\frac{Target\ yield - Stochastic\ yield}{Target\ yield}\right) * (Nutreint\ applciation\ )\right] \quad \cdots\cdots(5.24)$$

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[26] If the actual yield is greater than the target yield, it is assumed that the additional nutrients required to support that yield came from the soil itself.

where the stochastic yield is less than the target yield.

Not all of the residual soil nutrients are available for crops in the next growing season. In the non-growing season, a portion of residual soil nutrients will run off into bodies of water and leach down to depths of the soil which cannot be reached by crop roots. Thus, the actual amount of carryover nutrients for the next growing season equals the residual soil nutrients multiplied by their carryover factor. According to expert opinion, the runoff rates of residual soil nutrients are 15%, 0%, 0%, and 5% for N, P, K, and S, respectively, on an irrigated farm in southern Alberta (McKenzie 2012). The amount of carryover nutrients from fertilizer are considered as fertilizer credits for crops grown in the following year in the same field.

5.4.5.2. Economic Impacts of NMP BMP

Once the representative farm adopts the NMP and encounters a "bad" year (i.e., actual yield is lower than the target yield), there are residual nutrients available for crops in the next growing season. The amount of carryover fertilizer residues are calculated by subtracting the amount of runoff residues between the growing seasons from the residual soil nutrients. The value of carryover nutrients is the economic benefit from adopting NMP BMP.

The direct costs of applying NMP are related to soil testing. In this study, the cost of soil sampling tests is set at $50 per sample. The number of samples for a field depends on its size. Twenty and 15 samples are taken for fields of 432 acres and 288 acres, respectively.

5.5. Simulation and Cash Flows for Beneficial Management Practices Analysis

This study uses cash flow simulation to evaluate the economic impact of BMP adoption. Annual modified cash flow is used to determine the yearly farm performance. The series of modified cash flows in each scenario is converted into Net Present Value (NPV). Farm models are analyzed using Monte Carlo simulation. The simulated results of NPVs of the representative farm without and with BMPs are compared. The differences are regarded as the economic impacts of BMPs on the representative farm.

5.5.1. Discount Rate

The discount rate applied to the Monte Carlo simulation result depends on the type of study being analyzed. The Treasury Board of Canada Secretariat recommended a discount rate of 10% in 1976 for federal cost-benefit analysis (Boardman et al. 2008). In 2007, this discount rate was changed to 8% with sensitivity rates of 3% and 10% (Treasury Board of Canada Secretariat 2007). Those discount rates were estimated using the weighted social opportunity cost of capital method; that is, a weighted average of the marginal cost of additional foreign capital inflows, the rate of return on postponed investment, and the rate of interest on domestic saving (Treasury Board of Canada Secretariat 2007). Recent studies (Cortus 2005; Koeckhoven 2008; Trautman 2012) which are similar to this study used a discount rate of 10% to evaluate the economic impact of farming practices on farms. This study uses 10% as a default discount rate.[27]

5.5.2. Number of Iterations in Simulation

This study uses the @RISK program to conduct a Monte Carlo simulation. In each iteration, @RISK selects a value from the pre-modelled probability distributions and recalculates the Excel worksheet using the new selected values. The results from a number of iterations generate the distribution. As more iterations are conducted, more results can be used to generate a distribution and the distribution will be more accurate. However, the time required for the simulation increases with the number of iterations.

To compare the results from different numbers of iterations (1,000, 5,000, and 10,000), two paired t-tests were used[28]. The null hypotheses in the paired t-tests are that means from models using 1,000 iterations and 5,000 iterations are equal, and means from models using 1,000 iterations and 10,000 iterations are equal. Neither hypothesis was rejected. However, the time used to produce 10,000 iterations is significantly longer than that required for 5,000 iterations and 1,000 iterations. To achieve a balance between accuracy and time, each simulation is run based on 5,000 iterations in this study.

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[27] The sensitivity of the model results to changes in the discount rate was done. While the numerical value of the NPVs changed, the overall BMP results were not sensitive to the discount rate; that is, whether or not adoption of specific BMPs generated positive or negative net benefits.

[28] An alternative is using the Kolmogorov-Smirnov (K-S) test.

5.5.3. Modified Net Cash Flow (MNCF)

Modified Net Cash Flow (MNCF) is used to represent the net cash flows in this study. It includes more cash flows than measuring a gross margin, but covers fewer items than quantifying a net cash flow (Koeckhoven 2008). The reasons for choosing MNCF are as follows. MNCF includes the revenues and expenses associated with farm production. It also takes cash flow from risk management programs (i.e., crop insurance and AgriStability) into account. Moreover, the cash outflow used to account for machinery maintenance and replacement is included in MNCF. By using MNCF, the capital structure regarding financing farm assets as either debt or equity is excluded.

In this study, the time horizon in the simulation analysis is 20 years. The baseline rotation cycles are all four years. Thus, there are five rotation cycles in each field over 20 years. When adopting a BMP such as adding alfalfa into rotation, a rotation cycle is extended to seven or eight years. Having a 20-year time horizon insures that this study analyzes at least two full rotation cycles when the representative farm adopts the BMPs in each field.

The 20-year cash flows are used to calculate an NPV in perpetuity. Perpetuity refers to a stream of cash flows that continues indefinitely into the future. It is used to estimate the NPV of a farm assuming an infinite time horizon for the farm business. The representative farm is considered able to continue crop production beyond the simulation time. In addition, the biological and financial impacts of BMP adoption are able to extend for a longer period than the simulation time. For example, adding alfalfa into rotation, green manuring, and nutrient management planning have positive impacts on soils over time. The method of calculating the NPV in perpetuity is shown in Equation 5.25:

$$NPV_{Perpetuity} = \sum_{t=0}^{20} \frac{C_t}{(1+r)^t} + \frac{C_{20}}{r} \frac{1}{(1+\mathrm{r})^{20}} \cdots\cdots (5.25)$$

where C_t is the cash flow at time t (t=0 to 20), and r is the interest rate.

Once the NPV is available, it is converted to an annualized value. For an NPV in perpetuity, the time horizon is infinite. The annualized equation is shown Equation 5.26:

$$A = NPV_{Perpetuity} * r \cdots\cdots (5.26)$$

where A is annualized NPV, and r is the interest rate.

5.5.4. Beneficial Management Practices Assessment

This study builds models to determine the Modified Net Present Value for each rotation on the representative farm. The impacts of BMP adoption in each rotation are then quantified. The simulated value of the difference in the NPVs with and without BMP adoption is regarded as the on-farm benefit or cost of BMP adoption on the representative farm. The Modified Net Present Value of difference is annualized and divided by the total farm acreage to establish the net benefit or cost of BMP per acre.

5.5.5. Chapter Summary

This chapter uses statistical data and expert opinions to build a representative irrigated farm in southern Alberta. Farm size, three possible rotation sequences, irrigation methods, and non-irrigated corners are identified.

Based on the historical data, stochastic crop price, crop yield and irrigation cost models are estimated. These stochastic variables present the major risks in agricultural production. Production revenue, production costs, and agricultural insurance programs are modelled by incorporating the built stochastic variables. Modified Net Cash Flows are converted into net present values.

Each BMP adoption will lead to changes in aspects of crop production such as crop yields, crop acreage, production costs and insurance. These changes are evaluated and quantified in the models. The changes in net present values with and without BMP adoption are regarded as the on-farm benefits or costs of BMP adoption.

Chapter 6. Results and Discussion

This chapter presents the results and key findings from the simulation scenarios that were identified in Chapter 5. These include the results of the baseline scenarios, BMP scenarios, and BMP sensitivity analyses, respectively. Both the BMP scenarios and sensitivity analyses are compared with the baseline scenarios to evaluate the economic effects of adopting BMPs on the representative farm. The key findings based on the results are also discussed.

6.1. Baseline Scenario Results

The baseline scenario assumes that none of the BMPs are adopted. The result of the baseline scenario for each rotation is used as a basis when comparing the changes due to the BMP adoption and the sensitivity analysis.

Table 6.1 shows the means and standard deviations of the NPV[29] for the whole farm, NPV per acre, and the annualized NPV per acre by rotation for the baseline scenario. As discussed in the previous chapter, the modified net cash flows (MNCFs) are used in the NPV calculation. As a result, the NPV for the representative farm can be used as a modified wealth measure for the farming operation. A higher NPV indicates greater wealth.

The annualized NPVs for the operations are $215, $589, and $544 per acre for Rotations WCaCeDb, PWSbDb, and PWCaCe, respectively. The highest annualized NPV is in Rotation PWSbDb, a rotation that includes red spring wheat, dry beans, potatoes, and sugar beets. Rotation PWCaCe, including two cereals, potatoes, and canola in the rotation sequence, has the second highest values. Rotation WCaCeDb, which has two cereals, canola, and dry beans in the rotation, generates the lowest value. NPV for the rotation with potatoes is more than twice as much as the one without potatoes. This is because the revenue per acre for potato is much higher than revenues for other crops. The NPV in Rotation PWSbDb is higher than Rotation PWCaCe because the sugar beets and dry beans in Rotation PWSbDb are more valuable than canola in Rotation PWCaCe. In addition, the standard deviations of the NPVs are increasing as the means of the NPVs increase. This is consistent with the economic theory which indicates as expected returns increase, so does the variance of returns.

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[29] In this chapter, the NPV represents the NPV with perpetuity unless noted otherwise.

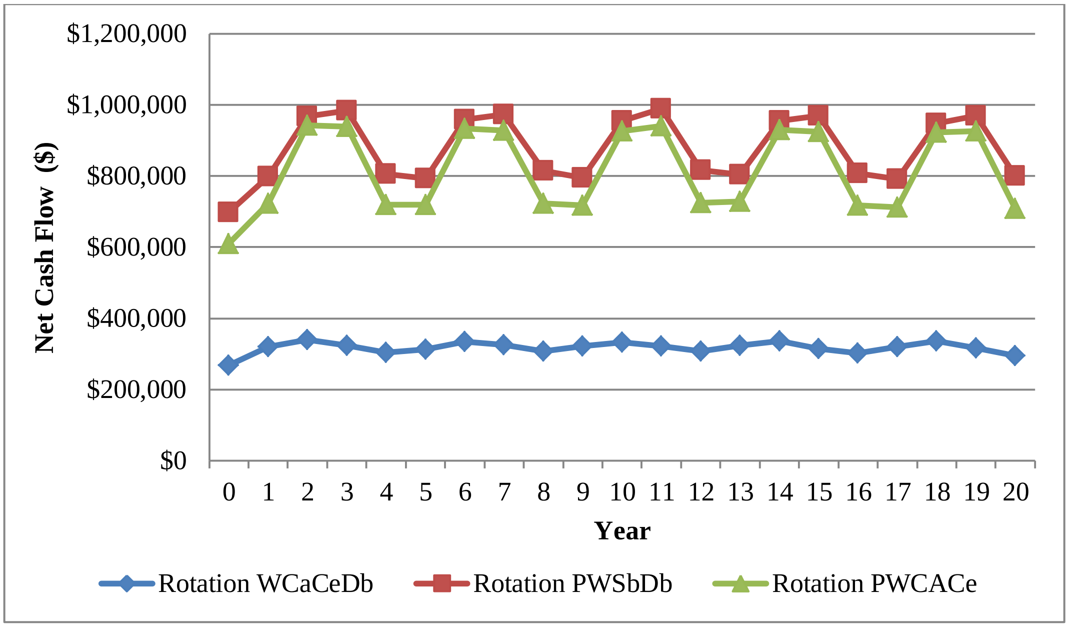
Table 6.1 Baseline results of the representative farms for the NPV variables, by rotation

Rotation	Mean NPV ($/farm)	Standard Deviation	Coefficient of Variation (C.V.)	NPV per acre ($/acre)	Annualized NPV per acre ($/acre)
WCaCeDb	3,441,828	466,234	0.135	2,151	215
PWSbDb	9,422,890	1,577,002	0.167	5,889	589
PWCaCe	8,703,008	1,450,891	0.167	5,439	544

Figure 6.1 shows the average annual modified net cash flows for the three rotations on the representative farm over the 20-year time period. According to Figure 6.1, Rotation PWSbDb has the highest modified cash flows over the 20 years, followed by Rotations PWCaCe and WCaCeDb. The modified net cash flows over the 20-year time period in Rotation WCaCeDb are fluctuating around $300,000. For Rotations PWSbDb and PWCaCe, cycles exist in the modified cash flows every four years. In Rotation PWSbDb, the average annual modified cash flows in the first year are approximately $800,000. The values jump to approximately $1,000,000 in the second and third years, with the second year slightly lower than the third year. In the fourth year, the values are slightly higher than $800,000. A similar cycle exists in Rotation PWCaCe.

There are reasons for having significant cycles in Rotations PWSbDb and PWCaCe but not in Rotation WCaCeDb. The representative farm is divided into four partitions, two that are 288 acres each, and two that are 432 acres each. Four crops are rotated on each partition. Therefore, the annual areas of a crop are not all the same in the 20-year time period: they change in a pattern. If the gross margins of crops in a rotation are similar, the total annual cash flows do not change significantly, even when the pattern of crop areas changes. However, if there are significant differences in gross margins for crops in a rotation, the total annual cash flows will change largely due to the change in crop area. In this study, the production margins of potatoes and sugar beets are much higher than those for cereals, canola, and dry beans. Therefore, there are significant cycles in Rotations PWSbDb and PWCaCe but not in Rotation WCaCeDb.

Figure 6.1 Modified net cash flows for the representative farm over a 20-year time period, by rotation



According to this study, the NPVs of modified cash flows for Rotations PWSbDb and PWCaCe are much higher than for Rotation WCaCeDb. The reasons that all farmers do not switch from Rotation WCaCeDb to Rotation PWSbDb or Rotation PWCaCe are as follows. Firstly, the modified net cash flows and NPVdo not correspond exactly to the net worth of an operation. The cash flows which are relevant for equity calculations such as the paid capital interests are not included in MNCFs. In this study, the paid capital interests for growing potatoes or sugar beets might be higher than for growing cereals/oilseed and dry bean because potato and sugar beet production requires a bigger investment in terms of machinery. This outflow is not included in the modified net cash flow. Secondly, licenses are required to grow potato and sugar beet in Alberta. Thirdly, producing potatoes and sugar beets is more risky than producing cereals/oilseeds and dry beans. As shown in Table 6.1, the variance of NPVs increases as the NPVs rise. The coefficients of variation (CV) for NPVs in Rotations PWSbDb and PWCaCe are higher than in Rotation WCaCeDb. Lastly, potato production may require higher quality land in terms of soil type or soil characteristics. Although this study assumes that the representative farm is identical for Rotations WCaCeDb, PWSbDb and PWCaCe, in reality, growing potato usually requires “better” farmland. For example, potato farmland is more likely well-drained, has flat topography, and is free of stones (MAFRI 2003). When Farm Credit Canada (FCC) presents the market farmland value for cultivated irrigated land, the land is identified as grain, potato, or forage land. This illustrates that potato production requires specific farmland.

6.1.1. Validation of Representative Farm Model

A method used to validate the baseline simulation model in current studies (i.e., Trautman 2012) is to compare the total value of the operation (e.g., NPV with perpetuity per acre) to farmland value. According to the theory of hedonic valuation (Swinton et al. 2007), there is a relationship between land property price and land property characteristics. In this study, the land property characteristic refers to the capability of land for crop production. The farmland values for irrigated grain farmland in Lethbridge and Taber from August 2010 to August 2012 were obtained from FCC. The values of irrigated potato land were not available from Lethbridge, Taber, or anywhere in southern Alberta. That is because FCC does not release farmland values if fewer than three sales occur.

Table 6.2 shows the NPVs with perpetuity per acre for the representative farm and farmland value per acre from FCC. The NPV for the whole farm for Rotation WCaCeDb is less than the average grain farmland values in this region. Crops in Rotation WCaCeDb are cereals (two years), canola (one year), and dry beans (one year), which can be regarded as a representative grain production system in southern Alberta. There are multiple reasons why the NPV per acre for Rotation WCaCeDb is lower than the market value for the land. For example, currently, due to the high commodity prices and increase in specialty crops grown under contract, there is a high demand for irrigated farmland in southern Alberta (FCC 2013). The farmland value in Alberta is increasing (FCC 2013). The NPVs with perpetuity in this study are calculated based on the assumption that the prices of crops are stationary over time. The prices were modelled based on the historical crop prices from 1984 to 2010, while the current grain farmland values are more likely being determined based on the current high crop prices and expectations for continuous high or even higher prices in the future.

For Rotations PWSbDb and PWCaCe, potatoes are grown every four years. Since potato is a high value crop, the high NPVs in Rotations PWSbDb and PWCaCe are expected. Although potato farmland value is not available from the FCC, the value of potato farmland will be higher than that of grain farmland. The NPVs of farmland in Rotations

PWSbDb and PWCaCe are higher than the average grain farmland values, which is expected.

Table 6.2 Comparison of NPV and farmland value, per acre, by rotation ($/acre)

Rotation	NPV with perpetuity per acre	Grain farmland value per acre in Lethbridge and Taber[a]		
		Minimum	Maximum	Average
WCaCeDb	2,151	2,845	7,000	5,068
PWSbDb	5,889			
PWCaCe	5,439			

[a] Source: FCC (2012).

6.2. Results of BMP Scenarios

6.2.1. Adding Alfalfa BMP

When alfalfa is added into the rotations, a part of the representative farm is taken from annual crop production and used for forage production. As discussed in the previous chapter, the representative farm is divided into five partitions when implementing this BMP. Each partition is 288 acres. Each year, there are four irrigated annual crops (the same as the baseline model) and an irrigated perennial forage crop[30]. The change in crop area will impact the cash flow. Other economic benefits assumed to occur when adopting this BMP include savings of nitrogen and increases in the yields of subsequent crops following alfalfa (i.e., as discussed in Section 5.4.1.2).

Table 6.3 displays the results for the baseline and BMP scenarios. The mean NPV decreases when Rotation WCaCeDb adopts the BMP. In Rotation WCaCeDb-Alf, the total area of cereals (including wheat and barley), canola and dry bean decreases in comparison with the baseline scenario (Rotation WCaCeDb). The average cash inflow per acre and per year for alfalfa is greater than that for red spring wheat, barley and canola, but less than that for durum wheat and dry beans. The total economic benefit from alfalfa production, yield increasing and nitrogen saving in subsequent crops is less than the loss due to the reduced area of durum wheat and dry bean production.

Compared with the baseline rotation (Rotation PWSbDb), the mean NPV in the BMP scenario (Rotation PWSbDb-Alf) decreases. That is because in the BMP scenario the area of more valuable crops such as potatoes and sugar beets decreases and is replaced by

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[30] The non-irrigated corners are still grown with dryland alfalfa.

alfalfa and the cereal crop. The loss due to the reduced area of potato and sugar beet production is greater than the total benefit from yield increasing and nitrogen saving on subsequent crops.

Rotation PWCaCe-Alf results in a positive net benefit compared to the baseline scenario (Rotation PWCaCe). The BMP scenario has a smaller area of potato, cereal and canola. The net cash inflow per acre and per year for alfalfa is greater than that for red spring wheat, barley and canola, but less than that for durum wheat and potatoes. Growing alfalfa instead of canola, red spring wheat and barley will generate a net benefit. In addition, the subsequent crops (e.g., potato) following alfalfa benefit economically from the yield gains and saving of fertilizer. In addition, there is economic benefit from yield increases and fertilizer saving on the subsequent crops (e.g., potato) following alfalfa in the BMP scenario. As a result, the total benefit from alfalfa production, increase in crop yields and reduction in fertilizer costs is greater than the loss in potato and cereal production.

The patterns for the standard deviations of NPVs and NPV means are the same in the BMP scenarios as the baseline scenarios. With the decreases in NPV means for Rotation WCaCeDb-Alf and PWSbDb-Alf, the standard deviations of NPVs decrease. In Rotation PWCaCe-Alf, both the mean NPV and standard deviation increase in the BMP scenario. The changes in standard deviations in BMP scenarios are expected. Generally, a higher expected return goes with a higher risk. Thus, the variance of returns increases with higher expected returns. Compared to the coefficient of variation (CV) in the baseline, the CV in the BMP scenario does not change significantly in each rotation. Thus, there is not a significant change in relative variability from the baseline to the BMP scenario.

Table 6.3 Results of the NPV variable with/without the alfalfa BMP on the representative farm, by rotation

Rotation	Mean NPV ($/farm)	Standard Deviation	Coefficient of Variation (CV)	NPV per acre ($/acre)	Annualized NPV per acre ($/acre)
WCaCeDb-Alf	3,302,007	433,494	0.131	2,064	206
WCaCeDb	3,441,828	465,475	0.135	2,151	215
Change[a]	-139,821	140,714		-87	-9
% of Change					-4%
PWSbDb-Alf	7,925,021	1,328,749	0.168	4,953	495
PWSbDb	9,422,890	1,576,505	0.168	5,889	589
Change	-1,497,869	366,145		-936	-94
% of Change					-16%
PWCaCe-Alf	9,060,753	1,497,102	0.165	5,663	566
PWCaCe	8,703,008	1,450,436	0.167	5,439	544
Change	357,645	645,835		224	22
% of Change					4%

[a] These values are the mean and standard deviation of the change in NPV, calculated directly from simulation results. They do not represent changes in mean and standard deviation NPV values for each scenario reported in this table.

