RESOURCE ECONOMICS AND ENVIRONMENTAL SOCIOLOGY

Beneficial Management Practice (BMP) Adoption – Direct Farm Cost/Benefit Tradeoffs

Dawn Trautman, Scott Jeffrey and Jim Unterschultz

Project Report #12-02

Project Report

UNIVERSITY OF ALBERTA
DEPARTMENT OF RESOURCE ECONOMICS
AND ENVIRONMENTAL SOCIOLOGY

Beneficial Management Practice (BMP) Adoption – Direct Farm Cost/Benefit Tradeoffs

Dawn Trautman, Scott Jeffrey and Jim Unterschultz

Project Report # 12-02
(Final Report for Agricultural Funding Consortium
Project 2009F018R)

Authors

Dawn Trautman is a research assistant, and Scott Jeffrey and Jim Unterschultz are professors, in the Department of Resource Economics and Environmental Sociology, University of Alberta.

Acknowledgements

Research funding for this project was provided by Alberta Crop Industry Development Fund (ACIDF) and Alberta Pulse Growers (APG). The authors would also like to thank Karla Bergstrom, Dale Kaliel, Rob Dunn, and Lawrence Papworth at Alberta Agriculture and Rural Development for data and input.

Abstract

Monte Carlo simulation was used to examine the on-farm economics from adoption of Beneficial Management Practices (BMPs) on four representative Alberta cropping farms. Adoption of shelterbelts, buffer strips, residue management, and the addition of annual and perennial forages, field peas, and oats in crop rotations were included as BMPs that contribute positively to Ecological Goods and Service production from agriculture.

Results suggest positive on-farm benefits associated with perennial forage and field pea BMPs. Conversely, BMPs that reduce availability of land for cropping activities, such as shelterbelts and buffer strips, and BMPs that do not increase revenues, such as oats and annual forages in rotation, are costly to producers. The results presented and discussed in this report have important policy implications. Policy mechanisms that incorporate positive mechanisms may improve adoption of BMPs that are costly to producers, while extension mechanisms, such as information programs, may improve the adoption of economically feasible BMPs.

JEL codes: C15, Q12, Q15, Q24, Q25, Q28, Q57

Keywords: representative farm analysis, cropping economics, Monte Carlo simulation, BMP, ecosystem services, net private benefits

Table of Contents

List of Tables

List of Figures

List of Acronyms

AAFC – Agriculture and Agri-Food Canada
AARD – Alberta Agriculture and Rural Development
ADF – Augmented Dickey-Fuller
AEPB – Agri-Environmental Policy Bureau
AESB – Agri-Environment Services Branch
AFSC – Agricultural Financial Services Corporation
AIC – Akaike Information Criterion
ANPV – Annualized Net Present Value
ANS – Allowable Net Sales
AOPA – Agricultural Operations Practices Act
APF – Agricultural Policy Framework
ARR – Accounting Rate of Return
BMP – Beneficial Management Practices
BRM – Business Risk Management
CCPP – Cover Crop Protection Program
CLT – Central Limit Theorem
CML – Capital Market Line
CPI – Consumer Price Index
CSC – Crop Sequence Calculator
CWB – Canadian Wheat Board
DUC – Ducks Unlimited Canada
ECSWCC – Eastern Canada Soil and Water Conservation Center
EFP – Environmental Farm Plan
EG&S – Ecological Goods & Services
ELS – Entry Level Stewardship
EPEA – Environmental Protection and Enhancement Act
FCC – Farm Credit Canada
FEMS – Farm Environmental Management Survey
IRR – Internal Rate of Return
KPSS – Kwiatkowski-Phillips-Schmidt-Shin
MAFRI – Manitoba Agriculture, Food, and Rural Initiatives
MNCF – Modified Net Cash Flow
MSUE – Michigan State University Extension
NPKS – Nitrogen-Phosphorus-Potassium-Sulfer
NPV – Net Present Value
NRCBA – Natural Resources Conservation Board Act
OLS – Ordinary Least Squares
PFRA – Prairie Farm Rehabilitation Act
PM – Production Margin
PP – Payback Period
PSP – Prairie Shelterbelt Program
RM – Reference Margin
SAF – Saskatchewan Agriculture and Food
SAGES – Sustainable Agriculture Environment Systems
SC – Schwartz Criterion
SIP – Spring Insurance Price
SPE – Spring Price Endorsement
SUR – Seemingly Unrelated Regression
TSX – Toronto Stock Exchange
USDA – United States Department of Agriculture
VAR – Vector Autoregression
VPB – Variable Price Benefit
WAAF – Western Australia Agriculture and Food
WTA – Willingness to Accept

Chapter 1: Introduction

1.1 Background

Agricultural practices can have a variable impact on the surrounding environment and these impacts are often experienced at the societal level. Well managed agricultural lands provide more than food; they provide improved water quality, carbon sequestration, wildlife habitat, reduced soil erosion, and recreational opportunities (AAFC, 2001; DUC, 2006). As demand for land and water resources increases with population and economic growth it is essential that farmers and society use these resources with care (AARD, 2004-a). Efficient use of resources in agriculture protects and prevents degradation of natural resources while providing society with natural capital (DUC, 2006). Natural capital, the stock of natural ecosystems that yields ecological goods and services (EG&S) such as food production, materials for manufacturing and improved air and water quality, is essential to the economy (DUC, 2006). EG&S are the benefits humans derive from the services provided to ecosystems (Costanza et al., 1997).

Agricultural production can contribute to EG&S through the implementation of on-farm Beneficial Management Practices (BMPs). BMPs are practices that are beneficial to the environment and at the same time, practical for producers and meet or exceed legal requirements (AARD, 2004-a). Adoption of agricultural BMPs can result in increased environmental benefits and/or mitigate the negative environmental impacts from agricultural production (DUC, 2006). Agriculture and Agri-Food Canada (AAFC) recognize three general categories of agricultural BMPs: reducing inputs, controlling erosion and runoff, and barriers and buffers to intercept and contain contaminants (AAFC, 2000). Examples of agricultural BMPs include fertilizer/nutrient management, strip cropping, shelterbelts, buffer strips, cover crops, crop residue management, and conversion of cropland to permanent forage. These practices all contribute in some way to the supply of EG&S in ecosystems where agriculture plays a significant role.