The MCNFs for the baseline and alfalfa BMP scenarios over the 20-year period are shown in Figures 6.2, 6.3, and 6.4 for each rotation, respectively. Since BMPs are adopted starting in Year 1, the cash flows for the baseline and BMP adoption all start from the same point in Year 0. In the first three years, the cash flows for BMP adoption are lower than the baseline scenarios for all the rotations. That is because the representative farm has just started its BMP adoption. There is a net cost for alfalfa establishment.

The cash flow for Rotation WCaCeDb-Alf (BMP scenario) is greater than that for Rotation WCaCeDb (baseline scenario) in Year 4. That is because one of the partitions has finished the alfalfa rotation in Year 3 and starts delivering the yield increase and fertilizer-saving benefits in Year 4. The first year following alfalfa BMP has the largest yield increase and fertilizer-saving benefits. As a result, the cash flow increases every three years starting from Year 4.

In Rotations PWSbDb-Alf and PWCaCe-Alf, a large increase of cash flow occurs in the second year following alfalfa. That is because in that year, potato yield rises because of the BMP adoption. Potatoes are a valuable crop. The increase in potato yield generates a significant growth in cash flow. In general, there is an increase in cash flow every three years from Year 4, with an exception between Year 14 and Year 18 in Rotation PWSbDb-Alf, as alfalfa is not grown in Year 17.

Figure 6.2 MCNFs for Rotation WCaCeDb (baseline) and Rotation WCaCeDb-Alf (BMP scenario) over the 20-year time period

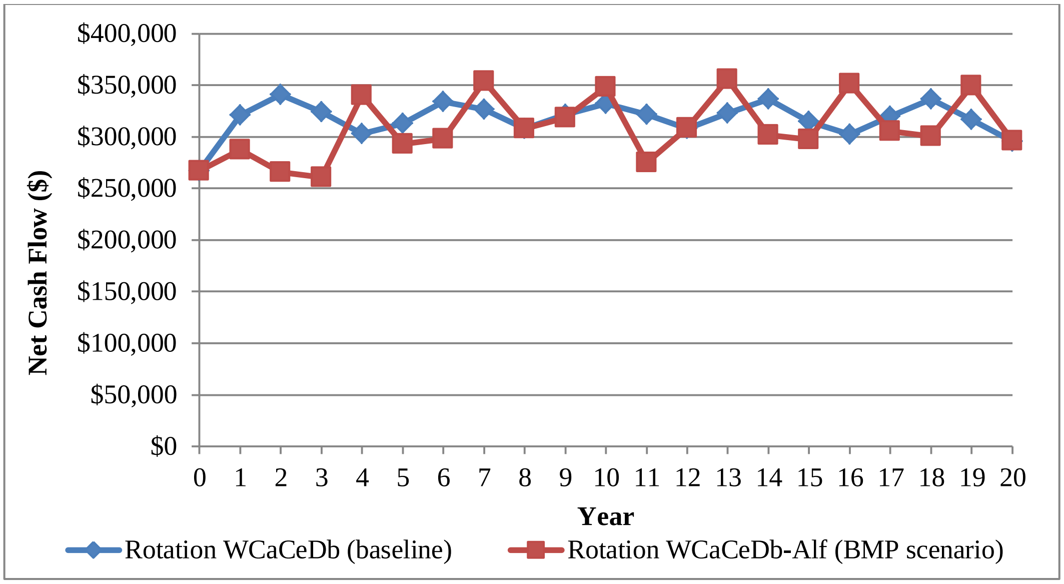


Figure 6.3 MNCFs for Rotation PWSbDb (baseline) and Rotation PWSbDb-Alf (BMP scenario) over the 20-year time period

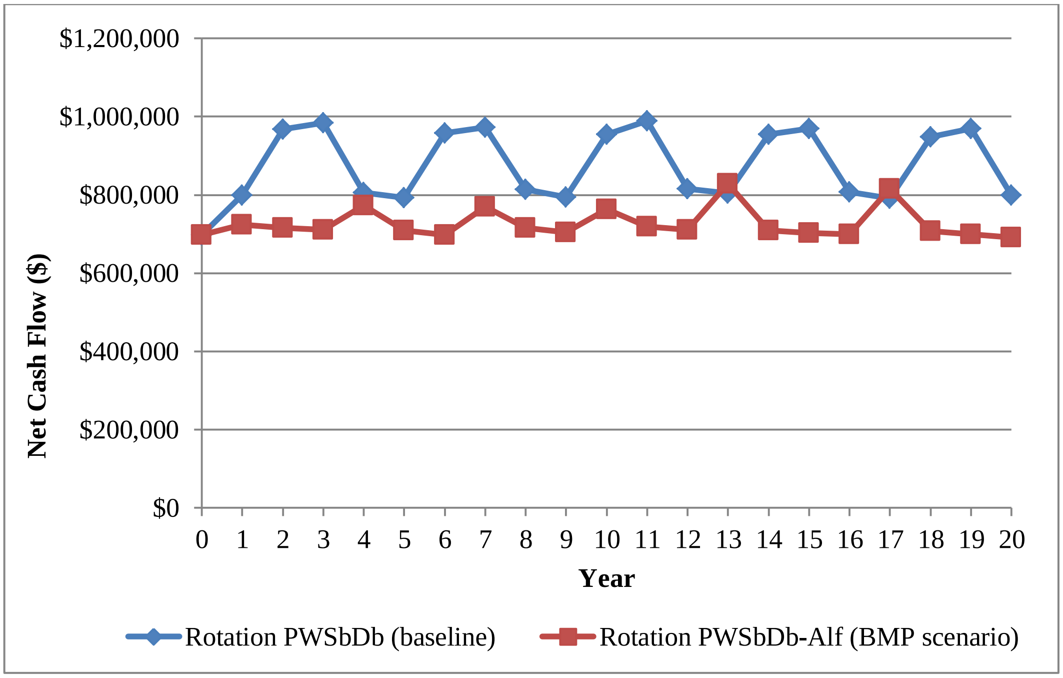
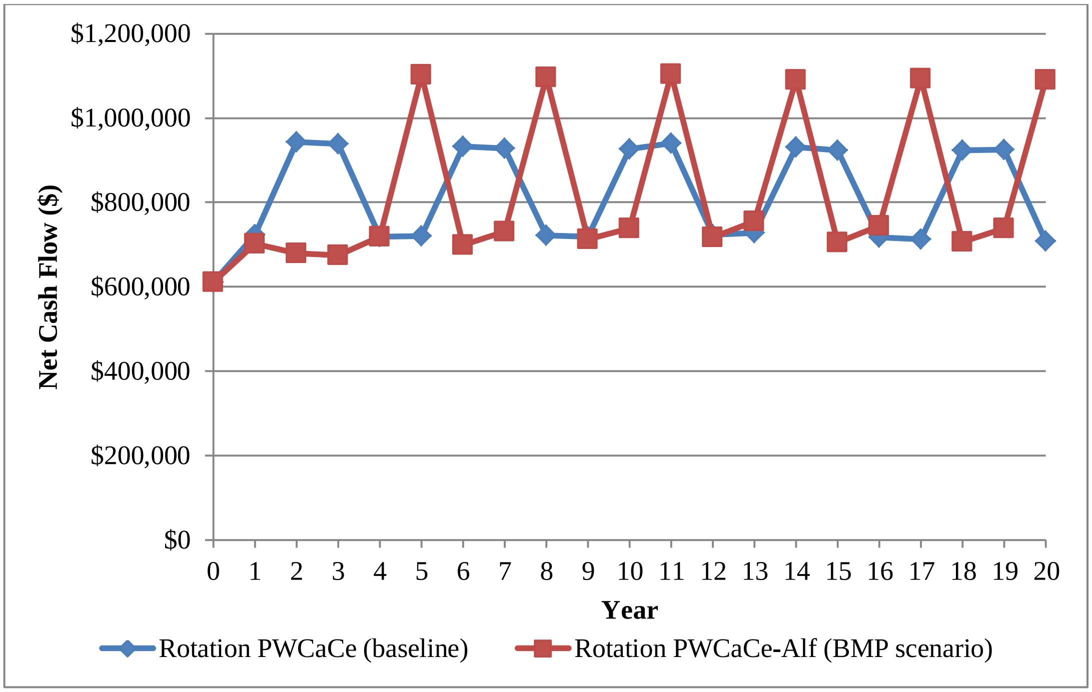


Figure 6.4 MNCFs for Rotation PWCaCe (baseline) and Rotation PWCaCe-Alf (BMP scenario) over the 20-year time period



6.2.2. Green Manure BMP

Two green manure BMPs are considered in this study: barley under-seeded with vetch, and adding fababeans. Adopting the green manure BMP results in additional costs for seed and/or seeding and incorporating the green manure into the soil. In addition, green manuring may also reduce the area of cash crop production and the yield for the crop with which it is under-seeded. Other short-run effects of green manure, as discussed in the last chapter, are assumed to be the nitrogen-fixing benefit and improved yield in subsequent crops.

6.2.2.1. Barley under-seeded with Vetch Green Manure BMP

When adopting the barley under-seeded with vetch green manure BMP, Rotation WCaCeDb- BV and Rotation PWCaCe-BV keep the same crop areas as the baseline scenario. This is because there is cereal production prior to canola in Rotation WCaCeDb and potato in Rotation PWCaCe, respectively, that can be used for under-seeding vetch. When implementing the BMP, the "cereal" year in the rotation is used to grow barley under-seeded with vetch. However, in Rotation PWSbDb, the crop prior to potato is dry beans, which is also considered a valuable cash crop. To maintain the cash crop production as well as receive potato yield increasing benefit from green manure, one-year barley-vetch is added into the rotation between potato and dry bean. In addition, to have potato production every year after BMP adoption, the representative farm in Rotation PWSbDb is divided into 5 equal-sized partitions (i.e., 288 acres/partition). The costs associated with BMP adoption are green manure establishment and termination costs and opportunity costs.

Table 6.4 presents the results for the baseline and BMP scenarios. In each rotation, adopting the barley-vetch green manure BMP results in a negative net benefit. The mean NPV decreases in each rotation when adopting the BMP. When vetch is under-seeded with barley as a green manure BMP, there are additional costs for vetch seed and termination. Moreover, the barley yield is assumed to be lower when it is under-seeded with vetch, because less herbicide is applied. For Rotation WCaCeDb- BV and Rotation PWCaCe-BV, the total cash outflow due to the extra input cost and crop yield loss is greater than the cash inflow from the saving of fertilizer and the crop yield increase. Therefore, changes in annualized NPV per acre in Rotation WCaCeDb- BV and Rotation PWCaCe-BV are close: -$87/acre and -$77/acre, respectively. Since potatoes are more valuable than canola, the net cash inflow from the potato yield increase is greater than that for the canola increase. As a result, the decrease of annualized NPV per acre in Rotation PWCaCe-BV is less than that for Rotation WCaCeDb- BV. For Rotation PWSbDb-BV, besides the above-mentioned reasons, the annual area of each crop is constant in the BMP scenario. The change of annualized NPVs when adopting the BMP is -$41/acre.

According to Table 6.4, there are no significant changes in CVs between the baseline and BMP scenarios in the three rotations. The standard deviation of the mean NPV in the BMP scenario decreases with the decrease of the mean NPV in Rotation WCaCeDb-BV and Rotation PWSbDb-BV. However, Rotation PWCa-BV has lower mean NPV but a higher standard deviation than the baseline.

Table 6.4 Results of the NPV variable with/without barley under-seeded with vetch BMP on the representative farm, by rotation

Rotation	Mean NPV ($/farm)	Standard Deviation	Coefficient of Variation (CV)	NPV per acre ($/acre)	Annualized NPV per acre ($/acre)
WCaCeDb-BV	2,049,463	400,804	0.196	1,281	128
WCaCeDb	3,441,828	466,234	0.135	2,151	215
Change[a]	-1,392,364	220,870		-870	-87
% of Change					-40%
PWSbDb-BV	8,772,983	1,452,972	0.166	5,483	548
PWSbDb	9,422,890	1,577,002	0.167	5,889	589
Change	-649,906	308,782		-406	-41
% of Change					-7%
PWCaCe-BV	7,478,577	1,467,788	0.196	4,674	467
PWCaCe	8,703,008	1,450,891	0.167	5,439	544
Change	-1,224,431	217,078		-765	-77
% of Change					-14%

[a] These values are the mean and standard deviation of the change in NPV, calculated directly from simulation results. They do not represent changes in mean and standard deviation NPV values for each scenario reported in this table.

The modified net cash flows for the baseline and BMP adoption scenarios over the 20-year period are shown in Figures 6.5, 6.6, and 6.7 respectively. The cash flows for baseline and BMP scenarios start at the same point in Year 0 in each rotation because the BMP has not been adopted at Year 0. From Year 1, adopting BMP leads to costs for vetch establishment and termination, and reduces barley production. Therefore, the cash flows for the BMP scenario are lower than for the baseline scenario.

For Rotation WCaCeDb-BV and Rotation PWCaCe-BV, the representative farm keeps the same crop areas as the baseline when adopting BMP. As a result, the cash flows in the BMP scenario have the same cycle as the baseline scenario from Year 2. According to Figure 6.5, cash flows for Rotation WCaCeDb-BV peak around $200,000 every five years from Year 2 and drop in the following two years, reaching $150,000. As shown in Figure 6.7, cash flows for Rotation PWCaCe-BV fluctuate between $830,000 and $580,000 from Year 3. For Rotation PWSbDb-BV, four commercial crops and one barley-vetch are grown on the five equal-sized partitions each year in the BMP scenario. Therefore, there are no significant differences in cash flows among years. Instead of having cycles in the baseline scenario, cash flows for Rotation PWSbDb-BV stabilize around $800,000 from Year 2.

Figure 6.5 MNCFs for Rotation WCaCeDb (baseline) and Rotation WCaCeDb-BV (BMP scenario) over the 20-year time period

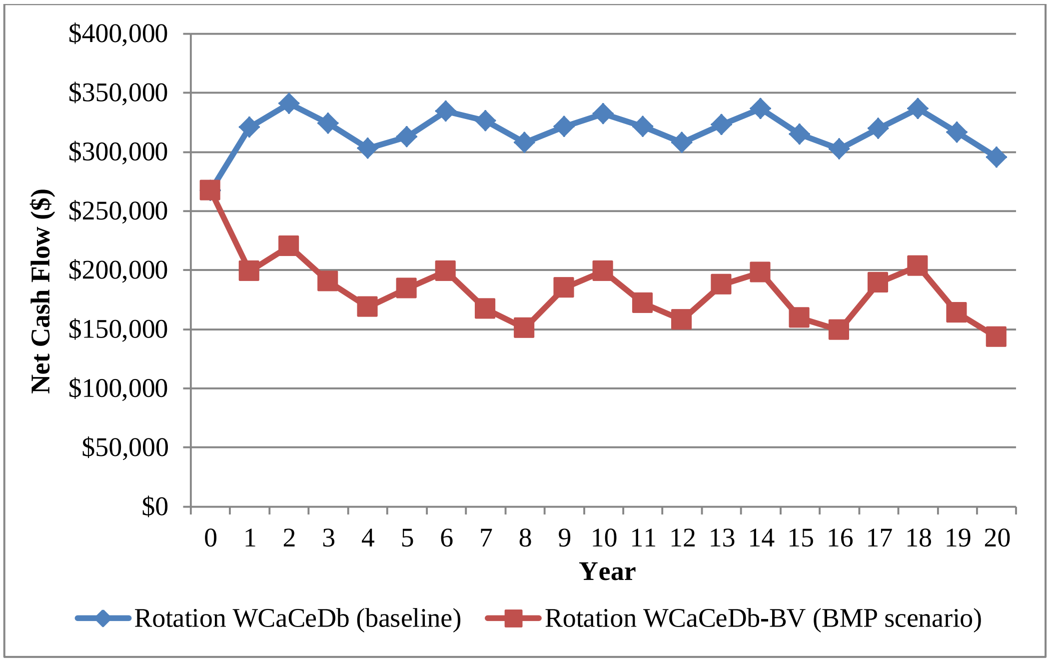


Figure 6.6 MNCFs for Rotation PWSbDb (baseline) and Rotation PWSbDb-BV (BMP scenario) over the 20-year time period

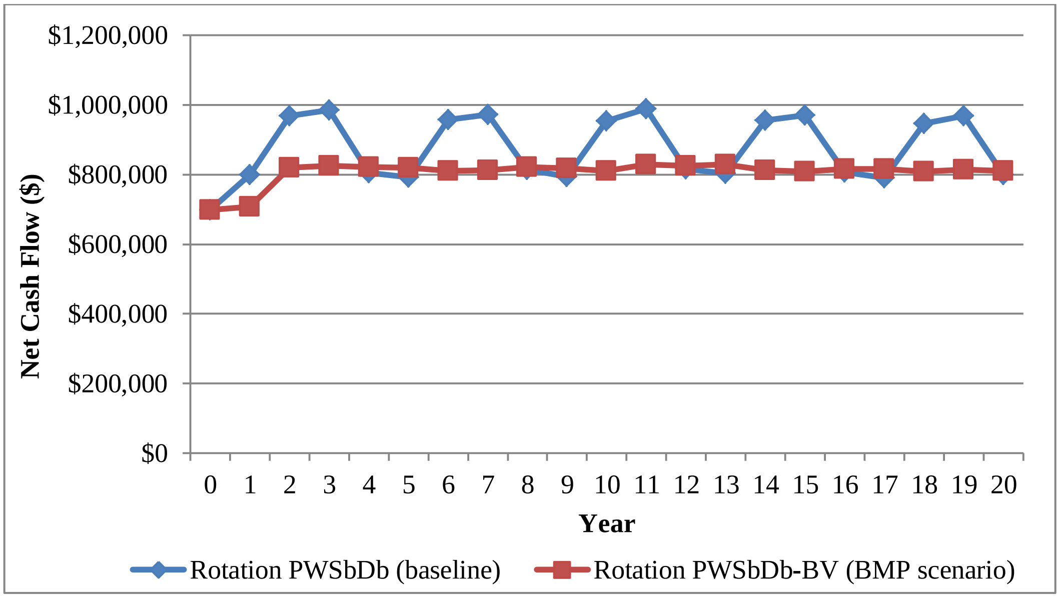
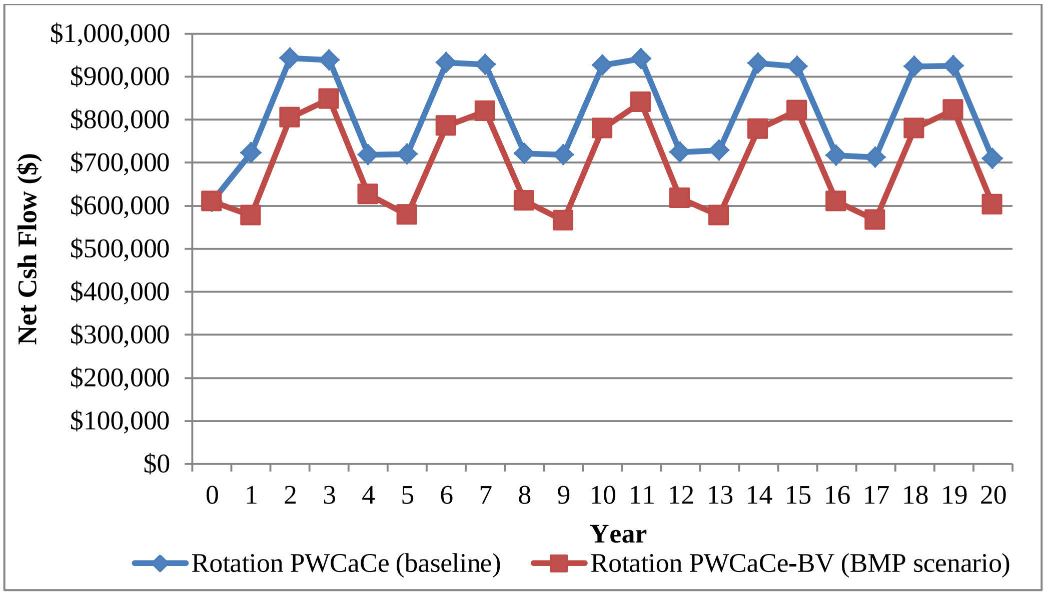


Figure 6.7 MNCFs for Rotation PWCaCe (baseline) and Rotation PWCaCe-BV (BMP scenario) over the 20-year time period



6.2.2.2. Fababean Green Manure BMP

To implement the fababean green manure BMP, the representative farm is divided into five equal-sized partitions (i.e., 288 acres/partition). Each year, a partition is taken from growing commercial crops to grow fababeans. Thus, there is an opportunity cost for “cash crop” production due to green manuring. In addition, there are costs associated with green manure establishment and termination. As discussed in Section 2.1.2.2, the benefit from green manuring is assumed to include savings on nitrogen fertilizer and increased yields for subsequent crops.

Table 6.5 shows the results for the baseline and BMP scenarios. Adopting fababean green manure results in negative net benefits for all three rotations. Thus, although there are benefits from this BMP on the subsequent crops, the total benefit cannot totally offset the total costs. The standard deviation in each BMP scenario is smaller than that for the baseline scenario. However, the CV in the BMP scenario increases slightly in each rotation. There is no a significant change in relative variability in NPVs from the baseline to the BMP scenario.

Rotation PWSbDb-Fa has the largest loss in the BMP scenario, follow by Rotation WCaCeDb-Fa, and Rotation PWCaCe-Fa. In the green manure BMP scenarios, the cost of these BMPs (i.e., seed, seeding, incorporating) are almost the same. In addition, the benefits from nitrogen fertilizer saving on the subsequent crop are the same because the same areas of fababeans are grown in the rotations each year. Moreover, the ranges of yield increases in the BMP scenarios are the same in the three rotations. The different net losses among the three rotations are mainly because of the different opportunity costs and values of the “cash crops” (i.e., potatoes and canola) that benefit from increased yields. Rotation PWSbDb-Fa and Rotation PWCaCe-Fa have the same “cash crop” (i.e., potatoes) that benefits from increased yields. Thus, the yield increasing benefits between these two rotations are identical. But Rotation PWSbDb-Fa has the largest NPV in the baseline scenario, which implies that the opportunity cost in the BMP scenario is the largest. Therefore, compared to the baseline scenarios, Rotation PWSbDb-Fa incurs a larger loss in NPV than Rotation PWCaCe-Fa. Rotation WCaCeDb-Fa has the lowest opportunity cost among the three rotations, but its net loss in NPV is greater than that of Rotation PWCaCe-Fa. That is because the “cash crop” that benefits from the increased yield in Rotation WCaCeDb-Fa is canola, which is less valuable than its counterpart in Rotation PWCaCe-Fa, which is potato. As a result, the loss in NPV in Rotation WCaCeDb-Fa is greater than that in Rotation PWCaCe-Fa.

Table 6.5 Results of the NPV variable with/without fababean green manure BMP on the representative farm, by rotation

	Mean NPV ($/farm)	Standard Deviation	Coefficient of Variation (CV)	NPV per acre ($/acre)	Annualized NPV per acre ($/acre)
WCaCeDb-Fa	2,361,834	393,349	0.167	1,476	148
WCaCeDb	3,441,828	466,234	0.135	2,151	215
Change[a]	-1,079,994	107,497		-675	-67
% of Change					-31%
PWSbDb-Fa	8,338,313	1,436,673	0.172	5,211	521
PWSbDb	9,422,890	1,577,002	0.167	5,889	589
Change	-1,084,577	311,613		-678	-68
% of Change					-12%
PWCaCe-Fa	7,792,176	1,331,420	0.171	4,870	487
PWCaCe	8,703,008	1,450,891	0.167	5,439	544
Change	-910,832	303,606		-569	-57
% of Change					-10%

[a] These values are the mean and standard deviation of the change in NPV, calculated directly from simulation results. They do not represent changes in mean and standard deviation NPV values for each scenario reported in this table.

The MNCFs for the baseline and fababean green manure BMP scenarios over the 20-year period are shown in Figures 6.8, 6.9, and 6.10 respectively. The cash flows start from Year 0 when no BMP is adopted either in the baseline or BMP scenario. In each rotation, the difference in cash flow starts from zero. In Year 1, a partition starts growing fababeans. After that, each year there are two partitions related to green manuring: one receiving the BMP benefits, and one adopting the BMP. In addition, since "cash crops" and green manure are grown in equal-sized areas each year, there is not a significant change in cash flow overtime. Therefore, the pattern of cash flows in the BMP scenario varies less than it does in the baseline scenario. Over the 20 years, the net cash flows are approximately $200,000, $800,000 and $730,000 for Rotation WCaCeDb-Fa, Rotation PWSbDb-Fa, and Rotation PWCaCe-Fa, respectively.

Figure 6.8 MNCFs for Rotation WCaCeDb (baseline) and Rotation WCaCeDb-Fa (BMP scenario) over the 20-year time period

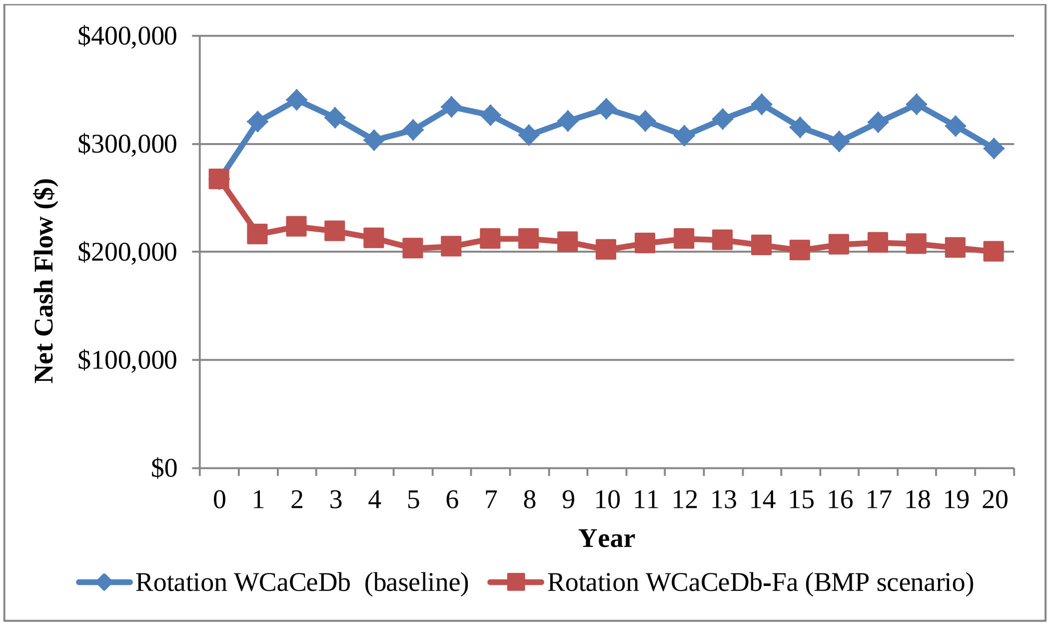


Figure 6.9 MNCFs for Rotation PWSbDb (baseline) and Rotation PWSbDb-Fa (BMP scenario) over the 20-year time period

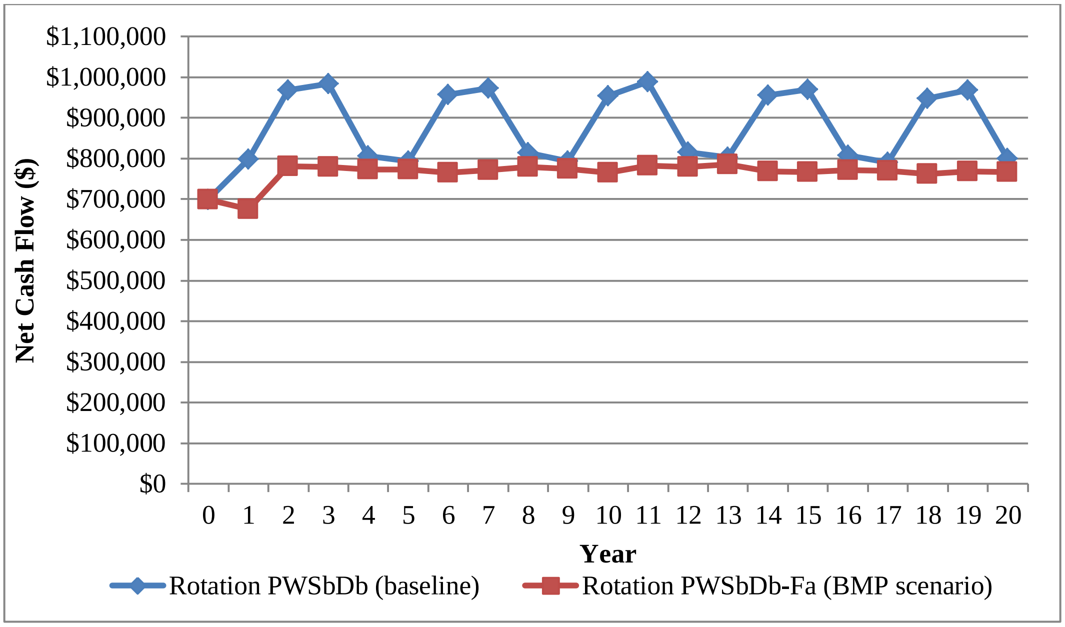
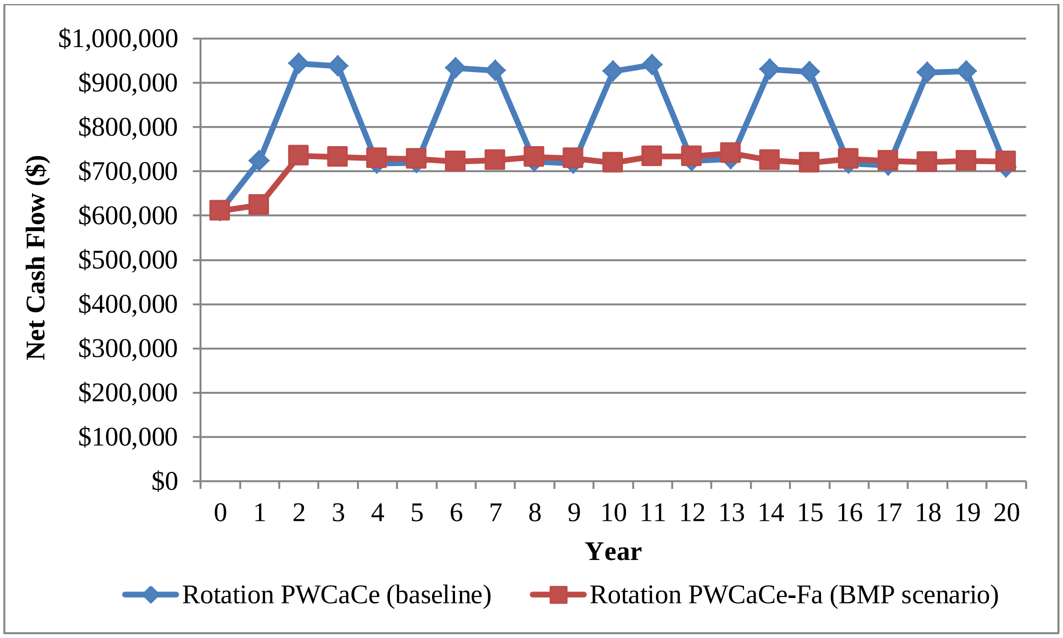


Figure 6.10 MNCFs for Rotation PWCaCe (baseline) and Rotation PWCaCe-Fa (BMP scenario) over the 20-year time period



6.2.3. Crop Residue Management

Implementing residue management BMP results in a loss, in part due to a reduction in revenue for baled residues. If the representative farm could not produce enough cereal residues to cover the required fields, it would incur an extra cost to buy crop residues. Moreover, spreading residues on the field requires additional expenses for residue chopping and broadcasting.

Table 6.6 shows the results for the baseline and BMP scenarios. The mean NPV for the BMP scenario is lower than that for the baseline in each rotation. The decrease in mean NPV is expected since adopting BMP will generate no cash inflow for baled residues, and will create additional cash outflows for residue chopping and broadcasting, and buying extra crop residues. Both the standard deviation and CV in the BMP scenario are greater than the ones in the baseline, indicating an increase in the variability of NPV. The increase in variability may be due to the introduction of stochastic BMP costs. This study assumes that if there are not enough cereal residues, the farmer will buy extra residues. This will lower the margin and reinforce the poor financial performance of BMP scenarios. However, since the change in the CV is not greater than 0.1, the change in variability is not significant.

The differences in annualized NPV per acre for Rotation WCaCeDb and Rotation PWCaCe are close: -$33/acre and -$32/acre, respectively. That is because both rotations have two partitions to grow with cereal each year. Thus, the amounts of residue supply are similar. In addition, the fields with dry bean in Rotation WCaCeDb and potato production in Rotation PWCaCe require a similar amount of residue application on the fields. As a result, the changes of annualized NPV per acre are similar in these rotations when adopting BMP.

Compared with Rotation WCaCeDb and Rotation PWCaCe, Rotation PWSbDb has less cereal residue supply but more residue demand. Rotation PWSbDb includes only one partition with cereal production to supply residue each year. The rest of the partitions with sugar beet, dry bean, and potato production all require residue covers after harvesting. Based on the assumption in Section 5.4.3, the representative farm will buy residues when its own farm residues are not enough to cover the required fields. As a result, it is more costly to implement BMP in Rotation PWSbDb. The difference in annualized NPV per acre is -$102/acre.

Table 6.6 Results of the NPV variable with/without residue management BMP on the representative farm, by rotation

	Mean NPV ($/farm)	Standard Deviation	Coefficient of Variation (CV)	NPV per acre ($/acre)	Annualized NPV per acre ($/acre)
Rotation WCaCeDb					
BMP scenario	2,913,012	474,461	0.163	1,821	182
Baseline scenario	3,441,828	466,234	0.135	2,151	215
Change[a]	-528,816	25,612		-331	-33
% of Change					-15%
Rotation PWSbDb					
BMP scenario	7,795,337	1,601,903	0.205	4,872	487
Baseline scenario	9,422,890	1,577,002	0.167	5,889	589
Change	-1,627,553	73,845		-1,017	-102
% of Change					-17%
Rotation PWCaCe					
BMP scenario	8,188,550	1,463,712	0.179	5,118	512
Baseline scenario	8,703,008	1,450,891	0.167	5,439	544
Change	-514,458	32,191		-322	-32
% of Change					-6%

[a] These values are the mean and standard deviation of the change in NPV, calculated directly from simulation results. They do not represent changes in mean and standard deviation NPV values for each scenario reported in this table.

The MNCFs for the baseline and BMP scenarios over the 20-year period are shown in Figures 6.11, 6.12, and 6.13, respectively. When the representative farm adopts the crop residue management BMP, unlike the adding alfalfa BMP and green manure BMP, the areas of each cash crop in each year between the baseline and BMP scenario are the same. Thus, the cash flows in the 20-year time period will have a cycle similar to that of the baseline scenario. The largest differences between the baseline and BMP scenarios are in Rotation PWSbDb. That is because Rotation PWSbDb has more fields to be covered by residues.

Figure 6.11 MNCFs for the baseline and crop residue management BMP scenarios over the 20-year time period for Rotation WCaCeDb

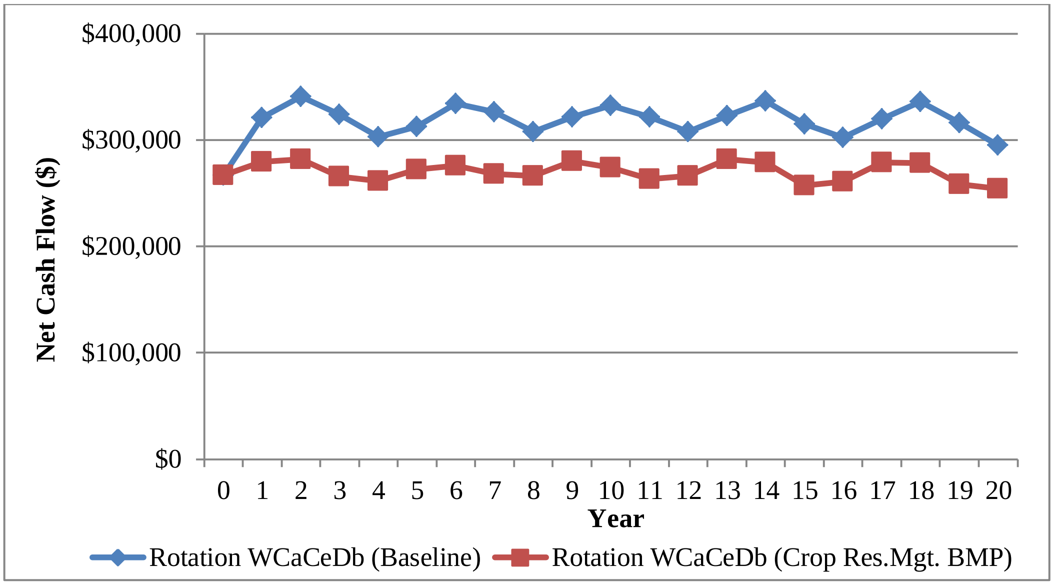


Figure 6.12 MNCFs for the baseline and crop residue management BMP scenarios over the 20-year time period for Rotation PWSbDb

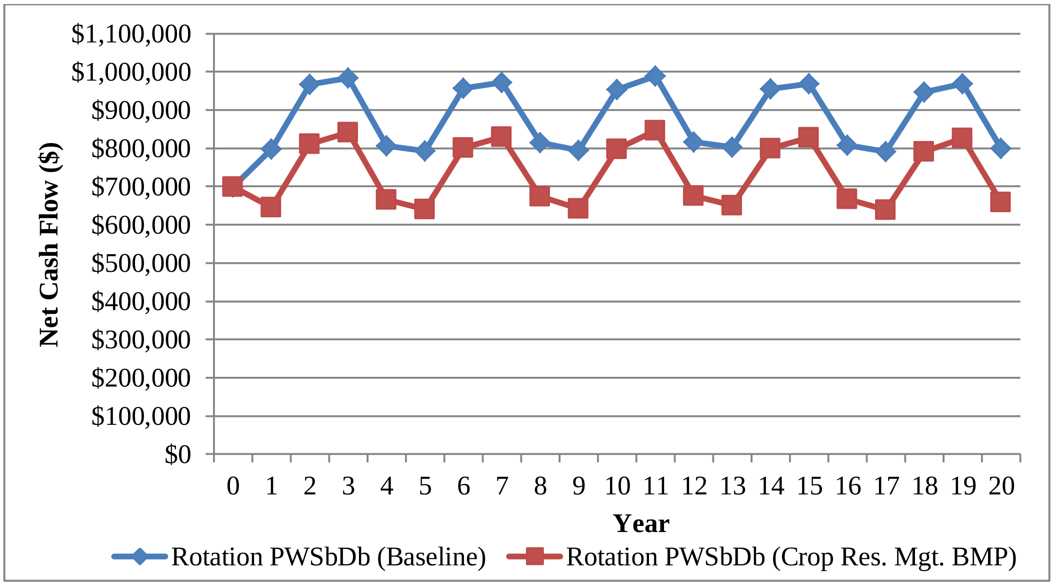
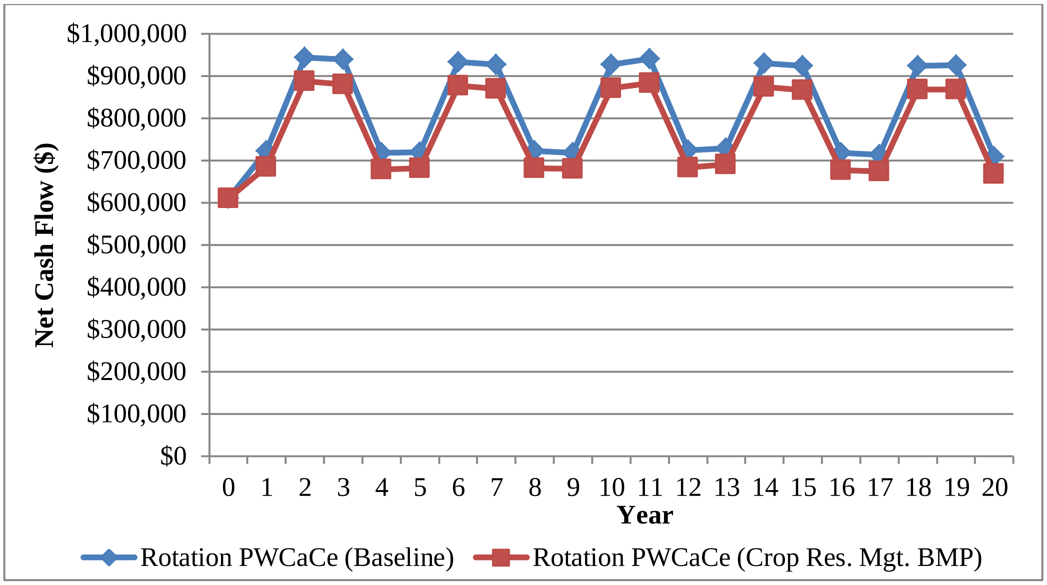


Figure 6.13 MNCFs for the baseline and crop residue management BMP scenarios over the 20-year time period for Rotation PWCaCe



6.2.4. Cattle Manure

When applying cattle manure on the representative farm, there are costs for manure transportation, application, and farm soil testing. Applying cattle manure on the representative farm results in yield increases and fertilizer savings on subsequent crops.

The NPVs for the baseline and BMP scenarios are shown in Table 6.7. Both the means and standard deviations of the NPVs increase when cattle manure is applied on the farm. The increase in NPV in each rotation is expected. That is because applying cattle manure reduced the amount of fertilizer application, and increased the crop yield. The costs for using cattle manure are lower than the total economic benefit. Thus, applying cattle manure results in a positive net benefit. The increase in the standard deviation in the BMP scenario is consistent with economic theory: that is, with the higher expected returns, the variance of expected returns increases. However, the differences of CVs between the baseline and BMP scenarios are all less than 0.01. There is not a significant change in relative variability from the baseline to the BMP scenario.