Since healthy, diverse habitats provide economic and quality of life benefits for farmers and rural communities it is worthwhile to protect and preserve them (AARD, 2004-a). However, pressure to be competitive in the agricultural industry often results in extensive use of practices such as the cultivation of marginally productive lands and wetland drainage, and the higher use of agricultural chemicals, all of which contribute negatively to EG&S (DUC, 2006). When this happens, costs are incurred by society, such as increased water treatment costs, increased government payments, increased illness and healthcare costs due to decreased air and water quality, and increased costs for agricultural production (DUC, 2006). To correct for these externalities, governments may introduce policies to encourage the adoption of BMPs among producers or penalties for producers who are not meeting obligatory standards for management practices.

1.2 Economic Problem

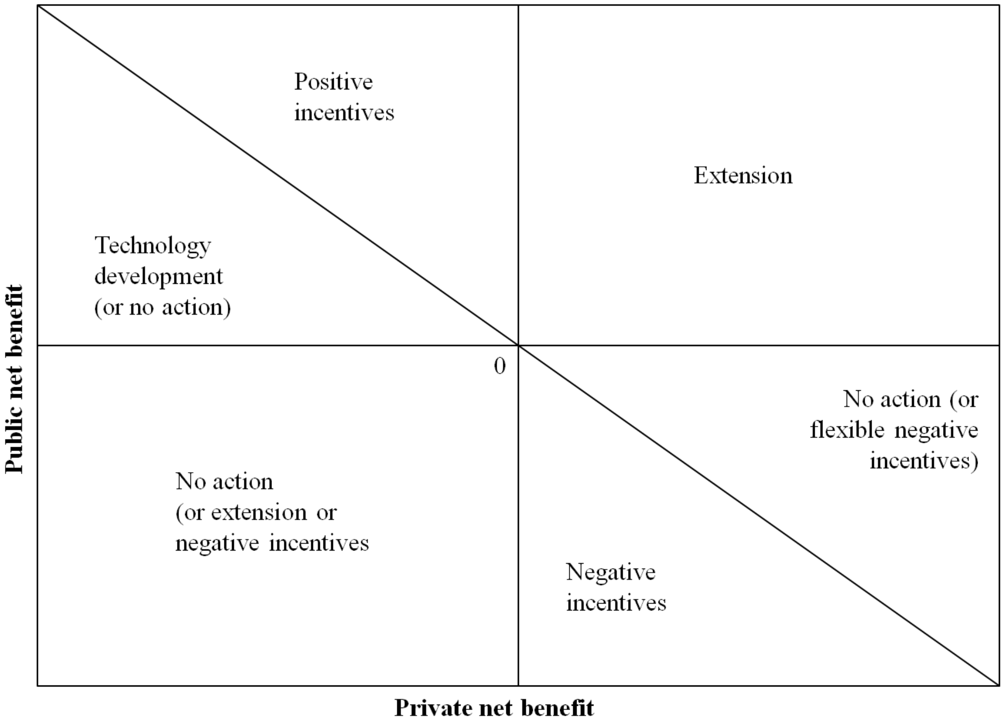
For the purposes of this project it is assumed that producers are rational economic agents. While it is not always the case in reality that farmers minimize costs or maximize profits it is assumed that they act in an optimal way given labour, land, and financial constraints and unpredictable events. Therefore, producers provide an optimal level of EG&S, given their objectives. However, the optimal level of EG&S production from a producer perspective may be lower than what would be optimal from society's perspective. In this case, further adoption of BMPs to provide additional EG&S is not beneficial for producers and would likely result in net direct costs to producers. Previous research has shown that many BMPs come at a net cost to producers, such as lost agricultural land base and increased management costs (Cortus, 2005; Koeckhoven, 2008; Kort, 1988).

If BMP adoption is associated with a net cost for producers it is likely that policy intervention will be necessary for increased adoption to occur, with increased EG&S production as a consequence. Environmental issues have become one of the main factors driving policy decisions at the international, national, and provincial levels as human actions are linked to climate change and global warming (Toma and Bouma Management Consultants, 2007). Policy mechanisms to encourage change include programs and incentives that educate, increase awareness, provide regulation, subsidize, or use technology transfer for private land owners (Pannell, 2008).

The optimal type and degree of intervention should be based on relative costs and benefits associated with the resulting outcomes. One possible framework for examining this question is provided by Pannell (2008). Pannell's framework suggests that policy decisions should be made based on the relative levels of private net benefits and public net benefits associated with the resulting land use change or production practice, where private benefits represent the direct impact on the agricultural producer and public benefits correspond to the effect on society as a whole. Both private and public benefits may be positive or negative (i.e., the net effect may be a cost).

The resulting policy framework is illustrated in Figure 1.1 (Pannell, 2008). In this figure private net benefits for a land use change (horizontal axis) may be positive (right hand quadrants) or negative (left hand quadrants). Similarly, public net benefits (vertical axis) may also be positive (upper quadrants) or negative (lower quadrants). Pannell's policy framework suggests that the appropriate environmental policy depends on whether public/private benefits are positive/negative as well as the relative absolute magnitude of those benefits. Policy mechanisms could include positive and negative incentives, such as subsidies and taxes when the public net benefit is greater than the private net cost or when the public net costs are greater than the private net benefits, respectively. Other policy mechanisms could include education programs where the BMP is beneficial to both society and producers but the practice is not yet known to producers. A full discussion of this framework is provided in Pannell's (2008) paper.

Figure 1.1 – Classes of policy mechanisms for different levels of public and private benefits



Source: adapted from Pannell (2008)

Applying this framework to the economic problem in the current study, the public benefit is the potential value of increased EG&S production resulting from adoption of cropping BMPs. In identifying an appropriate policy response, this public benefit should be compared to the private benefit which is the direct financial impact of BMP adoption for crop producers. As suggested above, in many cases adoption may result in a net cost, which represents a negative private benefit. Quantitative estimates of these benefits, both public and private, are often lacking in many previous studies. This represents the economic problem addressed by the analysis in this report.