As discussed in Section 5.4.4.1, the amounts of cattle manure application among rotations are the same. Thus, the costs of transportation and application are similar among rotations. However, according to Table 6.7, the difference in annualized NPVs for Rotation WCaCeDb ($27/acre) is much lower than for Rotation PWSbDb ($52/acre) and Rotation

PWCaCe ($50/acre). This is because different crops are grown in the third year after the manure application. Dry beans in Rotation WCaCeDb do not need potassium nutrients, while potatoes in Rotation PWSbDb and Rotation PWCaCe do. The portion of potassium nutrients required by potatoes in Rotation PWSbDb and Rotation PWCaCe can be provided by manure. Thus, there are potassium fertilizer savings in Rotation PWSbDb and Rotation PWCaCe, but not in the Rotation WCaCeDb. In addition, the yield increase in potato in Rotation PWSbDb and Rotation PWCaCe in the BMP scenario can result in higher cash inflows than the yield increase in red spring wheat in Rotation WCaCeDb. As a result, the net benefit from BMP adoption in Rotation PWSbDb and Rotation PWCaCe is higher than in Rotation WCaCeDb.

Table 6.7 Results of the NPV variable with/without cattle manure BMP on the representative farm, by rotation

	Mean NPV ($/farm)	Standard Deviation	Coefficient of Variation (CV)	NPV per acre ($/acre)	Annualized NPV per acre ($/acre)
Rotation WCaCeDb					
BMP scenario	3,875,196	487,807	0.126	2,422	242
Baseline scenario	3,441,828	466,234	0.135	2,151	215
Change[a]	433,368	38,386		271	27
% of Change					13%
Rotation PWSbDb					
BMP scenario	10,251,050	1,637,451	0.160	6,407	641
Baseline scenario	9,422,890	1,577,002	0.167	5,889	589
Change	828,161	100,235		518	52
% of Change					9%
Rotation PWCaCe					
BMP scenario	9,499,201	1,520,005	0.160	5,937	594
Baseline scenario	8,703,008	1,450,891	0.167	5,439	544
Change	796,193	109,789		498	50
% of Change					9%

[a] These values are the mean and standard deviation of the change in NPV, calculated directly from simulation results. They do not represent changes in mean and standard deviation NPV values for each scenario reported in this table.

Figures 6.14, 6.15 and 6.16 show the MNCFs for the baseline and cattle manure BMP scenarios over the 20-year time period. For each rotation, the modified net cash flows for the baseline and BMP scenarios in Year 0 are the same due to no BMP adoption in either scenario in Year 0. In Year 1, cattle manure is applied to one field in each rotation. As time goes on, cattle manure is applied to more fields. The benefit of cattle manure application increases as the number of fields with cattle manure applications increases. Therefore, the modified cash flows in the BMP scenario are higher than the ones in the baseline scenario from Year 1. In addition, the crop areas in the baseline and BMP scenarios are the same in each rotation. As a result, the cycles of cash flows for these two scenarios are similar.

Figure 6.14 MNCF for the baseline and cattle manure BMP scenarios over the 20-year time period for Rotation WCaCeDb

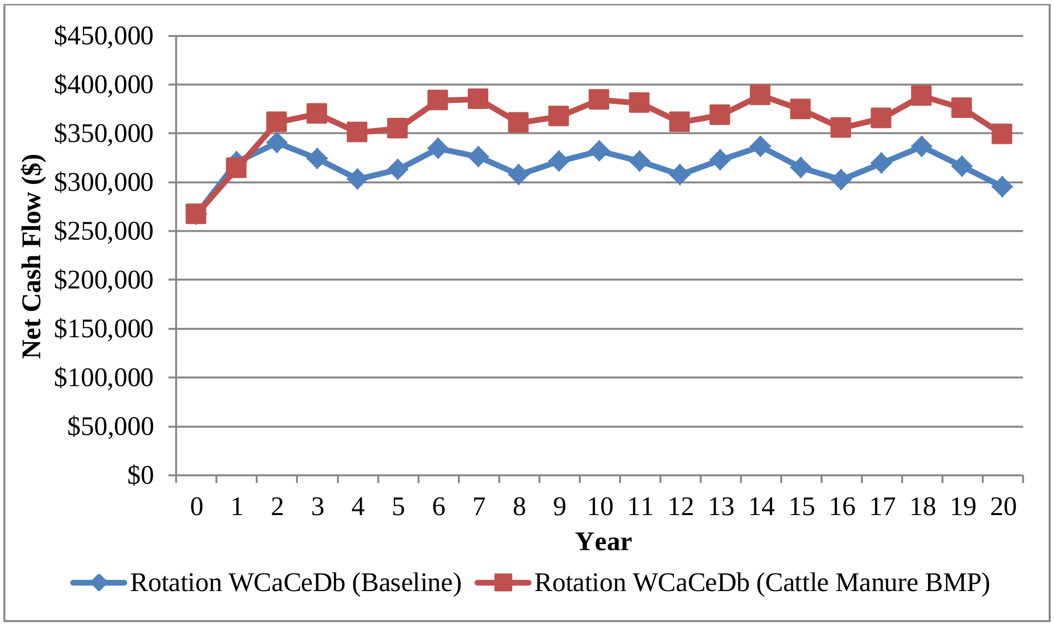


Figure 6.15 MNCFs for the baseline and cattle manure BMP scenarios over the 20-year time period for Rotation PWSbDb

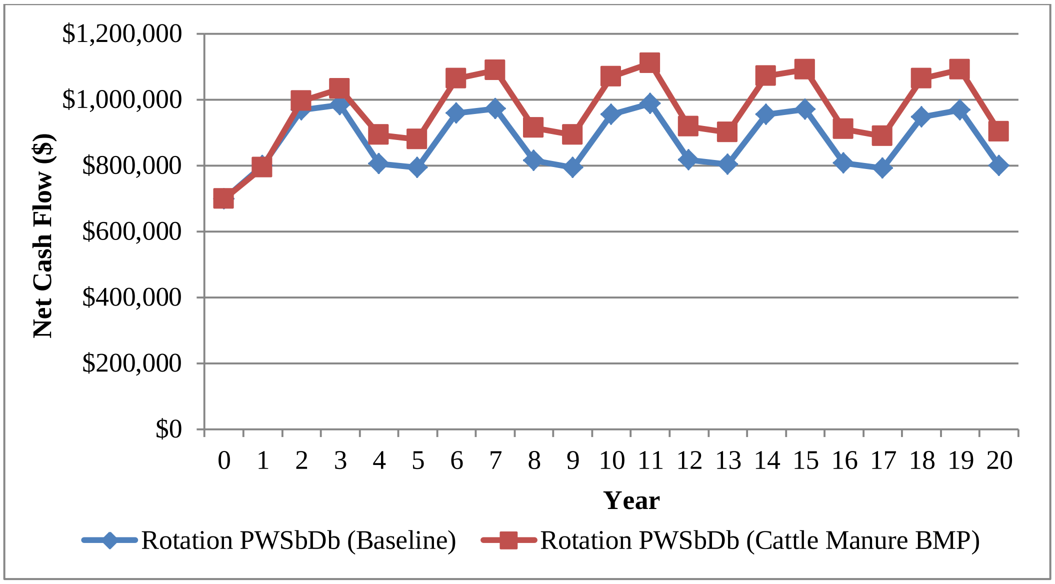
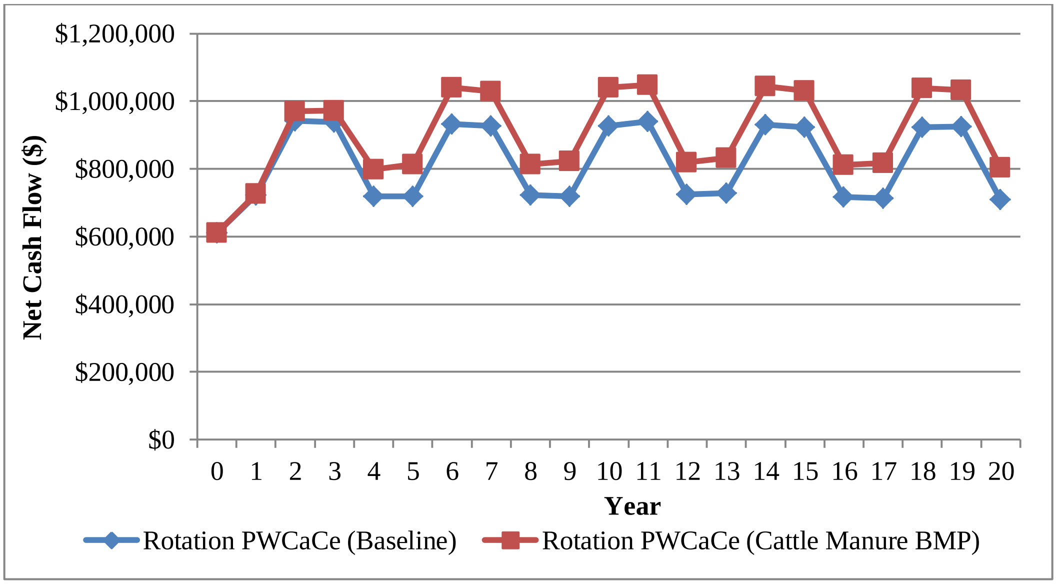


Figure 6.16 MNCFs for the baseline and cattle manure BMP scenarios over the 20-year time period for Rotation PWCaCe



6.2.5. Nutrient Management Planning (NMP) BMP

When the representative farm adopts NMP BMP, less fertilizer is applied on the farm in cases where the previous year's crop fell short of the target. The cost of BMP adoption is the cost of soil tests.

According to Table 6.8, mean NPV increases when adopting the NMP BMP. The increase occurs because the unused previous-year fertilizer is taken into account, which can save fertilizer application. The savings are more valuable than the cost of the soil test required in the BMP, especially when unused fertilizer nutrients are left in the soil from crops such as potato, sugar beet and canola, which require a high level of fertilizer application. These savings mean that the BMP can bring net benefit for the representative farm. With the NPV increase, the standard deviation in the BMP scenario also increases. However, the differences in CVs between the baseline and BMP scenarios are less than 0.01. There is not a significant change in relative variability from the baseline to the BMP scenario.

The differences in annualized NPVs for Rotation PWSbDb and Rotation PWCaCe are close: $12/acre and $13/acre, respectively. That is because both rotations include potatoes which require the highest fertilizer application compared to other crops. The primary fertilizer savings in the BMP scenario is from fertilizer used on potato crops. For Rotation WCaCeDb, the amount of fertilizer applied in the baseline is less than that for the other rotations. As a result, the net benefit from the NMP is the lowest: $6/acre.

Table 6.8 Results of the NPV variable with/without nutrient management planning BMP on the representative farm, by rotation

	Mean NPV ($/farm)	Standard Deviation	Coefficient of Variation (C.V.)	NPV per acre ($/acre)	Annualized NPV per acre ($/acre)
Rotation WCaCeDb					
BMP scenario	3,542,182	468,357	0.132	2,214	221
Baseline scenario	3,441,828	466,234	0.135	2,151	215
Change[a]	100,354	35,949		63	6
% of Change					3%
Rotation PWSbDb					
BMP scenario	9,620,388	1,592,932	0.166	6,013	601
Baseline scenario	9,422,890	1,577,002	0.167	5,889	589
Change	197,498	73,781		123	12
% of Change					2%
Rotation PWCaCe					
BMP scenario	8,904,982	1,480,070	0.166	5,566	557
Baseline scenario	8,703,008	1,450,891	0.167	5,439	544
Change	201,974	84,951		126	13
% of Change					2%

[a] These values are the mean and standard deviation of the change in NPV, calculated directly from simulation results. They do not represent changes in mean and standard deviation NPV values for each scenario reported in this table.

The MNCF for the baseline and NMP BMP scenarios are shown on Figures 6.17, 6.18, and 6.19, respectively. In each rotation, the cash flows for the BMP scenario are higher than the baseline from Year 2. When adopting the NMP BMP, the crop areas are the same with the baseline rotation. Therefore, the cycles of cash flows for these two scenarios are similar.

Figure 6.17 MNCF for the baseline and NMP BMP scenarios over the 20-year time period for Rotation WCaCeDb

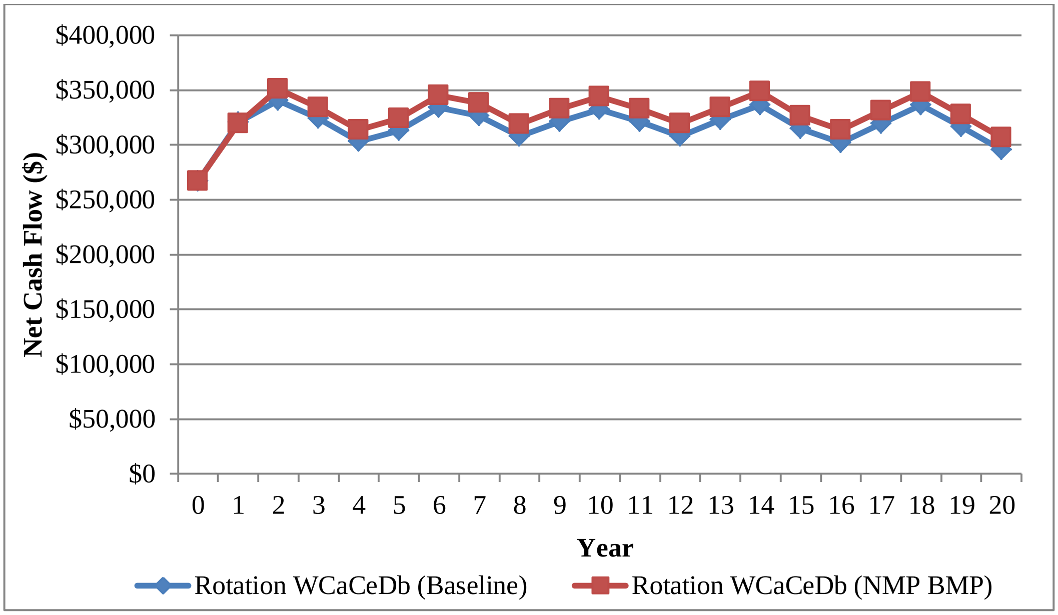


Figure 6.18 MNCF for the baseline and NMP BMP scenarios over the 20-year time period for Rotation PWSbDb

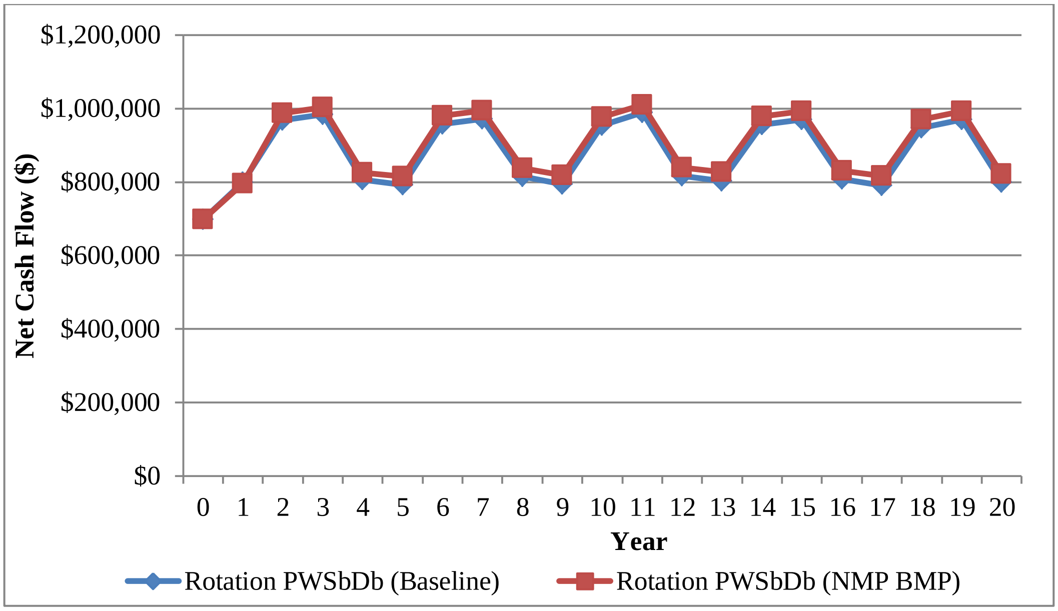
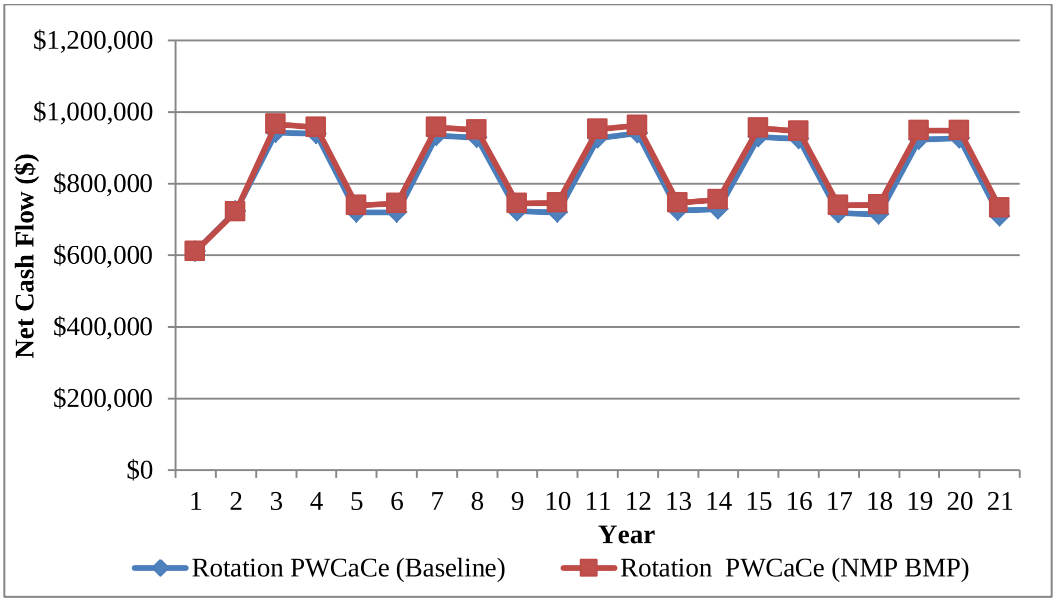


Figure 6.19 MNCF for the baseline and NMP BMP scenarios over the 20-year time period for Rotation PWCaCe



6.3. Results of Sensitivity Analyses

Sensitivity analysis involves examining the effects of changes in the value for individual parameters. Results of sensitivity analyses will show how sensitive the economic feasibility of BMPs are to the changes in the selected parameters. In this study, two methods are used in the sensitivity analysis. One method is to use the “Goal Seek” command in @RISK program. “Goal Seek” can be used to identify the value of a particular parameter needed to obtain a specific simulated value for a spreadsheet cell when the value of another cell is changed in a specific way. An alternative approach is to change the value of one parameter and then identify the updated result after the simulation. This method has been used in previous BMP studies (e.g., Koeckhoven 2008; Trautman 2012).

The “Goal Seek” procedure in this study is used to try and identify the value of a parameter (e.g., price, carryover rate, and yield) that will result in a zero difference in NPV between two scenarios so that adopting the BMP is “break even” relative to the baseline. In addition, through systematically changing the related parameter and identifying the new value for the other parameter that results in “break even”, “Goal Seek” can obtain a series of “break even” values. Presenting the bundles of conditions and “break even” values in a graph results in a “break even” curve.

For any point on the “break even” curve, there is zero difference between the baseline and BMP scenarios. The “break even” curve divides the graph into two areas with the two areas implying different likely adoption decisions by producers. One area is where the NPV in the BMP scenario is greater than the NPV in the baseline scenario: that is, the net benefit from BMP adoption is positive. Since there is a positive net benefit from BMP adoption, it is more likely that farmers will voluntarily adopt the BMP. The other area is where the net benefits from BMP adoption are negative, making it unlikely that farmers will voluntarily adopt the BMP. The advantage of using the “break even” curve is that it can show different bundles of BMP parameters between which the producer would be “indifferent” in terms of net benefit. In addition, using the “break even” curve makes it easy to check a bundle of BMP parameters to see whether they results in a positive or negative benefit.

However, processing a “Goal Seek” procedure requires a long simulation time. In some scenarios, it is impossible to change the value of a parameter to fulfill the “break even” condition. For example, implementing crop residue management BMP always results in a negative net benefit because there are only costs to conduct the BMP and no short run benefit based on the assumptions made in the analysis. In addition, the value of a parameter identified through the “Goal Seek” procedure might not make sense in practice.

For example, when using the “Goal Seek” to find the “break even” carryover rate for nutrients in NMP BMP scenarios, the identified carryover rate is out of the range of 0-100%, which cannot be applied in reality. When using the “Goal Seek” procedure is problematic, the “standard sensitivity analysis” is used, which involves changing the value of one parameter and identifying the updated result after the simulation. The “standard sensitivity analysis” also requires a shorter processing time than the “Goal Seek” procedure.

6.3.1. Adding Alfalfa into Rotations

For adding alfalfa BMP, the sensitivity analyses analyze the effects of alfalfa yield, alfalfa price, and yield increase benefit on the changes in NPV. These three parameters have major impacts on the change in cash flow resulting from adoption of the alfalfa BMP. For example, the increase in the alfalfa price will result in an increase in cash inflows for the BMP scenario. Once the net benefit increases, the likelihood that farmers will voluntarily adopt BMP will increase.

6.3.1.1. Alfalfa Price and Alfalfa Yield

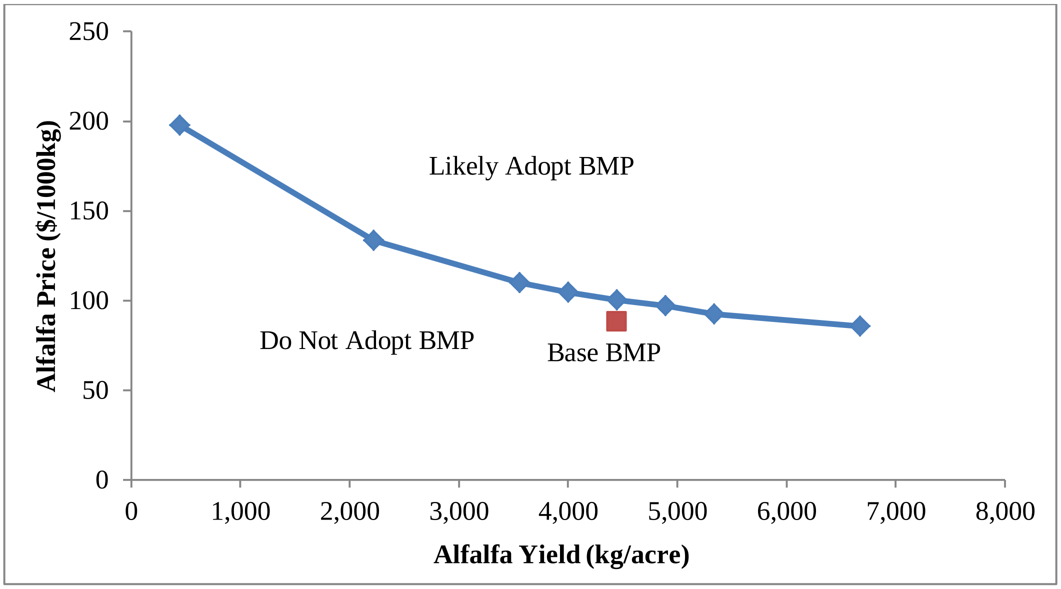
The sensitivity analyses in this section analyze the changes of alfalfa prices under different alfalfa yields to fulfill the “break even” condition. In this study, the prices and yields of alfalfa are all assumed to be stochastic. As discussed in Section 5.2.1.2, the stochastic alfalfa yields in the simulation are based on the average yield, the change in barley from previous year to current year, and the correlation coefficient between barley and alfalfa. Changing the average alfalfa yields can change the stochastic yields in the simulation. As shown in Section 5.2.2.2, a stochastic alfalfa price is a function of constant, lagged prices and error terms. Since the price model is stationary, changing the value of the constant will change the overall stochastic prices and the mean of prices in the simulation. In the sensitivity analysis, the average yield of alfalfa (4451kg/acre), was changed by -90%, -50%, -20%, -10%, 0%, 10%, 20% and 50%, respectively. The “break even” value of the constant in the alfalfa price function was identified respectively through the “Goal Seek” procedure in @RISK. The mean of the alfalfa price based on the new price function was then identified.

Figures 6.20, 6.21, and 6.22 show “break even” curves for adding alfalfa BMP based on prices and yields of alfalfa for each rotation. Each “break even” curve presents different bundles of alfalfa yields and prices where there is zero difference in NPV between the baseline and BMP scenarios. As shown in the graphs, there are very different scales on the vertical axis. Thus, the curves are presented in different graphs. However, the squares (in red) labelled as “Base BMP” in the three graphs, which represent the baseline parameters of alfalfa price and yield, are the same in each graph. As shown in Figures 6.20 and 6.21, the “Base BMP” bundle is below the “break even” curve. Therefore, there is a negative net benefit to BMP adoption and farmers are not likely to voluntarily adopt this BMP. In Figure 6.22, the “Base BMP” bundle is above the “break even” curve. Adopting the BMP will result in a positive net benefit. It is more likely that producers in Rotation PWCaCe will voluntarily implement this BMP. These conclusions are consistent with Section 6.2.1.

The slopes of “break even” curves in the three figures are all negative. This is expected. Increases in the alfalfa price and alfalfa yield can result in cash inflows for the BMP scenario. To be “break even,” an increase in alfalfa yield will require a decrease in the alfalfa price. The scale in Figure 6.21 is the largest among the three figures. That is because adopting the BMP causes the largest change in NPV in this rotation. To be “break even,” the change of parameter in this rotation will be the biggest.

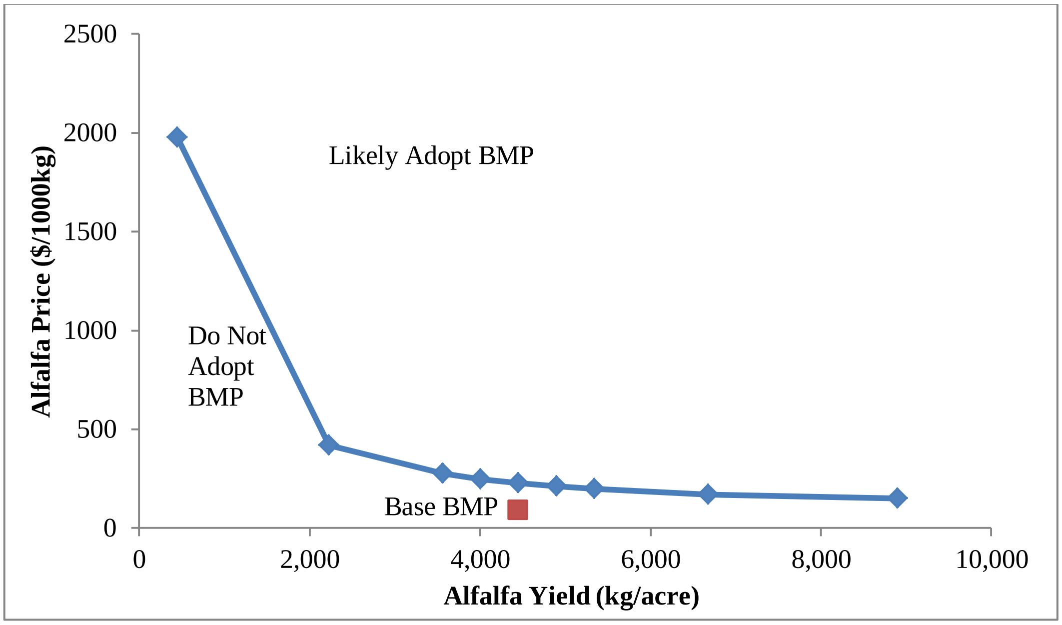
According to Figure 6.20, when keeping the alfalfa yield the same as the “base BMP” and changing the alfalfa price to meet the “break even” condition, the alfalfa price should be approximately $100/10000kg, which is 10% higher than the price in the “base BMP.” If changing the alfalfa yield and keeping alfalfa price the same as the “base BMP” scenario, the alfalfa yield should increase by 20% to approximately 6200kg/acre in the “break even” condition. Therefore, the overall result of BMP adoption in Rotation WCaCeDb-Alf is more sensitive in terms of the change in alfalfa prices than alfalfa yields. In Figure 6.21, the alfalfa price should increase by 158% to $227/1000kg in the “break even” condition, when the alfalfa yield does not change. However, this significant increase in the alfalfa price is unlikely to occur in reality. Moreover, it is difficult to identify the alfalfa yield in the “break even” condition when holding the alfalfa price the same as the “base BMP.” As a result, the overall BMP adoption decision is not sensitive in terms of alfalfa prices or yields in Rotation PWSbDb-Alf. According to Figure 6.22, either the alfalfa price decreases by 40% to approximately $55/1000kg or the alfalfa yield reduces by 90% to 445kg/acre, ceteris paribus, to meet the “break even” condition. Therefore, the overall BMP adoption results are more sensitive in terms of alfalfa prices than alfalfa yields in Rotation PWCaCe-Alf.

Figure 6.20. “Break even” curve for adding alfalfa BMP based on price and yield in Rotation WCaCeDb-Alf [a]



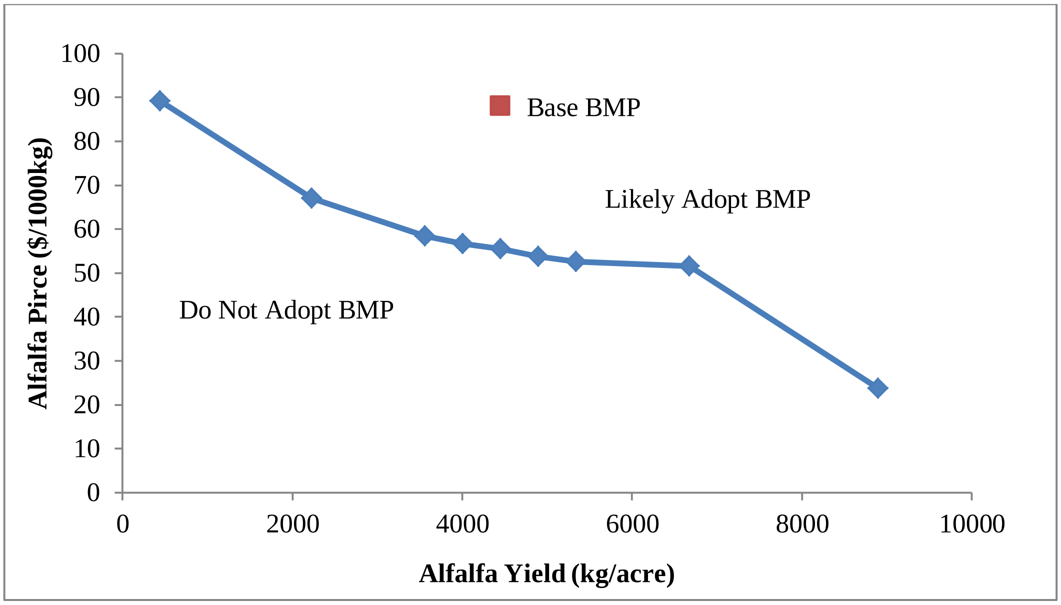
[a] In the base BMP scenario, the means of the alfalfa price and yield are $88/1000kg and 4451kg/acre, respectively. This bundle is marked in the figure with a square.

Figure 6.21. “Break even” curve for adding alfalfa BMP based on the price and yield in Rotation PWSbDb-Alf [a]



[a] In the base BMP scenario, the means of the alfalfa price and yield are $88/1000kg and 4451kg/acre, respectively. This bundle is marked in the figure with a square.

Figure 6.22 “Break even” curve for adding BMP based on the price and yield in Rotation PWCaCe-Alf [a]



[a] In the base BMP scenario, the means of the alfalfa price and yield are $88/1000kg and 4451kg/acre, respectively. This bundle is marked in the figure with a square.

6.3.1.2. Alfalfa Yield and Yield Increase Benefit due to BMP

The base BMP scenario assumes that implementing alfalfa BMP will have a positive effect on crops following the alfalfa. The amounts of changes in crop yields are identified based on a literature review. The sensitivity analyses will identify the change in crop yield increase under the conditions with different alfalfa yields. As discussed in Section 5.4.1.2.2, the positive effect on yields of crops following alfalfa can last for three years. The range of crop yield increase in each year, which is set within the lower and upper limits in a uniform distribution, is different for the range in other years. For example, in Rotation WCaCeDb-Alf, the ranges of increases are 10-50%, 5-55%, and 5-40% for crops in the subsequent years 1, 2, and 3, respectively. Since the “Goal Seek” procedure can only identify one parameter to be the “break even” condition, the parameter is set as the percentage point changes in the upper limit of the uniform distributions for the crop yield increase. For example, if the “Goal Seek” procedure identifies that the value of the parameter is 10 in Rotation WCaCeDb-Alf, the range of increase in the “break even” condition should be 10-60%, 5-65%, and 5-50%, respectively.

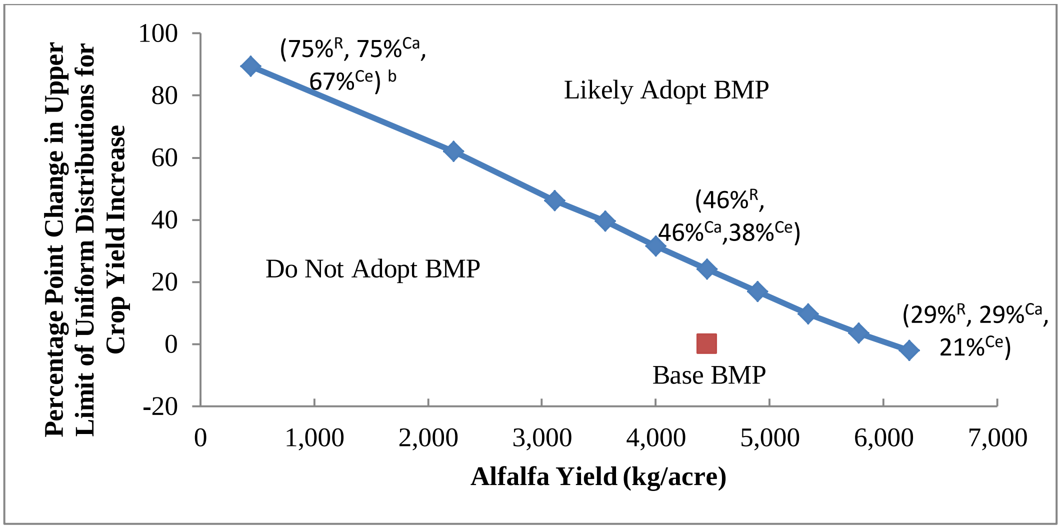
Figures 6.23, 6.24, and 6.25 display, by rotation, the “break even” curves for adding alfalfa BMP based on yield increase benefit for crops subsequent to alfalfa and alfalfa yield. The “Base BMP” bundles in Rotation WCaCeDb-Alf and Rotation PWSbDb-Alf are all below the “break even” curve. The net benefits from BMP adoption in these two rotations are negative. It is unlikely that producers will voluntarily implement this BMP. However, in Rotation PWCaCe-Alf, the “Base BMP” bundle is above the curve. As a result, adopting adding alfalfa BMP will bring net benefit for producers. It is likely that the producer will voluntarily adopt it. These conclusions are consistent with findings in Section 6.2.1.

The slopes of “break even” curves in Figures 6.23, 6.24, and 6.25 are all negative. That is because an increase in either yield increase benefit or alfalfa yield can result in net cash inflow for NPV in the BMP scenarios. To keep the “break even” condition, an increase in one parameter will require a decline in the other parameter.

In Figure 6.23, the upper limit of uniform distribution should increase 24 percentage points to meet the “break even” condition, ceteris paribus. Thus, the upper limits of the uniform distribution are 74%, 79%, and 64% for the subsequent Year 1, 2 and 3, respectively. If the upper limit remains the same as the “base BMP,” the alfalfa yield should increase by 40% to 6230kg/acre. As a result, the decision of BMP adoption is sensitive to the change in the alfalfa yield and yield increases of subsequent crops in Rotation WCaCeDb-Alf. For Rotation PWSbDb-Alf, it is difficult to meet the “break even” condition by increasing the alfalfa yield, ceteris paribus. Moreover, if the alfalfa yield is the same as that for the “base BMP,” the upper limit of the yield increase should increase by about 770 percentage points, which bears no relation to reality. Therefore, the change in NPV in Rotation PWSbDb-Alf is not sensitive in terms of the alfalfa yield and changes in upper limits. To meet the “break even” condition in Rotation PWCaCe-Alf, ceteris paribus, either the upper limits in “base BMP” are reduced by 35 percentage points or the alfalfa yield is reduced by 90%. Thus, the NPV in Rotation PWCaCe-Alf is more sensitive to the yield increases of subsequent crops than alfalfa yield.

The sensitivity analysis reaffirms the overall results for adding alfalfa BMP in Rotation PWSbDb-Alf and that the results are “stable” over a realistic range of the alfalfa price, alfalfa yield and crop yield gain. In Rotations WCaCeDb-Alf and PWCaCe-Alf, the results appear to be sensitive to the choice of values for crop yield gain. Therefore, care should be taken in putting too wide an interpretation on the results.

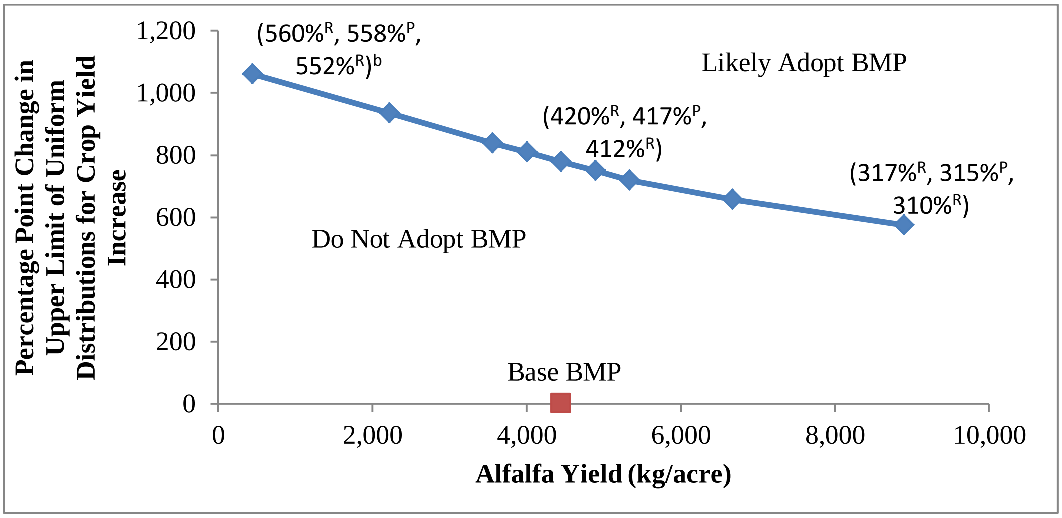
Figure 6.23 “Break even” curve for adding alfalfa BMP based on yield increase benefit on the crop following alfalfa and alfalfa yield in Rotation WCaCeDb-Alf [a]



[a] In the base BMP scenario, the upper limits of the uniform distributions in Rotation WCaCeDb-Alf are 50%, 55%, and 40% higher for the subsequent years, 1, 2, and 3, respectively; the mean of the alfalfa yield is 4451kg/acre.

[b] The bracket includes the average yield increase based on the three selected values in the Y Axis. The numbers are for red spring wheat (R), canola (Ca), and cereal (Ce) grown in the subsequent years, 1, 2 and 3, respectively.

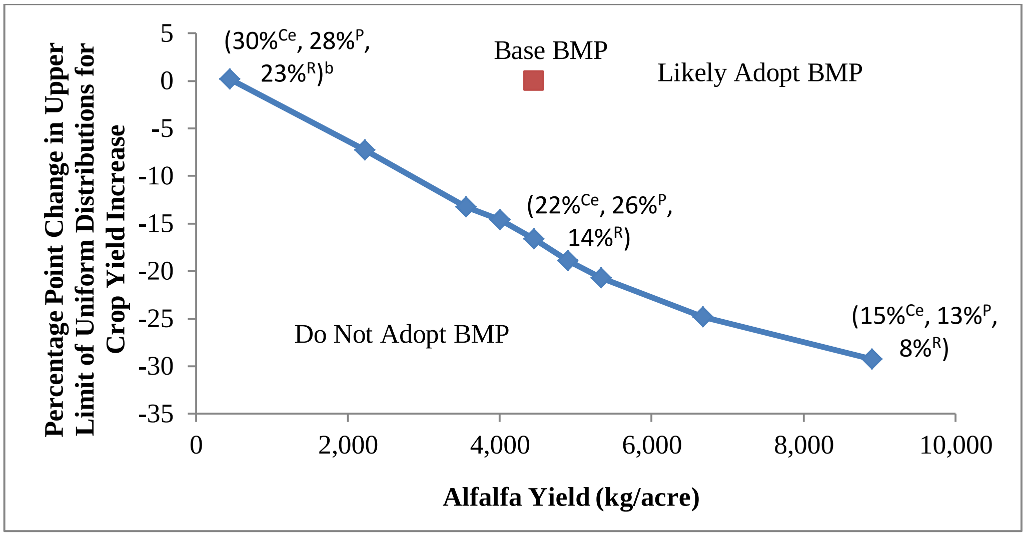
Figure 6.24. The “break even” curve for adding alfalfa BMP based on the yield increase benefit on the crop following alfalfa and the alfalfa yield in Rotation PWSbDb-Alf [a]



[a] In the base BMP scenario, the upper limits of the uniform distributions in Rotation PWSbDb-Alf are 50%, 50%, and 40% higher for the subsequent years, 1, 2, and 3, respectively; the mean of the alfalfa yield is 4451kg/acre.

[b] The bracket includes the average yield increase based on the three selected values in the Y Axis. The numbers are for red spring wheat (R), potato (P), and red spring wheat (R) grown in the subsequent years, 1, 2 and 3, respectively.

Figure 6.25. The "break even" curve for adding alfalfa BMP based on the yield increase benefit on the crop following alfalfa and the alfalfa yield in Rotation PWCaCe-Alf [a]



[a] In the base BMP scenario, the upper limits of the uniform distributions in Rotation PWCaCe-Alf are 50%, 50%, and 40% higher for the subsequent years, 1, 2, and 3, respectively; the mean of the alfalfa yield is 4451kg/acre.

[b] The bracket includes the average yield increase based on the three selected values in the Y Axis. The numbers are for cereal (Ce), potato (P), and red spring wheat (R) grown in the subsequent years, 1, 2 and 3, respectively.