Literature on adopting BMPs in agricultural production to improve or create additional EG&S is relatively new and incomplete. In some cases, practices that have been used on farms for many years, such as shelterbelts, are now being recognized as potential BMPs. Other practices, such as zero-tillage seeding, have emerged (relatively) more recently due to technological innovation. Much of the current literature on this subject area describes the costs and benefits of BMP adoption in a qualitative manner. Other studies have quantified the costs and benefits using dynamic simulations, opportunity costs methods, and direct measurement of actual farming practices. This research proposes to quantify the benefits and costs of agricultural BMP adoption, accounting for stochastic events in agriculture and incorporating the assumption that producers will optimize production decisions based on current information.

1.3 Research Problem and Objectives

The purpose of this study is to quantify and evaluate the economic performance of representative Alberta crop farms with and without the adoption of BMPs.

Specifically, the objective of the study is to evaluate the private economic costs and benefits associated with adoption of alternative BMPs for a set of representative Alberta farms. The motivation of the study includes determining quantifiable estimates of the net cost or benefit associated with BMP adoption for producers. The approximations from the study will be useful to both producers for making informed decisions and producer organizations in estimating sector impacts when consulting with government in policy development.

This study will also assess alternative BMPs in terms of the direct economic impact for producers. The results from this analysis are again useful to producers in providing estimates of the incentives required to make BMP adoption feasible. In addition to producers, policymakers will find this element of the analysis relevant in terms of identifying optimal policy instruments to ensure the appropriate mechanisms are used to encourage producers to adopt BMPs.

1.4 Organization of the Report

In addition to the introductory chapter, there are six subsequent chapters in this report. Chapter 2 provides a detailed look at BMPs in agriculture. This chapter discusses the background information of the issues the research problem in this report will address. The difficulties in implementing BMPs on crop farms and the currently measured economic costs and benefits of adopting BMPs will be discussed. This chapter will also provide an overview of the BMPs of interest for this project and how BMPs contribute to the production of EG&S. A review of previous BMP studies is also provided.

Chapter 3 will provide an overview of agriculture in the regions of the representative farms. Specifically current adoption of BMPs in Alberta will be presented. Chapter 3 will also present results from agricultural data at the provincial and county level. For instance, the average farm size, crops grown and farming practices used will be discussed. This chapter also begins the methodology as to how each representative area is chosen, based on statistical agricultural activity.

In Chapter 4 a detailed description of the representative farms and the simulation model is given. The characteristics of the representative farms are given here as well as the simulation model structure which includes stochastic crop yield and crop price models. Chapter 4 outlines the economic relationships to be included in the final models to determine the effect of BMP adoption. Scenarios are developed and sensitivity analyses are discussed in this chapter. Chapter 5 presents the results and provides discussion of the modelling introduced in Chapter 4.

The final chapter, Chapter 6 will draw conclusions from the results presented in Chapter 5. These conclusions will determine the potential net benefit or cost to producers and how this impact affects producers and policy decisions. This chapter will then conclude with model limitations and future research that could be extrapolated from this study.

Chapter 2: Beneficial Management Practices and Agriculture

This chapter provides an overview of the issues and existing literature related to Beneficial Management Practices (BMPs) and agriculture in Alberta. The objective of the chapter is to use past studies and literature to identify areas of concern in agricultural practices and identify suitable BMPs to address the concerns. From this, BMPs can be analyzed based on the need for further research as indicated from past studies. This chapter summarizes what BMPs are, how they are relevant for agricultural operations, explores relationships between BMPs and ecological goods and services (EG&S), and examines how BMPs are implemented. Following this, a discussion of findings from BMP related studies and simulation modelling studies is presented.

2.1 Ecological Goods and Services

Ecological systems provide ecological goods and services (EG&S), which are the valued goods and services humans get from nature (Constanza et al., 1997; Daily, 1997). Agricultural practices affect surrounding ecological systems, which can then affect agricultural productivity and societal well-being through changes in the production of EG&S (Dale and Polasky, 2007). EG&S can be classified into four general categories: provisioning, regulating, cultural, and supporting services (Zhang et al., 2007). Provisioning includes providing food, fiber and fuel; provisioning services are often optimized at the expense of environmental conditions (Ruhl, 2008). Regulating services maintain the balance of systems at levels that allow human survival, and include climate, water quality, and disease regulation (Swinton, 2008). Cultural services include recreational and spiritual human activities. Supporting services allow the previous three services to be possible by enabling organic matter and nutrient cycling, soil formation, photosynthesis, and other services. It should be noted that some agricultural production practices result in “dis-services”, or reduced levels of EG&S production. For example, some practices may reduce productivity (e.g., competition among species for water and nutrients) or increase production costs (e.g., increased use of fertilizers in marginally productive soils) (Zhang et al., 2007).

EG&S that contribute to the success of managed agricultural systems include soil structure and fertility, pollination, water provision, and genetic diversity. Soil fertility is essential for agricultural productivity. Soil structure and fertility can be maintained with soil organic matter, soil carbon, and nutrient cycling (Swinton et al., 2007; Zhang et al., 2007). Carbon provides energy for invertebrates and microbes that allow the release and fixation of nutrients (Swinton et al., 2007; Zhang et al., 2007). Non-crop plants, such as cover crops, contribute to soil fertility by reducing soil erosion (as compared to summerfallow) and replenishing nutrients (Sullivan, 2003; Zhang et al., 2007). Seeding riparian areas to greencover or buffer zones further reduces erosion and improves soil fertility and structure (Blanco and Lal, 2008).