6.3.2. Green Manure BMP

The green manure BMP sensitivity analysis evaluates the effects of "cash crop" prices, yield increase benefits, and green manure costs on BMP adoption in different scenarios. The criterion for choosing a "cash crop" to analyse is that the crop is grown in the year subsequent to the green manure because there is a yield increase benefit for this crop.

6.3.2.1. Crop Price and Yield Increasing Benefit

The reasons for finding the relationship between "cash crop" prices and yield increasing benefit in the sensitivity analyses are as follows. These two parameters are both related to cash inflows in the BMP scenario. In addition, the economic value of the crop yield benefit depends on the range of the crop yield increase and the price of the crop. The cash crop price discussed in this section is the average price in the simulation.

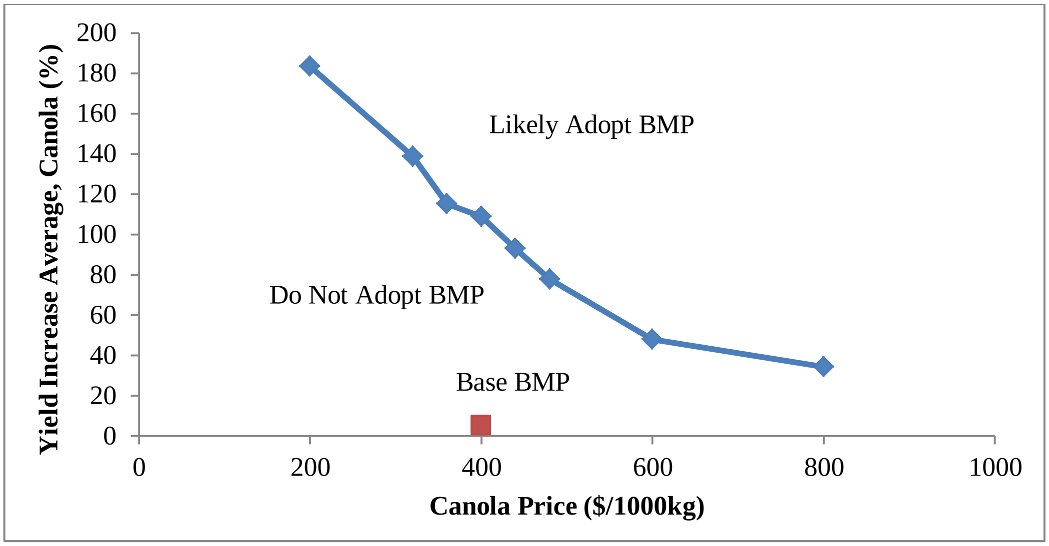
6.3.2.1.1. Barley under-seeded with Vetch

Figure 6.27 shows the "break even" curve for vetch-barley BMP based on the canola price and the level of the canola yield increase for Rotation WCaCeDb-BV. The other two "break even" curves are shown in Figure 6.28 because they are based on the potato price and the level of the potato yield increase. As shown in Figures 6.27 and 6.28, the "base BMP" bundle is below the "break even" curve in each rotation. In other words, adopting BMP will result in a negative net benefit, which is consistent with the results in Section 6.2.2.1.

The slope of the "break even" curve for Rotation WCaCeDb-BV is negative. That is because either an increase in canola price or canola yield will result in cash inflows to the NPV in the BMP scenario. To keep the "break even" condition, the canola yield decreases with the increase in canola prices. In Rotation PWSbDb-BV, the slope of the "break even" curve changes from positive to negative around the (300, 20) bundle. That occurs because adopting the vetch-barley BMP changes the rotation cycle in Rotation PWSbDb-BV. The representative farm is divided into five partitions in the BMP scenario, while the baseline without the BMP has only four partitions. The total area of cash crops in the BMP scenario decreases. Thus, the change in potato prices will have two opposite impacts on the NPV in the BMP scenario. On one hand, the increase in the potato price will increase the loss in the BMP scenario due to the decrease in potato production. On the other hand, the increase in the potato price will result in a higher cash inflow due to the potato yield increase. When the slope is positive, the value of the loss caused by the decrease in potato production is higher than the benefit from the potato yield increase. When the slope is negative, the benefit from the potato yield increase can offset the loss caused by the decrease in potato production in the BMP scenario.

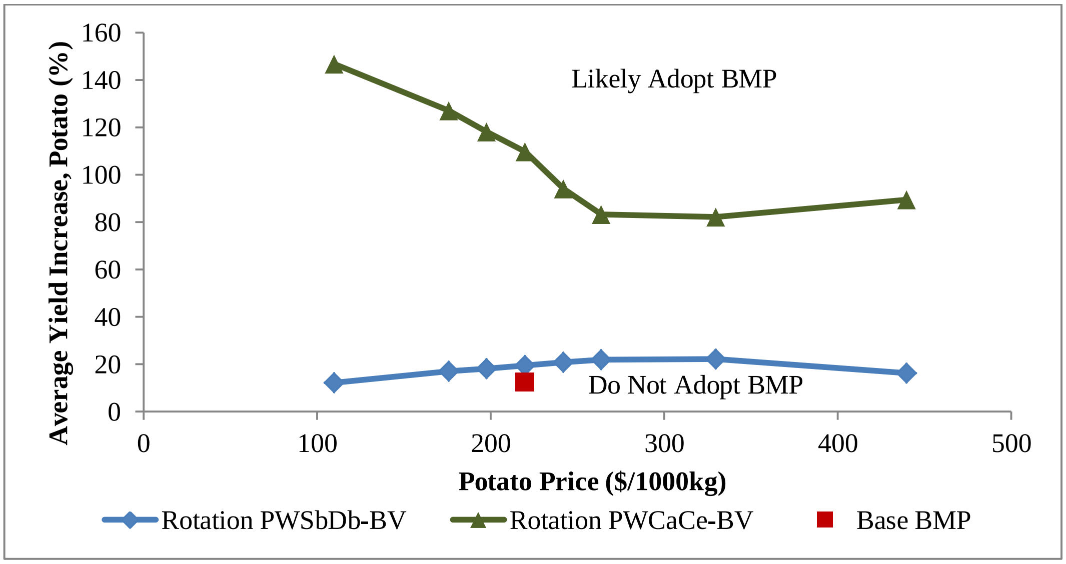
According to Figure 6.26, the average yield increase of canola should be 109% to meet the "break even" condition, ceteris paribus, in the "base BMP" scenario. This is unlikely to happen in reality. Moreover, it is difficult to identify the canola price which can fulfil the "break even" condition while the other parameters are the same as the "base BMP" scenario. Therefore, the BMP adoption decision is not significantly affected by the changes in the canola prices and yields. The same is true in Rotation PWCaCe-BV, where changes in the potato prices and yields do not significantly affect the BMP adoption in reality. In Rotation PWSbDb-BV, the "break even" condition can be met when the yield increase average rises from 12.5% to 19.6%, ceteris paribus. An alternative to fulfil the "break even" condition is reducing the potato price from $220/1000kg to $120/1000kg, ceteris paribus. Once the potato price decreases, the opportunity cost of green manure also decreases. Therefore, the benefits from green manure are more likely to cover the opportunity cost. As a result, the decision to adopt BMP is more likely influenced by the potato price and yield increasing benefit on potatoes following green manure in Rotation PWSbDb-BV.

Figure 6.26. The “break even” curve for vetch-barley BMP based on the canola price and yield increase benefit in Rotation WCaCeDb-Alf [a]



[a] In the base BMP scenario, the lower and upper limits of the uniform distribution for the canola yield increase are 0% and 10%, respectively. Therefore, the average yield increase of canola is 5%. The canola price is $400/1000kg. This bundle is marked in the graph.

Figure 6.27. “Break even” curves for vetch-barley BMP based on the potato price and yield increase benefit in Rotation PWSbDb-BV and Rotation PWCaCe-BV [a]



[a] In each base BMP scenario, the lower and upper limits of the uniform distribution for the potato yield increase are 5% and 20%, respectively. Therefore, the average yield increase for the potato crop is 12.5%. The potato price is $220/1000kg. This bundle is marked in the graph.

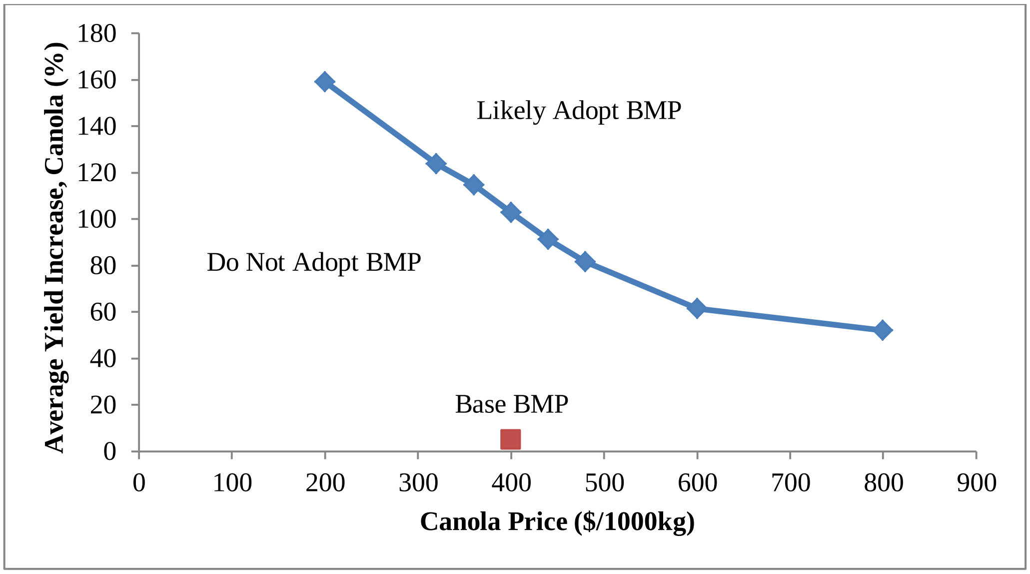
6.3.2.1.2. **Fababean Green Manure**

Figure 6.28 shows the “break even” curve for Rotation WCaCeDb-Fa. The other two “break even” curves for Rotation PWSbDb-Fa and Rotation PWCaCe-Fa are shown in Figure 6.29. The “Base BMP” bundles are all below the decision curve. That is because adopting fafabean green manure BMP causes a negative net benefit for all three rotations. Therefore, it is unlikely that producers would voluntarily implement this green manure BMP.

Compared with the rotation in the baseline, each BMP rotation has one more year in the cycle. Thus, the total area of cash crops in the BMP scenario is less than that in the baseline. Increases in prices of cash crops will have two different impacts on the NPV: it will reinforce the negative effect of the BMP due to reduced area of cash crop production, and it will increase the cash inflows from the yield increase due to BMP. In Rotation WCaCeDb-Fa, the cash inflows from the canola yield increase are higher than the cash outflows due to the loss in the canola production area. Therefore, the slope of the “break even” curve is negative. For Rotation PWSbDb-Fa and Rotation PWCaCe-Fa, the slopes of the “break even” curve change from positive to negative around the (246, 25) and (246, 24) points, respectively. One possibility is that the cash outflows from less potato production are higher than the cash inflows from the increase in the potato yield in the BMP scenario before the changing points. After the changing points, the cash inflows from the increase in the potato yield are higher than the cash outflows from less potato production.

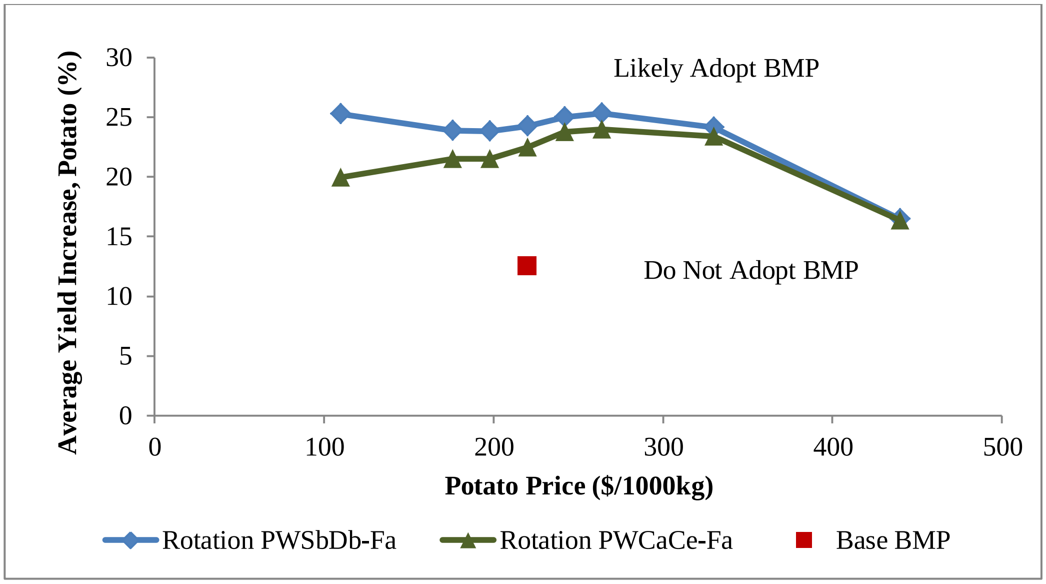
According to Figure 6.28, the average yield increase on canola following green manure should reach 103% to fulfil the “break even” condition, ceteris paribus. However, causing the canola yield to double is probably not possible in reality. In addition, it is difficult to identify the canola price which can meet the “break even” condition while holding the other parameters constant in the “base BMP” scenario. For Rotation PWSbDb-Fa and Rotation PWCaCe-Fa, the average potato yield increase should be around 24.3% and 22.5%, respectively, to meet the “break even” condition, ceteris paribus. It is not possible to identify a potato price which can result in being “break even” when holding the rest parameters in the “base BMP” constant. In sum, changing crop prices does not significantly change the decision to adopt the fababean grean manure BMP. The decision to adopt BMP is more sensitive in terms of the yield increasing benefit on the potato crop following green manure in Rotation PWSbDb-Fa and Rotation PWCaCe-Fa.

Figure 6.28 The "break even" curve for fababean green manure BMP based on the canola price and yield increase benefit in Rotation WCaCeDb-Fa [a]



[a] In the base BMP scenario, the lower and upper limits of the uniform distribution for the canola yield increase are 0% and 10%, respectively. Therefore, the average yield increase of canola is 5%. The canola price is $400/1000kg. This bundle is marked in the graph.

Figure 6.29. "Break even" curves for fababean green manure BMP based on the potato price and yield increase benefit in Rotation PWSbDb-Fa and Rotation PWCaCe-Fa [a]



[a] In each base BMP scenario, the lower and upper limits of the uniform distribution for the potato yield increase are 5% and 20%, respectively. Therefore, the average yield increase of the potato crop is 12.5%. The potato price is $220/1000kg. This bundle is marked in the graph.

6.3.2.2. Crop Price and Green Manure Cost

The cash crop price and green manure cost are selected for consideration in the sensitivity analysis. The changes in cash crop prices impact the cash inflow in the BMP scenario because there is a yield increase benefit from adopting green manure, but this may also have a negative effect, if the area of the cash crop also changes in the BMP scenario. The change in green manure cost will affect the cash outflow in the BMP scenario. The green manure costs include the seed and/or seeding costs and incorporating cost. In the base BMP scenario, the green manure costs are \$31/acre and \$158/acre for barley-vetch BMP and fafabean BMP, respectively.

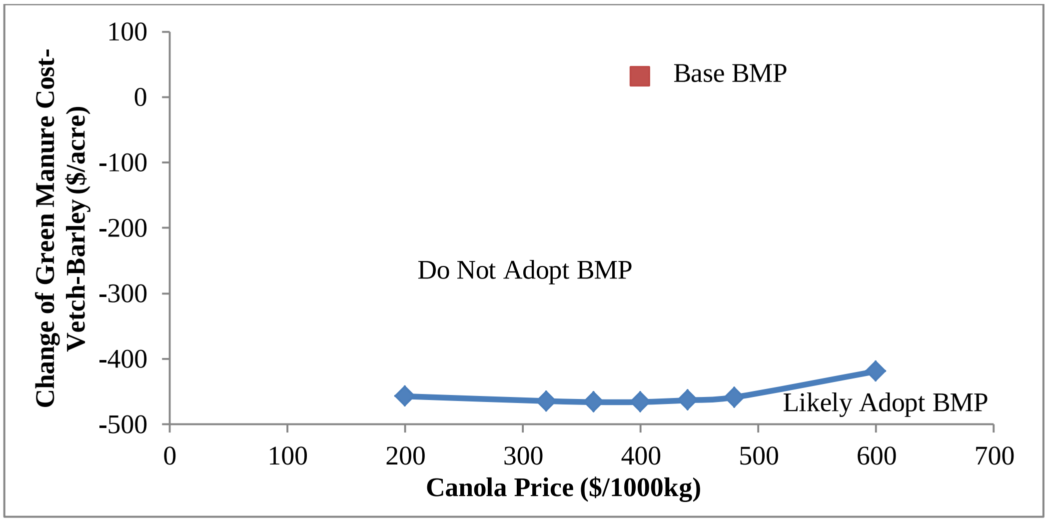
6.3.2.2.1. Barley under-seeded with Vetch

Figures 6.30 and 6.31 show the “break even” curve for Vetch-Barley BMP adoption in each rotation. The three “break even” curves are all located in the area where the changes of green manure costs are negative. The negative change in green manure costs can be regarded as an economic incentive to encourage BMP adoption. Moreover, unlike the above-mentioned figures, the area above the “break even” curve in Figure 6.30 shows where the farmers do not voluntarily adopt the BMP. The area below the curve shows where the net benefit of BMP adoption is positive because of the economic incentive. The same is true for Figures 6.31, 6.32 and 6.33.

As shown in Figure 6.30, the slope of the “break even” curve for Rotation WCaCeDb-BV changes from negative to positive. The negative slope is not expected. The increase in the canola price will increase the cash inflow from the yield increasing benefit in the BMP scenario. To keep the “break even” condition, when the cash inflow from the increase in the canola price increases, the requirement for an economic incentive decreases. As a result, the slope of “break even” curve is positive. The same is true for the positive slope in the “break even” curve for Rotation PWCaCe-BV in Figure 6.31. The slope of the “break even” curve for Rotation PWSbDb-BV is negative. That is because the area of potato production in the BMP scenario is lower than the baseline without BMP adoption. The increase in the potato price increases the cash inflows from the increase of the potato yield due to adopting BMP, but this is more than offset by the negative effect due to the loss from decreased potato production. Therefore, to be “break even,” when the price of the potato crop increases, the requirement for an economic incentive increases.

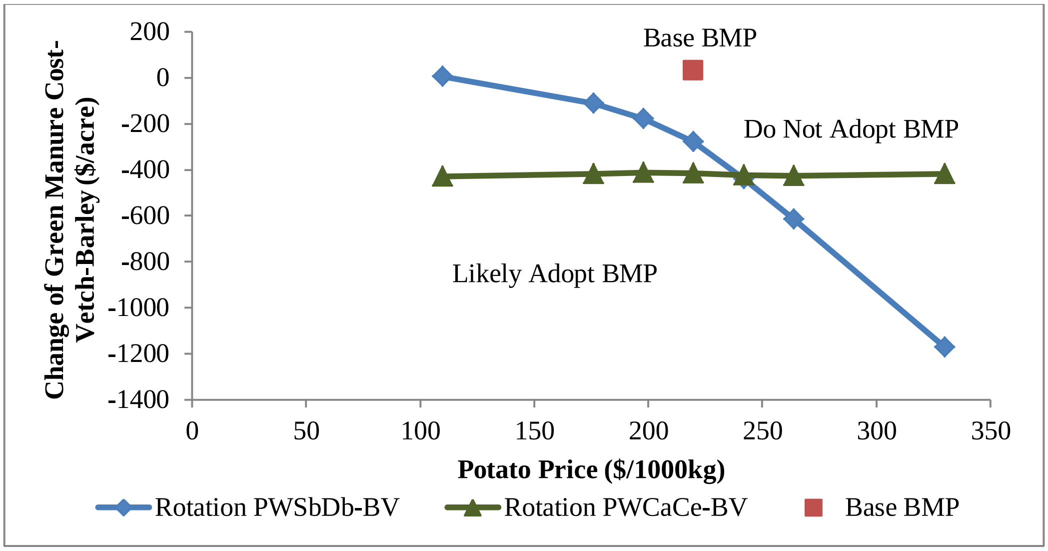
According to Figures 6.30 and 6.31, it is difficult to identify the crop prices (i.e., canola and potato) that can meet the "break even" condition, when holding the other parameters constant in the "base BMP" scenarios. The same is true in Figures 6.32 and 6.33. Thus, crop prices do not significant influence whether producers adopt the BMP. However, if there is economic incentive to adopt the BMP, it is more likely that farmers will voluntarily adopt the BMP. When holding the other parameters in the "base BMP" scenario constant, the incentives to fulfil the "break even" condition will be $466/acre, $277/acre, $416/acre , $475/acre, $479/acre, and $416/acre, for Rotation WCaCeDb-BV, Rotation PWSbDb-BV, Rotation PWCaCe-BV, Rotation WCaCeDb-Fa, Rotation PWSbDb-Fa, and Rotation PWCaCe-Fa respectively.