Agriculture depends on EG&S such as soil formation, nutrient cycling, and pollination, but the benefits from many EG&S have no direct value to the private producer (Swinton et al., 2007). Provisioning services are valued through commodity markets and as such producers have incentives for efficient production of these services. Crop and livestock production are the best quantified services provided from agriculture, as production benefits are typically proportional to the amount of effort extended (Dale and Polasky, 2007). However, in considering EG&S that provide regulating, cultural, and supporting services, they are either not fully captured in the commercial market, or there is no explicit market for these services (Costanza et al., 1997; Tilman et al., 2002). As such there are no private incentives for these services to be produced (Ruhl, 2008; Zhang et al., 2007). Many EG&S that are considered regulating services are only currently measured qualitatively. Currently there are no market based methods for measuring the private or social benefit of non-provisioning services (Dale and Polasky, 2007; Rae, 2007). In addition, most EG&S are specific to locations, making it difficult to define a market for such services (Kroeger and Casey, 2007). As such, farms tend to produce more provisioning services than regulating services, even though they are capable of producing multiple services (Ruhl, 2008).

To an extent the private cost of land reflects the supply of EG&S in terms of soil fertility and depth, as this relates to higher yields and production value for producers (Swinton et al., 2007). However this value does not consider EG&S provided at a societal or global scale. Since these types of EG&S benefit many people there is a lower incentive to produce them privately (Swinton et al., 2007). This creates a common pool resource problem at higher scales (Zhang et al., 2007). Producers are faced with the problem of all "public goods" in that they are non-rival and non-exclusive (Kroeger and Casey, 2007; Ruhl, 2008) and neighbouring producers can benefit from the actions of another. While market mechanisms work well for guiding supply decisions for provisioning services, the benefits associated with many EG&S are public in nature (Farber et al., 2002), providing benefit to producers and society at different scales. Since many policies do not consider coordinated behaviour among crop producers (Swinton et al., 2007), this promotes the problem of under-supply of EG&S at larger scales. Also a single producer who reduces environmentally damaging actions, such as high levels of nitrogen fertilizer application, would improve surrounding environments, but this could occur at the cost of lower yields and profit; the benefit of improving the surrounding environment has no direct benefit to the farm (Tilman et al., 2002). Appropriate policies may therefore be needed to balance the trade-offs between private financial gains and social losses from alternative management choices (Zhang et al., 2007)

2.2 Beneficial Management Practices and Environmental Issues in Alberta Crop Production

There are various definitions of what constitutes a BMP. Boxall et al. (2008) define an agricultural BMP as an agricultural management practice that "ensures the long-term health and sustainability of land related resources used for agricultural production, positively impacts the long-term economic and environmental viability of the agricultural industry, and minimizes negative impacts and risk to the environment" (p. 5). BMPs improve soil, water, air, and wildlife habitat, contributing to farm profitability and environmental quality (AARD, 2004-a). Benefits of on-farm BMPs also extend to societal benefits, such as improved water, air, and wildlife habitat quality in areas surrounding farming operations.

BMPs are seen by some as a means by which to increase agricultural production of EG&S. However, agricultural BMPs have a cost, whether in terms of time or money or both (Brethour et al., 2007). For adoption to occur it is assumed that producers would perceive the benefits to outweigh the costs of adoption, whether it be occurring from the practice itself or through policy programs. Before further analysis on the adoption of BMPs it is necessary to determine what types of practices qualify as BMPs and how these practices can be adopted.

Agriculture and Agri-Food Canada (AAFC) recognize three general types of BMPs: reducing inputs, controlling erosion and runoff, and barriers and buffers (AAFC, 2000). Within these categories, there are over 30 specific BMPs that are recognized by the Canadian Federal-Provincial Farm Stewardship program (AAFC, 2006). The following sub-sections discuss the BMPs considered to mitigate negative impacts of agriculture on water and soil quality. While there are numerous other BMPs that could be considered the practices discussed represent the scope of this project.

2.2.1 Beneficial Management Practices and Water Quality

Crop production can contribute pollutants to water, including excess nutrients, sediments and pesticides. Water contaminants can be transported to surface water or groundwater through various means. Transport of contaminants to surface waters typically occurs when there is a high risk of soil erosion and runoff into surrounding surface water sources. Contamination of groundwater often occurs when there are high infiltration rates.

Nitrogen and phosphorus are essential nutrients for plant growth and crop production (AARD, 2004-a; McRae et al., 2000). Both are also components of chemical fertilizers, manures and decomposing crop residues. However, after fertilizers are applied to cropland, the residual components can be transported to surface water and groundwater through runoff and leaching. Once nitrogen and phosphorus have reached a source of water, elevated levels of the nutrients decrease water quality by promoting growth of aquatic plants and algae; this process is known as eutrophication (McRae et al., 2000). This effect is particularly observed for phosphorus where after algae and aquatic plants have absorbed the excess phosphorus they begin to decompose. During plant decomposition dissolved oxygen is used which contributes to increased rates of aquatic animal death. While this effect is not as prevalent for excess nitrogen the water soluble form of nitrogen, nitrate, is harmful to humans when consumed in excess. Nitrate can be leached into groundwater beneath lands where intensive agriculture is practised.

Sediment transfer, often due to soil erosion and runoff, to surface waters occurs in a similar manner. Increased sediment in surface water negatively affects the quality of water and is harmful to aquatic species. Sedimentation of surface waters can damage fish eggs and other aquatic larvae (AARD, 2004-a). High levels of sediments suspended in waters also decrease the amount of light penetration which affects the growth of bottom dwelling aquatic plants (AARD, 2004-a). When this occurs there can be an increase in the prevalence of algae, which is similar to the problem of excess phosphorus.

Another contributing factor to decreased water quality in areas of intensive agricultural practices is pesticides. Pesticides can move into surface water or ground water by being dissolved in water, attached to soil particles, or as a result of spray drift (AARD, 2004-a). When pesticides are present in water sources, problems that occur include bio-concentration, where pesticides concentrate in the tissues of affected organisms, and biomagnification, where the concentration of pesticides increases in species as it travels up the food chain (AARD, 2004-a). This is harmful to species diversity surrounding agriculture, but may also be harmful to humans as well.

The quality of water in areas of intense agricultural activity can be improved using BMPs. Many of the problems mentioned above occur due to the transportation of nutrients, sediments and pesticides to water supplies through runoff. Buffers around surface water trap some nutrients, sediments, and pesticides and improve overall water quality. Also areas at higher risk of water erosion contributing to runoff into surface waters typically have low levels of soil organic matter. High levels of soil organic matter hold soil particles together, reducing the risk of erosion, which can contribute to sedimentation and contamination of water bodies. Therefore BMPs such as residue management can improve water quality from runoff.

Crop rotation adjustments as BMPs are also considered. Adding alfalfa hay provides a semi-permanent cover on the land which reduces the amount of runoff that may occur during freeze-thaw cycles in the spring when the land is between annual crops. Also, alfalfa hay and other leguminous crops, including field peas, can fix nitrogen. As a result fewer inputs in the years these crops are grown, and potentially following these crops, are necessary. This reduces the amount of nutrient inputs on the land and as such there is likely a lower incidence of nutrient runoff entering aquatic ecosystems. Alternative crops, such as oats, require fewer herbicide inputs, which decreases the risk of chemicals entering waterways via runoff.

2.2.2 Beneficial Management Practices and Soil Quality

Intensive cropping practices also affect soil quality. Soil quality can be considered in terms of the levels of soil organic matter, soil salinity and soil acidity. A related factor in obtaining reasonable levels of organic matter and good overall soil quality in agricultural soils is erosion. Soil quality is correlated with agricultural production, and as such practices that degrade soil quality contribute to reduced agricultural production.

Soils that are high in organic matter have their soil particles held together better. This reduces the risk of erosion from both water and wind (AARD, 2004-a). Crop rotations that contain perennial forages, especially legumes (e.g., alfalfa), result in soils with higher levels of organic matter due to increased levels of retained residue. Crop rotations where summerfallow frequently occurs reduce soil organic matter over time because less plant residue is returned to the soil (AARD, 2004-a). Including crops that improve soil organic matter reduces erosion to an extent. However, wind erosion can be reduced further using shelterbelts and windbreaks while water erosion can be reduced using surface residue management. Additionally, practices such as no-till or zero-till seeding techniques can improve soil organic matter and reduce erosion.

Plant growth is affected by the salinity and acidity of soils as these issues affect the ability of the plant's roots to function efficiently (McRae et al., 2000). While soil salinity is somewhat naturally occurring, poor management practices can intensify this problem (AARD, 2004-a). High soil salinity results in poor plant growth due to excess salts in the plant's root zone. While also affecting plant growth, soil acidity inhibits the ability of microorganisms in the soil, such as nitrogen fixing bacteria that are present on leguminous plants (AARD, 2004-a). Fertilizer application can increase the acidity of the soils, so reducing inputs by including more crops that are able to provide a supply of nitrogen for subsequent crops, such as alfalfa hay and field peas, is beneficial.

2.3 Beneficial Management Practices of Interest

This section discusses BMPs of interest for the regions in Alberta being examined. As noted earlier, there are many practices that could be considered as BMPs for adoption in cropping operations. Just as some EG&S are specific to spatial areas, BMPs are chosen based on the suitability to the regions and vary slightly between regions.[1] BMPs considered include variation of the crop rotations to include forages, field peas, cover crops, and oats, as appropriate by region. Non-rotational BMPs considered

---

[1] BMPs for each region (i.e., each representative farm) are chosen based on the relevance of the BMPs in addressing an environmental concern in the area of interest, and the feasibility of the BMPs themselves.

include shelterbelts, buffer strips, and residue management, which are considered at varying degrees again, as appropriate by region.

2.3.1 Crop Rotation Beneficial Management Practices

Effective crop rotations reduce diseases, insect pests, and weeds (AARD, 2008-b; Johnston et al., 2005). Crop rotation systems can reduce dependence on external inputs through internal nutrient cycling, maintenance of the long-term productivity of the land, and breaking weed and disease cycles (Gebremedhin and Schwab, 1998). Criteria taken in choosing crop rotations include the impact of specific crops on soil fertility, environmental quality, and farm profitability (Gebremedhin and Schwab, 1998). Crops of interest that are considered BMPs for this project include alfalfa, field peas, legume green manures, and oats. It is assumed that farms have base rotations and the BMP crops are added to these rotations. Rotating cereals with broadleaf crops, such as oilseeds or pulses, improves weed control without increasing the risk of herbicide resistance and can break most disease cycles (AARD, 2004-a). Further information on the base and BMP crop rotations is provided in Chapter 4.

2.3.1.1 Alfalfa in Crop Rotations

Alfalfa is a member of the flowering legume or pulse (*Fabaceae*) taxonomic family, and is a commonly grown forage crop for use as livestock feed. Alfalfa is also important as a crop that can help to achieve broader social goals (Putnam et al., 2001). Putnam et al. (2001) outline several benefits of growing alfalfa. Introducing alfalfa hay to crop rotations has the potential to protect soil from erosion due to the perennial nature of the crop. Protection from erosion leads to reductions in sediment loss into waterways, and improves water quality. The ability of alfalfa to fix atmospheric nitrogen leads to a reduction in the need for added fertilizers. By reducing the fertilization of crops there are energy savings through reduction in inputs and energy required to run machinery used for applying fertilizer. Reducing chemical inputs also improves the soil structure and reduces the amount of chemical that is leached into groundwater and the amount that enters surface water through runoff. Many mammal and fowl species, including endangered species, make their homes in alfalfa fields. Alfalfa fields are a source of insect diversity, which includes beneficial insects that control other pest insects found in crops. Seeding land to a perennial crop such as alfalfa also provides aesthetic value and open spaces, which are valued for both their use and non-use (or passive use) values by humans.

Hoyt and others (e.g., Hoyt, 1990; Hoyt and Hennig, 1971; Hoyt and Leitch, 1983) have conducted experiments to examine crop yields with and without the presence of perennial forage crops. Hoyt and Hennig (1971) conducted experiments in northern Alberta where wheat was grown continuously after forage crops, including alfalfa, bromegrass and red fescue, or a fallow year. Yields of wheat crops were 71, 82, 75, and 68% greater in the first, second, fourth and fifth year following alfalfa, respectively, as compared to the wheat crops following summerfallow with no additional fertilizers applied.[2] For wheat crops following bromegrass or red fescue forages the yields were comparable to yields following fallow practices. Hoyt and Hennig (1971) found an average yield benefit of 93% for wheat crops following alfalfa, as compared to wheat crops following other grasses, and conclude that legume crops benefit succeeding crops more than do grasses.