Figure 6.30. The "break even" curve for Vetch-Barley BMP adoption based on change of green manure cost and canola price in Rotation WCaCeDb-BV [a]



[a] In the base BMP scenario, the green manure cost for barley-vetch is $31.19/acre and the mean of the canola price is $400/1000kg. This bundle is marked in the figure.

Figure 6.31 “Break even” curves for Vetch-Barley BMP adoption based on changes in the green manure cost and potato price in Rotation PWSbDb-BV and Rotation PWCaCe-BV [a]



[a] In the base BMP, the green manure cost for barley-vetch is $31.19/acre and the mean of the potato price is $220/1000kg. This bundle is marked in the figure.

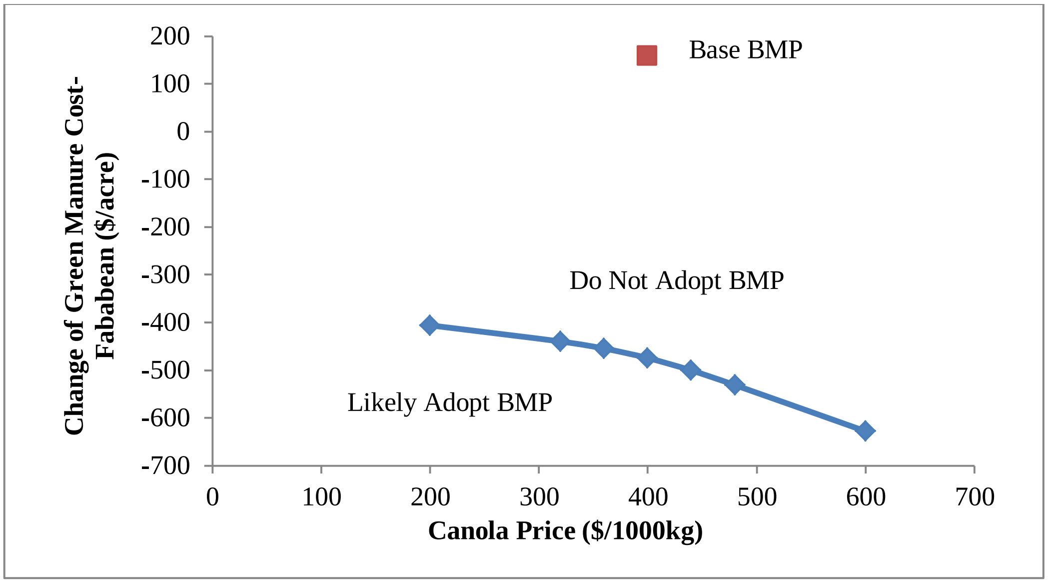
6.3.2.2.2. **Fababean Green Manure**

Figures 6.32 and 6.33 present “break even” curves based on the change in the green manure cost and cash crop price for fababean green manure BMP. The “Base BMP” bundles are all above the “break even” curves. That means adopting fababean BMP results in a negative net benefit in each rotation. It is not likely that the producers will voluntarily adopt fababean BMP.

The slopes of “break even” curves are all negative in the three rotations. Adopting fababean green manure changes the rotation cycle from four years to five years in each rotation. Therefore, the total area of cash crop production decreases. The increase in cash crop prices results in negative effects due to less cash crop production in the BMP scenario. It also increases the cash inflow from the increasing crop yield in the BMP scenario. However, the impact of the area change is greater than the positive effect of increased price. Therefore, the increase in cash crop prices requires a higher economic incentive to keep the “break even” condition. Thus, the slopes are negative.

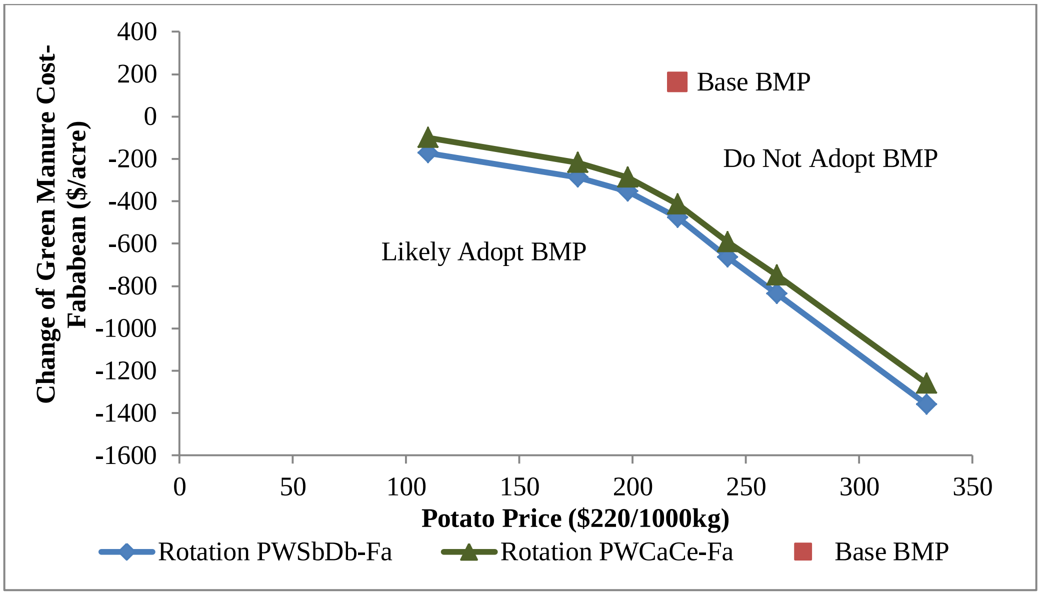
The sensitivity analysis reaffirms that the overall results for adding green manure BMP in Rotation WCaCeDb are “stable” over a realistic range of canola prices and crop yield gains. In Rotations PCaSbDb and PWCaCe, the results for adding green manure BMPs appear to be sensitive to the choice of values for crop yield gains. Therefore, care should be taken in putting too wide an interpretation on the results.

Figure 6.32. The “break even” curve for fababean green manure BMP based on changes in the green manure cost and canola price in Rotation WCaCeDb-Fa [a]



[a] In the base BMP scenario, the green manure cost for fababeans is $158.30/acre and the mean of the canola price is $400/1000kg. This bundle is marked in the graph.

Figure 6.33. “Break even” curves for green manure BMP based on the green manure cost and potato prices in Rotation PWSbDb-Fa and Rotation PWCaCe-Fa [a]



[a] In the base BMP scenario, the green manure cost for fababeans is $158.30/acre and the mean of the potato price is $220/1000kg. This bundle is marked in the figure.

6.3.3. Cattle Manure BMP

In the base cattle manure BMP scenario, there is no cost for cattle manure, but producers need to pay for the costs of transportation and on-farm application. As discussed in Section 6.2.4, applying cattle manure on the representative farm increases the NPV in comparison with the baseline without BMP adoption for all three rotations. In the sensitivity analysis, a cattle manure cost is introduced to the BMP scenario to evaluate its impact on BMP adoption. Another two parameters evaluated in the sensitivity analysis are yield increase benefit and fertilizer price. The changes in these parameters impact the NPV in the BMP scenario.

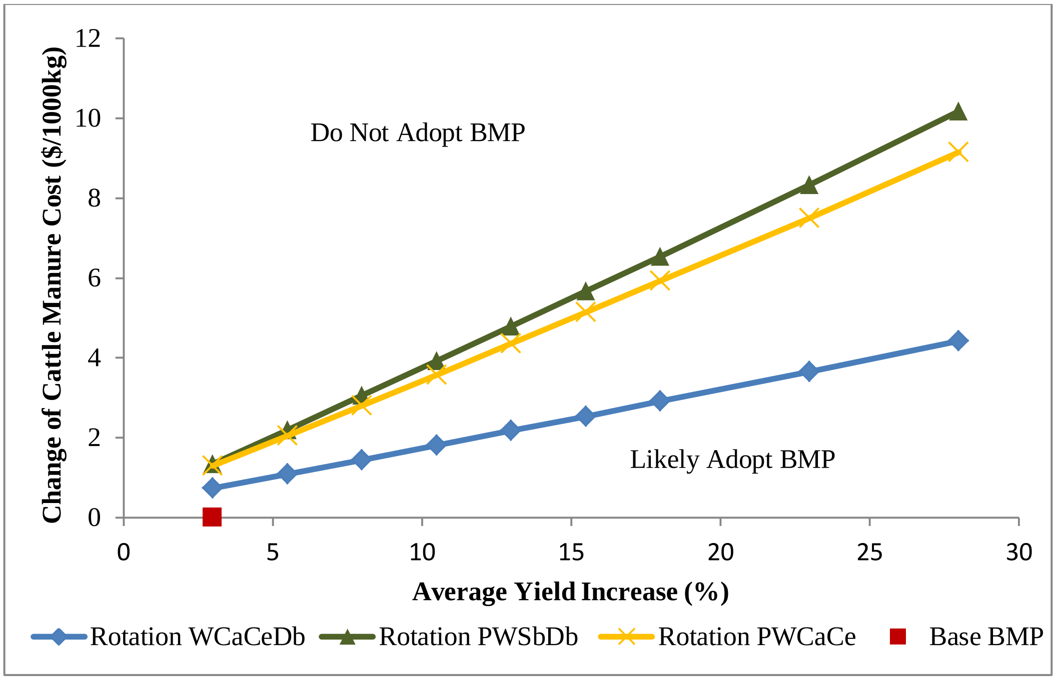
6.3.3.1. Yield Increase Benefit and Cattle Manure Cost

The increase in cattle manure costs results in an increase in cash outflow for the BMP scenarios. Thus, the net benefit from applying cattle manure will decrease. The cattle manure cost is in the vertical axis in Figure 6.34. Therefore, the area above the "break even" curve is where the net benefit from applying cattle manure is negative. It is not likely that the producers will voluntarily apply it. At points below the "break even" curve, there is a net positive benefit to applying cattle manure. This practice is likely to be voluntarily adopted by producers. The same is true for Figure 6.35.

The slopes of "break even" curves in Figure 6.34 are all positive. That is because those two variables have opposite impacts on the NPV in the BMP scenario: an increase in cost will decrease the NPV, while an increase in the crop yield will increase the NPV. To keep the "break even" condition, the increase in the crop yield should be offset by a higher cattle manure cost. Rotation PWSbDb has the steepest slope in the "break even" curve, followed by Rotation PWCaCe, and Rotation WCaCeDb. That is because Rotation PWSbDb gains the highest net benefit from applying cattle manure, as discussed in Section 6.2.4. It can afford to pay the highest cattle manure cost.

According to Figure 6.34, if there is a cost for cattle manure, the net benefit of BMP adoption will be reduced. When all other parameters in the "base BMP" are constant, in the "break even" condition, the cost will be \$0.73/1000kg, \$1.35/1000kg, and \$1.29/1000kg, for Rotation WCaCeDb, Rotation PWSbDb, and Rotation PWCaCe, respectively. The NPV in Rotation WCaCeDb is the most sensitive to the change of cattle manure, followed by the NPVs in Rotation PWCaCe and Rotation PWSbDb. In addition, if there is no cost for cattle manure, with all other parameters in the "base BMP" held constant, the change in the crop yield increasing benefit does not significantly affect the decision to adopt BMP.

Figure 6.34. “Break even” curves for cattle manure BMP based on changes in the cattle manure cost and yield increase, by rotation [a]



[a] In the base BMP scenario, the upper limit of the uniform distribution is 5%. There is no cost for cattle manure, but farmers need to pay for the costs of transportation and application. The manure application rate is 12520 kg/acre.

6.3.3.2. Cattle Manure Cost and Fertilizer Prices

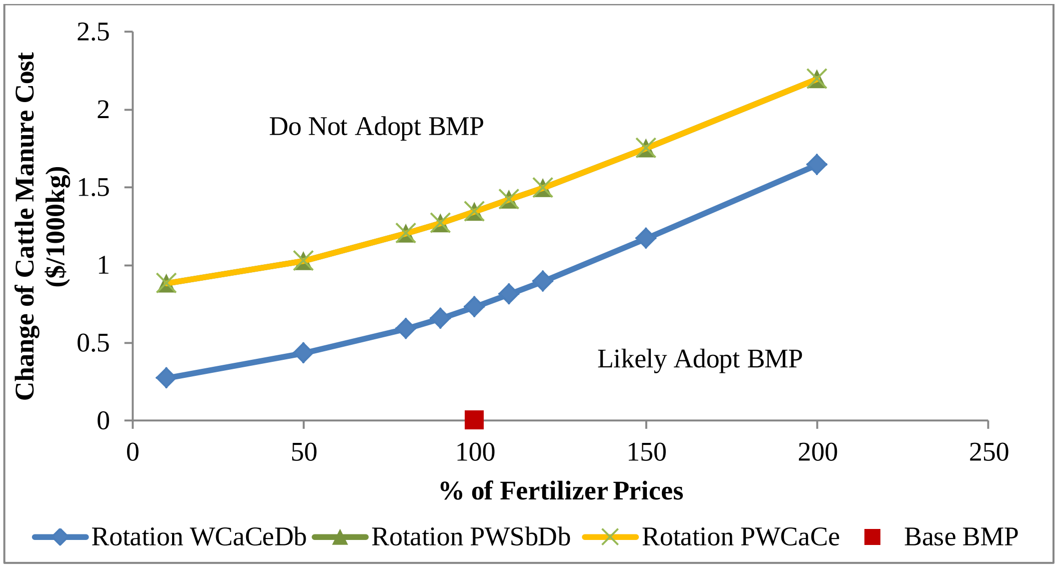
This sensitivity analysis looks at the relationship between the costs of cattle manure and fertilizer. Applying cattle manure can reduce the need for fertilizer. In addition, the base BMP scenario assumes that there is no cattle manure cost. Therefore, applying cattle manure can result in a net positive benefit. When there are changes in the cattle manure cost and fertilizer prices, the net benefit of applying cattle manure may change. Therefore, fertilizer prices and cattle manure cost are selected for the sensitivity analysis.

According to Figure 6.35, the “Base BMP” bundle is below the decision curves. It is likely that producers will voluntarily adopt this BMP. In addition, the decision curve for Rotation PWSbDb coincides with the one for Rotation PWCaCe. That is because the fertilizer savings from applying cattle manure are very close in these two rotations, which has been shown in Table 6.7. The “break even” curves all have positive slopes. Applying cattle manure can reduce the amount of on-farm fertilizer application. As fertilizer prices increase, the benefit from BMP adoption increases. The affordable cost to buy the cattle manure also increases. Therefore, the slopes of the “break even” curves are positive.

The costs of cattle manure in the “break even” condition, when all other parameters in the “base BMP” are constant, are $0.73/1000kg, $1.35/1000kg, and $1.29/1000kg, for Rotation WCaCeDb, Rotation PWSbDb, and Rotation PWCaCe, respectively. This is consistent with the finding in Figure 6.34. Moreover, with all other parameters in the “base BMP” held constant, if there is no cost for cattle manure, the changes in fertilizer prices do not significantly affect the BMP adoption decision.

Based on the sensitivity analysis, the overall results for applying cattle manure BMP in each rotation are “stable” over a realistic range of crop yield gains and fertilizer prices. However, the results appear to be sensitive to the choice of values for the cattle manure cost.

Figure 6.35. “Break even” curves for cattle manure BMP based on fertilizer prices and cattle manure costs, by rotation [a]



[a] In the base BMP scenario, the prices for N, P, K, and S are $1.80/kg, $1.19/kg, $1.18kg, and $0.69/kg, respectively. There is no cost for cattle manure, but farmers need to pay for the costs of transportation and application. The manure application rate is 12520 kg/acre.

6.3.4. Nutrient Management Planning (NMP) BMP

In the base BMP scenario, the carryover rates of the unused fertilizers are 85%, 95%, 95% and 90% for N, P, K and S, respectively. The changes in carryover rates will impact the amount of unused fertilizer available for the upcoming year, thus influencing the benefit from BMP adoption. Using the “Goal Seek” procedure to identify the “break even” carryover rates showed that the identified rates were not in the range of 0-100%, which is problematic in reality. Therefore, an alternative method is used. The alternative method changes the carryover rates for N, P, K and S simultaneously by the same amount and then updates the NPV from the simulation.

Table 6.9 shows the NPVs for the whole farm obtained from sensitivity analyses based on different fertilizer carryover rates. The NPVs decrease as long as the carryover rates decrease. When the change in carryover rates is 80 percentage points, the NPV of BMP adoption for each rotation is still greater than that for the baseline scenario. When the change in carryover rates is smaller than 80 percentage points, there is always a positive benefit from adopting this BMP. In sum, the change in carryover rates will change the NPV in the BMP scenario. However, even when the carryover rates are reduced to 5%, 20%, 20% and 15% for N, P, K and S, respectively, there is still a net benefit from adopting the NMP BMP.

Table 6.9. NPVs for the whole farm in sensitivity analyses based on different fertilizer carryover rates, by rotation ($/farm)

Decrease of Percentage Points for Carryover Rates[a]	Rotation WCaCeDb	Rotation PWSbDb	Rotation PWCaCe
0[b]	3,692,098	9,821,491	9,090,441
5	3,677,224	9,803,989	9,074,208
10	3,663,077	9,787,467	9,058,947
15	3,648,255	9,768,832	9,041,814
20	3,634,301	9,750,881	9,025,045
25	3,620,071	9,731,838	9,007,088
30	3,605,648	9,711,168	8,987,793
40	3,577,064	9,669,452	8,948,460
50	3,547,901	9,624,797	8,906,649
60	3,519,526	9,579,794	8,864,330
70	3,491,063	9,533,223	8,820,043
80	3,462,261	9,485,180	8,774,650
Baseline	3,442,080	9,423,238	8,703,361

[a] This decreases the carryover rates in N, P, K, and S simultaneously by fixed percentage points. For example, “5” reduces the original BMP carryover rates to 80%, 95%, 95%, and 90% for N, P, K and S, respectively.

[b] In the “Base BMP” scenario, the carryover rates are 85%, 100%, 100%, and 95% for N, P, K and S, respectively.

[c] The baseline scenario is the scenario without the BMP adoption.

6.4. Chapter Summary

There are six BMP scenario studies in each rotation in this analysis. In comparison with the baseline scenarios, the changes in NPVs are shown in Table 6.10. For the BMPs involved with adding legumes (i.e., alfalfa, vetch, and fafabean) into the rotations, adopting the BMPs decreases the NPVs, with the exception of adding alfalfa into Rotation PWCaCe. The reductions in NPVs in the BMP scenarios occur mainly because the opportunity costs of growing legumes are higher than the benefits, such as saving on fertilizer and increases in the yields of cash crops. When the representative farm implements the crop residue management BMP, it results in a negative net benefit in each rotation. That is primarily because there is a reduction in revenue for baled residues. Both applying cattle manure and nutrient management planning (NMP) can lead to increases in NPVs, in part due to the saving on fertilizer inputs. It is likely that the farmers will voluntarily adopt the BMPs that can bring positive net benefits. However, economic incentive might be required to encourage farmers to adopt the BMPs resulting in negative net benefits.

Table 6.10 Overall changes in NPVs in the BMP scenarios

BMP	Rotation WCaCeDb	Rotation PWSbDb	Rotation PWCaCe
Adding Alfalfa	-	-	+
Green Manure: Vetch & Barley	-	-	-
Green Manure: Fababean	-	-	-
Crop Residue Management	-	-	-
Applying Cattle Manure	+	+	+
Nutrient Management Planning	+	+	+

There are two types of sensitivity analysis used in this study: using “Goal Seek” to identify the “break even” condition, and “regular” sensitivity analysis. The presentation of the “break even” curve will help to easily identify whether a bundle of two parameters will result in positive or negative net benefit in the BMP scenarios, when all other parameters are held constant. The “break even” curve also helps to evaluate the change of one selected parameter to fulfil the “break even” condition when all other parameters are constant in the “base BMP” scenarios.

Chapter 7. Summary and Conclusions

BMPs are practices that are considered to be able to reduce the environmental impacts such as degradation of water and soil quality, caused by agricultural practices. Implementing BMPs on a farm is usually costly because most BMPs require additional costs and/or giving up a proportion of the farm from growing cash crops. The potential short term benefits from adopting the BMPs depend on the specific BMP, which include gains in crop yield or savings of inputs. Currently, there is a lack of knowledge about the net on-farm benefit from BMP adoption, especially on irrigated farms. To fill the gap, this study analyzed the farm-level costs and benefits of BMPs on a representative irrigated farm in southern Alberta.

This study identified a representative commercial farm in Taber, Alberta, through a combination of expert opinion and census data. The size of the representative farm is 1600 acres, including 10 equal-size fields. Each field is irrigated with a low pressure center pivot irrigation system. Three crop rotations were identified to represent the overall diversity in crops grown in southern Alberta. The first rotation includes red spring wheat, canola, a second cereal and dry bean (WCaCeDb). The second rotation includes potato, red spring wheat, sugar beet, and dry beans (PWSbDb). The third rotation includes potato, red spring wheat, canola and a second cereal (PWCaCe). To represent the risk in agricultural production, stochastic crop prices, crop yields and irrigation costs were incorporated in the analysis, along with participation in AgriInsurance and AgriStability.