---

[2] There is no recorded yield in the third year for Hoyt and Hennig's (1971) study due to loss from frost.

Hoyt and Leitch (1983) examined the effect of forages, including alfalfa, birdsfoot trefoil, alsike clover, red clover, and sweet clover, on subsequent barley yields in multiple regions in Alberta, as compared to yields following fallow practices. In three of the five regions studied barley yields were higher following the legumes when no additional fertilizer is applied, as compared to barley yields following fallow. In the remaining two locations there was no significant difference between barley yields following legumes or fallow. The authors also found moisture levels to be approximately the same in subsequent barley crops following both legumes and fallow. Due to significant yield increases in three of the five locations the authors concluded that including legumes that are used as hay crops (i.e., only the top layer is removed, retaining the roots) in rotation should generally be beneficial to grain crops, particularly in the Peace River region of Alberta.

A similar study by Hoyt (1990) found that the yield benefits to wheat crops following alfalfa extended up to thirteen years after the alfalfa stand is broken up, as compared to wheat following summerfallow. For the first eight crops of wheat following alfalfa, yields ranged from 66 to 114% greater than yields for eight years of continuous wheat following a year of fallow. This study also tested the effect of bromegrass and alfalfa mixtures and bromegrass alone on subsequent wheat yields. A bromegrass and alfalfa mixture had similar wheat yield results as alfalfa alone, while bromegrass alone resulted in significantly lower subsequent wheat yields than for the treatments that included alfalfa.

In other studies done in the United States, alfalfa is attributed to higher wheat yields for as long as fourteen years after alfalfa was in the rotation (Kansas Rural Center, 1998). Australian studies on alfalfa show similar yield impacts for subsequent crops. Holford (1980) found beneficial effects, including grain yield, nitrogen uptake and grain protein, on wheat crops following alfalfa, with the greatest effect reached in the second year, as compared to wheat grown after fallow practices. Many studies have reported the nitrogen benefit to crops following alfalfa stands to last up to seven years (Entz et al., 1995).

Holford (1980) also studied the effect of alfalfa stand length on subsequent crop benefits in Australia and found beneficial effects strongest when there are two or more years of alfalfa, with the optimal length being three years for improved wheat yields. Drawing from previous studies Entz et al. (1995) find that the minimum alfalfa stand duration for optimum nitrogen accumulation and weed suppression is two to three years, while the economically optimal alfalfa stand duration is four to five years. A three or four year stand of alfalfa provides the same nitrogen and weed suppression benefits as a six year stand, but according to Entz et al. (1995), Canadian prairie producers are less likely to break a stand of alfalfa after only two or three years due to difficultly in establishing alfalfa stands. Recommended lengths of alfalfa stands are four years in some areas of the United States, with the recommended subsequent crops in rotation being corn and small grains (Kansas Rural Center, 1998). Environmental benefits from including alfalfa in crop rotations can be improved by increasing the frequency with which this crop occurs in rotation and decreasing the length of the stand (Entz et al., 1995). The economics of reducing alfalfa stand length can be addressed with proper management of previous and subsequent crops. For example, in managing alfalfa in rotations it is best to follow alfalfa stands with a drought resistant crop (Kansas Rural Center, 1998). In preparing for seeding alfalfa a crop of wheat or oats in the same year helps establish young alfalfa plants (Kansas Rural Center, 1998).

One of the greatest benefits of growing alfalfa is the nitrogen fixing ability of *Rhizobium* bacteria in the roots of this crop (Hoyt and Hennig, 1971). However, considering that yield benefits are consistently seen five years following alfalfa it is likely that other benefits occur, such as increased permeability of soils due to the root systems in alfalfa (Hoyt and Hennig, 1971). Alfalfa stands contribute to grain yield increases from nitrogen contribution in the topsoil and subsoil, as well as rotational benefits from weed suppression (Entz et al., 1995; Holford, 1980; Hoyt, 1990; Hoyt and Leitch, 1983). While there are other non-nitrogen benefits of including alfalfa hay in rotation, including reduction of crop disease and soil structure improvements, this study considers yield changes following an alfalfa hay crop and potential fertilizer reduction from residual soil nitrogen following alfalfa as the beneficial effects of including leguminous forages in rotation.

2.3.1.2 Field Peas in Crop Rotations

The benefits of including pulse crops in crop rotations are well documented (Adderley et al., 2006; Lafond et al., 2007; Soon et al., 2004; Stevenson and van Kessel 1996). Field peas, as a member of the legume family are able to convert nitrogen gas into a form useable by plants. However, even with rotational benefits there must be market demand for producers to include this crop in rotations. Field peas are rich in protein, lysine, and starch, and are able to provide essential nutrients and energy to animals, making this crop a good source of animal feed (Lafond et al., 2007). Peas are generally less competitive with weeds and suffer greater yield losses in high risk years, as compared to barley or canola (Soon et al., 2004). However, studies have found that including pulse crops in rotation with cereal grains and oilseeds contributes to a higher and more stable net farm income, despite increased expenditures for inputs (Zentner et al., 2002).

Yields following field peas are often higher, as compared to cereal crop yields following cereal crops, due to improved nitrogen stores in the soil. Field peas have similar abilities as alfalfa, as both are leguminous crops, to fix atmospheric nitrogen. Some of the other, non-nitrogen benefits of alfalfa hay also transfer to field peas, including diversification of crops reducing weed species and crop diseases (AARD, 2008-e). There are direct and indirect benefits of including a pulse crop in rotation with cereal and other broadleaf crops. Direct benefits refer to the nitrogen dynamics in the soil as a result of pulse crops, while the indirect benefits refer to the positive effect of pulses for reducing root and leaf diseases in subsequent crops (Lafond et al., 2007).