Five BMPs were studied: adding alfalfa into rotations, adding green manure into rotations, crop residue management, applying cattle manure, and nutrient management planning (NMP). The main criteria for selecting these BMPs are their ability (real or hypothesized) to address water quality issues. Some BMPs can also be involved with controlling the wind and water erosion and/or improving soil quality. For example, adding legumes (i.e., alfalfa or green manure crops) into rotations, applying cattle manure, and nutrient planning can reduce fertilizer application, thus reducing fertilizer runoffs and increasing water quality. Moreover, all of the BMPs are beneficial for increasing the level of organic matter in the soil, with the exception of NMP. Applying crop residue management can also provide cover on the farm, thus leading to less wind and water erosion in the non-growing season. The on-farm costs and benefits of BMP adoption were quantified using

NPV analysis in conjunction with a Monte Carlo simulation. The difference in NPVs between the BMP scenario and the baseline was regarded as the net on-farm benefit from BMP adoption, which could be positive or negative. The key findings from the comparisons are presented in this chapter along with limitations and suggestions for further studies.

7.1. Economic Feasibility of BMP Implementation

To determine whether it is economically feasible to implement BMP on the representative farm, this study quantified the costs and the short-term on-farm benefit for adopting each BMP. When alfalfa is added into rotations (-Alf), alfalfa can fix nitrogen from the air and increase nitrogen supply in the soil. Therefore, the need for nitrogen for crops following alfalfa is reduced. In addition, adding alfalfa can lead to yield increases on the subsequent crops due to better growing conditions and a break in crop disease cycles. For Rotation PWCaCe-Alf, adding alfalfa into the rotation resulted in a gain in annualized NPV by $22/acre in comparison with the scenario without BMP. However, the annualized NPV per acre for adding alfalfa decreases by $9/acre and $94/acre for Rotation WCaCeDb-Alf and Rotation PWSbDb-Alf, respectively. That is because the gain from less fertilizer costs and yield increases is less than the loss of valuable crop production such as potato, durum wheat and dry bean. According to the sensitivity analyses, the results of BMP adoption in Rotation WCaCeDb-Alf are sensitive in terms of changes in alfalfa price and yield increasing benefit. The BMP adoption decision in Rotation PWSbDb-Alf is not sensitive to changes in either alfalfa yield and prices, or yield increasing benefit. In Rotation PCaCeDb-Alf, the decision to adopt BMP is more likely influenced by changes in the yield increasing benefit and alfalfa price, while it is not sensitive to changes in the alfalfa yield.

Implementing the green manure BMP results in nitrogen fertilizer and crop yield benefits for crops following it. However, there is no cash crop production on the field grown with green manure. In this study, two green manure BMPs were studied: under-seeding vetch with barley (-BV) and growing fababeans (-Fa). According to this study, adopting green manure causes a negative net benefit for all three rotations. The annualized NPVs decreased by $87/acre, $41/acre, $77/acre, $67/acre, $68/acre, and $57/acre for Rotation WCaCeDb-BV, Rotation PWSbDb-BV, Rotation PWCaCe-BV, Rotation WCaCeDb-Fa, Rotation PWSbDb-Fa, and Rotation PWCaCe-Fa, respectively. As discussed in Section

2.1.2.2, potato farmers might grow green manure prior to potatoes to break the disease cycle and obtain a better potato yield. The farmers believe that potatoes are a high revenue crop, making it possible to justify no crop revenue due to green manure. However, according to this study, assuming a 5-20% (12.5% on average) increase in the potato crop yield, the total benefit of green manure is negative. According to the sensitive analyses, either a change in the canola price or an increase in the canola yield when following green manure will influence the decision on whether to adopt the green manure BMP (i.e., vetch and fababean) in Rotation WCaCeDb. In Rotation PWSbDb, the decision to adopt green manure BMP (i.e., vetch and fababean) is sensitive in terms of the change in the yield increasing benefit for growing potato crops after green manure. In Rotation PWCaCe, whether or not to adopt fababean green manure BMP is more likely influenced by the change in the yield increasing benefit.

Spreading crop residues on fields with low crop residues was considered a BMP because the residues can cover the fields, reducing runoff in the non-growing season and adding more organic matter to the soil. In the BMP scenario, crop residues from cereal production are spread on potato, sugar beet and dry bean fields after harvest instead of being sold, as in the baseline. This results in negative net benefits for all three rotations. The annualized NPVs in the BMP scenarios decrease by $33/acre, $102/acre, and $32/acre for Rotation WCaCeDb, Rotation PWSbDb, and Rotation PWCaCe, respectively.

Applying cattle manure can reduce the need for inorganic fertilizer and improve soil quality. In this study, cattle manure is applied in each field once every four years based on one- year requirement of nitrogen for red spring wheat. Even though there are transportation and application costs when applying cattle manure, the savings from less fertilizer application and crop yield increases due to the better growing condition result in a positive net benefit in the BMP scenario. The increases in annualized NPVs are $27/acre, $52/acre, and $50/acre for Rotation WCaCeDb, Rotation PWSbDb, and Rotation PWCaCe, respectively. According to the sensitivity analyses, the change in yield gains or fertilizer prices will not significantly affect the economic feasibility of the BMP. In the base BMP scenarios, there is no cost for cattle manure. If farmers need to pay for the cattle manure, the costs of cattle manure could be $0.7/1000kg for Rotation WCaCeDb, and $1.3/1000kg for Rotation PWSbDb and Rotation PWCaCe, in the “break even” condition, ceteris paribus.

Nutrient management planning was considered a BMP because it may reduce fertilizer application, thus eliminating the runoff from fertilizer. In this study, the benefit from fertilizer savings is greater than the cost of soil tests in the BMP scenarios. Therefore, the annualized NPVs per acre increase by $6/acre, $12/acre, and $13/acre for Rotation WCaCeDb, Rotation PWSbDb, and Rotation PWCaCe, respectively. In the base BMP scenarios, the carryover rate is assumed to be 85%, 100%, 100% and 95% for N, P, K, and S respectively. When the carryover rates change to 5%, 20%, 20%, and 15% for N, P, K, and S respectively, the NPVs from the BMP scenarios are still greater than the baseline scenario. This shows that the decision to adopt this BMP is not sensitive to the changes in carryover rates.

7.2. Conclusions and Implications for Irrigation Crop Production and Policy in Southern Alberta

The objective of this study is to understand private benefits and costs to an irrigated crop producer who introduces BMPs to his or her operation. According to the results, most of the BMPs of interest are costly for producers because they add non-marketable crops (i.e., green manure) or lower value cash crops (i.e., alfalfa), or do not provide short-term productivity increases (i.e., crop residue management). However, both cattle manure BMP and NMP BMP that can provide significant reduction in input costs and/or gains in crop yields can result in positive benefits. Producers are more likely to voluntarily adopt the BMPs that provide direct net benefit for them. It is unlikely that farmers will voluntarily implement the “costly” BMPs. Under the currently upward trend in cash crop prices especially, the opportunity cost of reduced farmland being available for cash crop production is increasing. Thus, the possibility that farmers will voluntarily implement these “costly” BMPs is going to be smaller.

According to the framework developed by Pannell (2008), an appropriate policy decision on production practices is based on the relative signs and magnitudes of the private net benefit and public net benefit. In this study, the public net benefit of each BMP is considered positive in terms of water and soil quality preservation in the long run. It is unlikely that farmers will voluntarily adopt BMPs that provide negative net benefits, even though it will help to maintain the farmland and water quality. In these cases, economic incentives might be required to encourage BMP adoption. The on-farm level of net negative benefit of BMPs identified in this study can be used as a proxy in deciding the potential appropriate value of incentive or subsidization required to convince producers to adopt the BMPs. For example, the value of annualized reduction per acre in NPV evaluated in the analysis can be paid to producers who adopt the “costly” BMP. On the other hand, for the BMPs that can bring positive private net benefits to producers, the identified values of annualized increase per acre in NPV can be used in education programs to encourage producers to adopt the BMPs. With the farm-level positive net benefit, it is more likely that producers will voluntarily implement the BMPs.

7.3. Model Limitations and Assumptions

It needs to be recognized that the results of this study are specific to the characteristics of the representative irrigated farm in Taber, Alberta. Although this study tried to model the representative farm and producer behavior in such a way to be consistent with reality, many assumptions were still applied due to the restriction of modelling techniques or a lack of information.

In this study, producer decisions were taken as given because of using the simulation approach. However, adoption of BMPs might influence producer decisions. For example, if alfalfa is introduced into rotations, it is likely that the producer will change the rotations in terms of crop selection to maximize the profitability or minimize the loss. However, by using the simulation approach, there is limited flexibility in modelling the process of producer behavior. It might be more explicit and flexible if using an optimization modelling approach.

Many assumptions were applied in modelling the NMP BMP. This study assumed that once the actual crop yield is lower than the target yield, there are leftover nutrients from the fertilizer application. This is based on the assumption that nutrients used by crops correlate positively with crop yield. However, in reality, not all the scenarios that have “poor yields” will result in leftover nutrients. For example, bad weather before and/or during harvesting might cause a decreased yield. In this case, the level of nutrient consumption by crops might not necessarily be lower than the average. However, due to a lack of information about weather and its model in this study, the influence of this type of “bad yield” on leftover nutrients was not considered. If this influence is taken into account, the total net benefit from adoption of NMP BMP might decrease.

The lack of literature about the impacts of BMPs of interest on crop production in the study area also imposed limitations on quantifying the influences of BMPs. For example, there is a lack of literature about the level of crop yield gain from applying cattle manure on irrigated crops in southern Alberta. To resolve this shortcoming, this study had to make assumptions based on the literature that was not about the study area or based on the expert opinion instead of scientific research.

The representative farm's characteristics regarding the crop yields and land attributes among different rotations were also simplified in the study. When modelling the crop yields, the draw from crop yield distribution can represent the risks in agricultural production, such as weather and crop diseases. However, the types of crops included in a rotation might also impact crop yields. For example, Rotation WCaCeDb has two years of cereal production in the rotation cycle, while Rotation PWSbDb just has one year. The cycle of disease specific to cereal is more likely being broken completely in Rotation PWSbDb than in Rotation WCaCeDb. Therefore, in the same simulation year, the yields of a cereal between these two rotations might be different, while this study assumed there is no difference. Moreover, this study assumed that the attributes of farmland are the same regardless of the types of rotations. However, generally, growing potato requires a better farmland than growing cereals or oilseeds. For example, potato farmland is more likely well-drained, has flat topography, and is free of stones. The price for a potato farm is higher than that for cereal and oilseed farms.

Finally, the analysis in this study was conducted for a single 1600 acre representative farm. Farm size varies significantly in the area, with significant numbers of farms that are larger or smaller than the representative farm. Given the potential for economies of size in crop production, differences in opportunity costs based on farm size may contribute to measurable differences in net benefits for adoption of some BMPs.

However, despite the assumptions made due to the limitations in this study, the results of this study are representative of a commercial irrigated farm in Taber, Alberta. That is because the data used in the study can represent the local crop yields, prices, and production costs. In addition, the results of sensitivity analyses can provide a tool to identify whether or not the changes of "key parameters" will significantly influence the economic feasibility of a BMP in a specific rotation.

7.4. Further Research

In this study, the representative irrigated farm includes cereals, canola, dry bean, potato and sugar beet with three different rotations. However, in reality, irrigated crop rotations in southern Alberta are very diverse, depending on the type of farm. Many farms specialize in one or two areas such as beef feedlot or dairy (they mainly grow silage and barley), potato, sugar beet, canola, or timothy (used for export). Future studies should look at more types of farms.

In addition, this study assessed only the private costs and benefit of BMPs on the representative farm. According to the framework developed by Pannell (2008), an appropriate policy decision on production practices is based on the understanding of the private net benefit and public net benefit. Therefore, knowledge about the public benefits of these BMPs is also required. The public benefits of BMPs of interest in this study include soil and water quality preservation. On one hand, biophysical evaluations can be used to measure the environmental impact of these BMPs in the long run. This can provide scientific evidence for the environmental influence of BMPs. On the other hand, an economic evaluation of the environmental improvement can be performed. This can be conducted by determining producers' and society's willingness-to-pay or willingness-to-accept the environmental improvements that will result from adopting BMPs.

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Appendix A: Test Statistics for Distribution

Appendix A.1 Test statistics for distribution fitting, barley yields

Rank	Distribution	Chi-Sq Statistic	Rank	Distribution	A-D Statistic	Rank	Distribution	K-S Statistic
1	Gamma	2.8696	1	BetaGeneral	0.4097	1	Weibull	0.1455
1	BetaGeneral	2.8696	2	Gamma	0.4265	2	BetaGeneral	0.1706
1	Lognorm	2.8696	3	Lognorm	0.4502	3	Gamma	0.1817
2	Weibull	5.4783	4	Weibull	0.5841	4	Lognorm	0.1889
3	Triang	23.7391	5	Expon	8.5093	5	Triang	0.41
4	Uniform	37.2174	6	Uniform	12.6007	6	Expon	0.5394
5	Expon	47.6522	7	Triang	+Infinity	7	Uniform	0.602

Appendix A.2 Test statistics for distribution fitting, canola yields

Rank	Distribution	Chi-Sq Statistic	Rank	Distribution	A-D Statistic	Rank	Distribution	K-S Statistic
1	BetaGeneral	1.1304	1	BetaGeneral	0.2058	1	Weibull	0.0904
1	Weibull	1.1304	2	Weibull	0.2189	2	BetaGeneral	0.1185
2	Gamma	2	3	Gamma	0.2747	3	Gamma	0.1365
2	Lognorm	2	4	Lognorm	0.3005	4	Lognorm	0.1395
3	Expon	47.6522	5	Expon	8.6756	5	Triang	0.4514
4	Uniform	34.6087	6	Uniform	14.1368	6	Expon	0.5542
5	Triang	21.5652	7	Triang	+Infinity	7	Uniform	0.6426

Appendix A.3 Test statistics for distribution fitting, dry bean yields

Rank	Distribution	Chi-Sq Statistic	Rank	Distribution	A-D Statistic	Rank	Distribution	K-S Statistic
1	Weibull	0.6957	1	Weibull	0.3248	1	Weibull	0.1071
2	BetaGeneral	3.3043	2	Gamma	0.9194	2	BetaGeneral	0.1476
2	Gamma	3.3043	3	Lognorm	1.1156	3	Gamma	0.1675
3	Lognorm	5.4783	4	Expon	7.1527	4	Lognorm	0.1856
4	Triang	8.087	5	Uniform	10.7488	5	Triang	0.3569
5	Uniform	23.3043	6	BetaGeneral	+Infinity	6	Expon	0.4419
6	Expon	45.4783	7	Triang	+Infinity	7	Uniform	0.523

Appendix A.4 Test statistics for distribution fitting, durum wheat yields

Rank	Distribution	Chi-Sq Statistic	Rank	Distribution	A-D Statistic	Rank	Distribution	K-S Statistic
1	Gamma	0.6957	1	BetaGeneral	0.2409	1	Gamma	0.0932
1	Lognorm	0.6957	2	Gamma	0.2517	2	Lognorm	0.0967
2	BetaGeneral	3.7391	3	Lognorm	0.2739	3	BetaGeneral	0.1215
3	Weibull	6.3478	4	Weibull	0.2865	4	Weibull	0.1328
4	Triang	30.2609	5	Expon	9.076	5	Expon	0.5533
5	Uniform	58.9565	6	Uniform	19.3991	6	Triang	0.5726
6	Expon	73.7391	7	Triang	+Infinity	7	Uniform	0.6995

Appendix A.5 Test statistics for distribution fitting, potato yields

Rank	Distribution	Chi-Sq Statistic	Rank	Distribution	A-D Statistic	Rank	Distribution	K-S Statistic
1	Weibull	6.3478	1	Weibull	0.4923	1	Weibull	0.1193
2	BetaGeneral	7.2174	2	BetaGeneral	0.5972	2	BetaGeneral	0.134
2	Gamma	7.2174	3	Gamma	1.009	3	Gamma	0.1785
2	Lognorm	7.2174	4	Lognorm	1.0775	4	Lognorm	0.1844
3	Triang	30.2609	5	Expon	9.3746	5	Expon	0.5491
4	Expon	73.7391	6	Uniform	21.2272	6	Triang	0.6135
4	Uniform	73.7391	7	Triang	+Infinity	7	Uniform	0.7136

Appendix A.6 Test statistics for distribution fitting, red spring wheat yields

Rank	Distribution	Chi-Sq Statistic	Rank	Distribution	A-D Statistic	Rank	Distribution	K-S Statistic
1	Gamma	2	1	Lognorm	0.3666	1	Lognorm	0.1181
1	Lognorm	2	2	Gamma	0.3763	2	Gamma	0.1193
2	Weibull	6.3478	3	Weibull	0.6122	3	Weibull	0.1276
3	Triang	35.4783	4	Expon	9.1548	4	Expon	0.5841
4	Expon	65.913	5	Uniform	19.9508	5	Triang	0.6099
5	Uniform	65.913	6	Triang	+Infinity	6	Uniform	0.747
6	BetaGeneral		7	BetaGeneral		7	BetaGeneral	

Appendix A.7 Test statistics for distribution fitting, sugar beet yields

Rank	Distribution	Chi-Sq Statistic	Rank	Distribution	A-D Statistic	Rank	Distribution	K-S Statistic
1	Weibull	2	1	Weibull	0.1403	1	Weibull	0.0879
1	BetaGeneral	2	2	BetaGeneral	0.1594	2	BetaGeneral	0.1027
2	Gamma	3.7391	3	Gamma	0.4173	3	Gamma	0.1114
2	Lognorm	3.7391	4	Lognorm	0.484	4	Lognorm	0.119
3	Triang	23.3043	5	Expon	8.5803	5	Triang	0.486
4	Uniform	36.7826	6	Uniform	15.5563	6	Expon	0.5214
5	Expon	65.913	7	Triang	+Infinity	7	Uniform	0.6342

Appendix B. Detrended average depth of irrigation application and growing season precipitation (1976-2010)

Year	Detrended average depth of irrigation application in Taber(mm)	Growing season precipitation in TID (mm)
1976	388.64	247.90
1977	526.16	160.00
1978	135.83	410.40
1979	409.52	137.90
1980	407.64	296.20
1981	451.01	199.40
1982	370.12	232.70
1983	389.93	213.40
1984	400.37	217.80
1985	374.61	229.90
1986	402.97	326.30
1987	394.85	287.10
1988	496.43	174.90
1989	305.13	271.00
1990	376.51	181.50
1991	364.00	319.70
1992	385.33	348.60
1993	244.87	410.90
1994	398.08	265.70
1995	312.48	337.00
1996	496.27	155.50
1997	441.45	196.30
1998	441.20	332.90
1999	386.79	288.00
2000	522.31	131.90
2001	361.89	121.70
2002	199.88	491.80
2003	331.29	243.80
2004	247.37	291.00
2005	276.70	412.80
2006	320.72	298.80
2007	394.10	218.70
2008	330.28	318.50
2009	381.57	359.25
2010	221.89	523.30

Appendix C Irrigated crop acreage when adding alfalfa into rotations

Appendix C.1 Irrigated crop acreage in Rotation WCaCeDb-Alf (Acre)

Year	W (Irrigation.)	Ca (Irrigated)	Ce (Irrigated)	Db (Irrigated)	Alf (Irrigated)
0	432	432	288	288	0
1	288	288	288	288	288
2	288	288	288	288	288
3	288	288	288	288	288
4	288	288	288	288	288
5	288	288	288	288	288
6	288	288	288	288	288
7	288	288	288	288	288
8	288	288	288	288	288
9	288	288	288	288	288
10	288	288	288	288	288
11	288	288	288	288	288
12	288	288	288	288	288
13	288	288	288	288	288
14	288	288	288	288	288
15	288	288	288	288	288
16	288	288	288	288	288
17	288	288	288	288	288
18	288	288	288	288	288
19	288	288	288	288	288
20	288	288	288	288	288

Appendix C.2 Irrigated crop acreage in Rotation PWSbDb-Alf (Acre)

Year	P (Irrigated)	W (Irrigated)	Sb (Irrigated)	Db (Irrigated)	Alf (Irrigated)
0	288	432	432	288	0
1	288	432	288	288	288
2	288	432	288	288	288
3	288	432	288	288	288
4	288	432	288	0	288
5	288	432	288	288	288
6	288	432	288	288	288
7	288	432	288	0	288
8	288	432	288	288	288
9	288	432	288	288	288
10	288	432	288	0	288
11	288	432	288	288	288
12	288	432	288	288	288
13	288	432	288	288	0
14	288	432	288	288	288
15	288	432	288	288	288
16	288	432	288	288	288
17	288	432	288	288	0
18	288	432	288	288	288
19	288	432	288	288	288
20	288	432	288	288	288

Appendix C.3 Irrigated crop acreage in Rotation PWCaCe-Alf (Acre)

Year	P (Irrigated)	W (Irrigated)	Ca (Irrigated)	Ce (Irrigated)	Alf (Irrigated)
0	288	432	432	288	0
1	288	432	288	288	288
2	288	432	288	288	288
3	288	432	288	288	288
4	288	432	288	0	288
5	288	432	288	288	288
6	288	432	288	288	288
7	288	432	288	0	288
8	288	432	288	288	288
9	288	432	288	288	288
10	288	432	288	0	288
11	288	432	288	288	288
12	288	432	288	288	288
13	288	432	288	0	288
14	288	432	288	288	288
15	288	432	288	288	288
16	288	432	288	0	288
17	288	432	288	288	288
18	288	432	288	288	288
19	288	432	288	0	288
20	288	432	288	288	288