Lafond et al. (2007) conducted a study comparing continuous cropping of field peas with a rotation involving field peas and wheat. They found that continuous field peas resulted in yield reductions, as compared to rotations that had at least one year of wheat in between pea crops. While yields were unaffected by only having one or two years between pea crops, root rot and seedling diseases did become a factor if peas were grown too frequently. However, the disease issue was eliminated when there was a four year break between field pea crops. Hamel et al. (2007) also conducted a study in 2004 and 2005, comparing durum wheat yields following chickpeas, peas, lentils, and durum wheat. Durum wheat yields were highest following peas, as compared to any of the other crops tested, with yields being the lowest in a monoculture durum wheat rotation (Hamel et al., 2007).

Several studies have looked at the effect of field peas on subsequent cereal crops. Johnston et al. (2005) found that wheat is the best crop choice for pea stubble under drought conditions. Including field peas in annual crop rotations increased the yield and nitrogen uptake for subsequent wheat crops (Entz et al. 1995). A study in Saskatchewan found barley, canola and wheat yields to be 140, 126, and 147%, respectively, of yields for those crops when following peas (Saskatchewan Pulse Growers, 2000). In another Saskatchewan study Stevenson and van Kessel (1996) found wheat yields from six sites to be 43% higher following field peas in rotation, as compared to following wheat in rotation. From the Stevenson and van Kessel (1996) study it was further determined that approximately 8% of the yield increase is attributed to additional soil nitrogen from pea residue, while the remaining 92% is due to non-nitrogen rotation benefits, including reduction of wheat root diseases. Also in Saskatchewan, Adderley et al. (2006) compared spring wheat yields following field peas and lentils. Spring wheat yield and soil nitrogen levels were higher following field peas under conditions of low soil fertility. When soil nitrogen was already high, wheat yields were similar regardless of whether wheat was following field peas or lentil crops (Adderley et al., 2006). Soon et al. (2004) studied the effect of field peas on subsequent barley crops and found higher barley yields following field peas as compared to barley following barley or canola. In contrast to the study by Adderley et al. (2006), Soon et al. (2004) determined that the nitrogen benefit from field peas contributes more to barley yield increases than the rotational effect.

Johnston et al. (2005), looking at crop sequence in rotation, found that diverse cropping sequences, where cereal and broadleaf crops are not seeded on their own stubbles, are the least risky in terms of risk of yield and quality loss. Wheat seeded on pea stubble resulted in the highest grain protein while wheat seeded on wheat stubble resulted in the lowest grain protein, and represented the highest risk rotation (Johnston et al., 2005). Wheat or barley grown after peas or canola usually performs better (i.e., 10% to 20% higher yields) than a cereal grown after a similar cereal crop (AARD, 2004-a). Average yield increase in cereals following pulse crops compared with cereals following cereals is approximately 54%. However, yield increases from 0 to 100% have been reported (Evans et al., 1989).

2.3.1.3 Legume Green Manures in Crop Rotations

The practice of summerfallow in agriculture has historically been used in semi-arid regions of the Canadian prairies to retain soil moisture (AARD, 2008-b; Zentner et al., 2004). However, long term use of this practice, particularly when combined with conventional tillage, has been linked with declines in soil quality due to declines in soil organic matter, increased soil salinization, increased wind and water erosion, and depleted soil nitrogen reserves (AARD, 2008-b; Zentner et al., 2004). Replacing or partially replacing summerfallow with an annual legume green manure crop has been suggested as these crops have potential to protect soil against erosion and increase nitrogen fertility of the soil (Zentner et al., 2004). Previous studies have hypothesized that including legume green manure crops as a partial or complete replacement of summerfallow may be costly in terms of additional seed and annual care costs, but these costs may be offset by long term benefits such as enhanced grain yields and reduced fertilizer costs (Zentner et al., 2004).

Green manuring involves incorporating a forage crop into the soil after flowering occurs (Sullivan, 2003) to maximize nitrogen fixation (Zentner et al., 2004). Summer green manure crops occupy the land for a portion of the growing season and are used to improve soil conditions (Sullivan, 2003). Legumes are frequently used as green manures for their ability to add nitrogen and organic matter to soils (AARD, 2004-a). Nitrogen accumulations from legume crops range from approximately 40 to 220 kilograms of nitrogen per hectare (Sullivan, 2003). Tilling the crop mid-season returns residues to the soil, but it is good practice to leave some of the residue above the soil surface to reduce the risk of erosion (AARD, 2004-a). The addition of organic matter to soil improves soil aggregation, which further benefits soil quality as aggregates reduce risk of soil erosion.

Zentner et al. (2004) tested the impact of replacing fallow with a legume green manure in a three year rotation in the Brown soil zone of Saskatchewan where two years of spring wheat had followed fallow. They undertook a twelve year study in which wheat yields following summerfallow were compared to yields when wheat followed a legume green manure crop. In the study, when legume crops were not terminated before mid-July, soil moisture was affected and lower subsequent wheat yields were observed. However when the legume crop was terminated by mid-July wheat yield following legume green manures was not significantly different from wheat yield following summerfallow. Also, gradual nitrogen fertilizer savings were observed as well as savings from reduced use of tillage and herbicides, as compared to summerfallow practices. It was further determined that these benefits offset the additional seed and management costs associated with legume green manure crops.

Ross et al. (2009) conducted a study in central Alberta (i.e., Black soil zone) where multiple varieties of annual and perennial clovers and non-leguminous crops were ploughed down and followed by barley crops. Two soil types were tested, one with high fertility and the other with low fertility. At the high fertility site the legume green manures had only minor effects on subsequent barley yield or soil nitrate. At the low fertility site almost all clover green manures improved barley yields, with the yield being greater following perennial clovers as compared to annual clovers. Given the differences in between soil zones (e.g., there is less moisture and tends to be lower fertility in Brown soils than in Black soils), extrapolating their results for legume green manures should be done with care.

Hilliard et al. (2002) recommend caution with respect to the use of green manure crops, as depletion of soil water by the cover crop or an inter-crop may increase yield risk, particularly in the Brown soil zone. The authors note that it has been observed by previous studies that summer green manure crops in a year with greater than average precipitation may still lower the yield of the next crop. As mentioned previously, the timing to ensure beneficial green manure crops is critical. Hilliard et al. (2002) note that in trials in the Brown soil zone, planting of legume green manures must be early and the crop should be terminated in July to conserve moisture.

2.3.1.4 Oats in Crop Rotations

Oats are primarily grown as livestock feed, and to a lesser extent for human consumption and seed production. Benefits of growing oats include frost tolerance and high production potential (WAAF, 2007). Oat crops are also more successful on marginal lands (Wilde, 2011), such as lands with high moisture content and acidic soils, as compared to other cereal crops (ECSWCC, 2004). Properties of the crop may improve soil organic matter as there are higher residue amounts from oats, both on the surface and sub-surface root system (ECSWCC, 2004).

While including oats in crop rotations would not be considered by many crop producers as a BMP it is considered as such for this project. Oat crops require only about two thirds of the amount of inputs as other cereal grains (Wilde, 2011). Specifically, wild oat herbicide cannot be applied on oat crops, which implies that oats should only be grown on lands with low incidence of wild oats. Fewer inputs suggest fewer chemicals to leach into groundwater or enter waterways in runoff. Fewer inputs also imply lower costs for producers. Also, the ability of oats to generate higher quantities of residue than some other cereal crops may be beneficial to producers as either revenue if it is removed or as a soil erosion management tool if it is retained.

2.3.2 Non-Rotational Beneficial Management Practices

The non-rotational BMPs considered in this study have the potential to improve crop yields by reducing risk of erosion by wind or water. This directly improves soil condition and quality and may lead to improved yields. BMPs discussed in this section include shelterbelts, buffer strips around wetlands, and crop residue management techniques.

2.3.2.1 Shelterbelts

A shelterbelt is a barrier of trees or shrubs (AARD, 2007-a) that is typically established to reduce soil erosion by wind. While modern agricultural practices, such as zero tillage, have reduced the risk of wind erosion there continues to be significant risk of soil loss due to wind erosion as a result of agricultural practices. This is particularly true for regions of southern Alberta in the Brown and Dark Brown soil zones (i.e., see discussion in Chapter 3).

The primary benefit of shelterbelts is wind reduction. Wind velocity can be reduced over a distance equal to twenty times the height of the trees (AAFC, 2007-b; AARD, 2007-a). Reducing wind velocity by directing wind up off the land with shelterbelts reduces the risk of soil erosion and soil moisture evaporation (Kock, 1990). Field shelterbelts may also increase yield productivity through increased snow retention and by providing protection for crops from damaging weather (i.e., wind and rain) (AAFC, 2007-b). Shelterbelts also provide social benefits, including increased biodiversity and habitat for wildlife, reduced greenhouse gas emissions through storage of carbon dioxide, odour reduction, reduction in pesticide drift and beautification of the landscape (AAFC, 2007-b; AARD, 2007-a; Kulshreshtha and Kort, 2009). However, with the benefits of shelterbelts there are also associated costs, such as the foregone opportunity associated with land taken out of production.

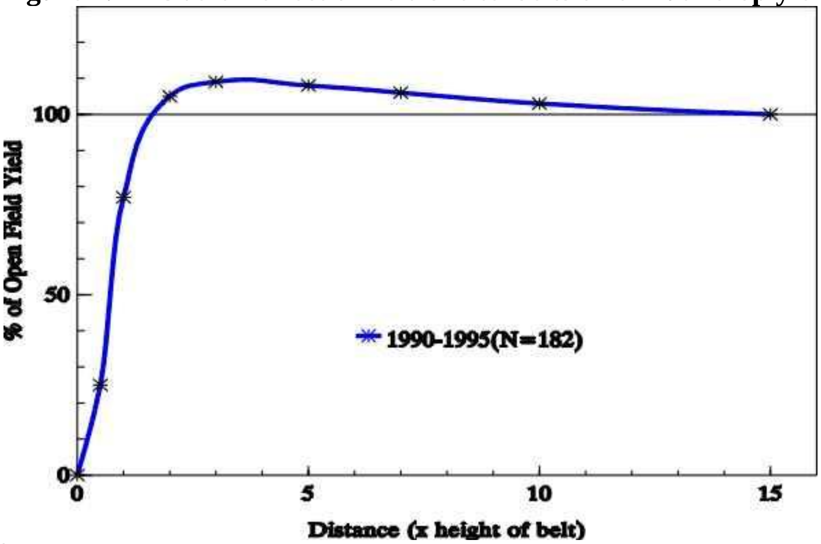
Properly designed shelterbelts prevent or greatly reduce the risk of wind erosion (AARD, 2007-a). Dense thick walled shelterbelts do not reduce wind speed, but rather deflect wind upward temporarily (Kock, 1990). A single row of trees is a more effective shelterbelt as more wind will pass through the trees with resistance, thereby reducing wind speed (Kock, 1990). To provide protection to highly erodible prairie soils up to five to eight single rows of trees per quarter section planted at right angles to the prevailing winds is recommended (AAFC, 2007-b; AARD, 2007-a). However, while several rows per quarter section are recommended, any shelterbelt in the field is beneficial (AAFC, 2007-b).

Since field shelterbelts should be tall and long-lived, approximately 50% to 60% should be foliage from species such as scotch and white pine or spruce (AAFC, 2007-b; Kock, 1990). Taller trees, such as those previously mentioned, are also preferred since the area that can be protected is directly related to the height of the shelterbelt (AAFC, 2007-b). Shelterbelts are planted as young trees that will eventually mature and reach heights up to 15 metres and widths up to 10 metres (AAFC, 2007-b). Therefore, in planning field shelterbelts it is important to account for sufficient space between shelterbelt rows to permit the passage of maintenance equipment in the years immediately after establishment (AAFC, 2007-b). Spacing between trees also allows adequate light, moisture and nutrients for proper growth and establishment of the shelterbelt (AAFC, 2007-b). The cumulative effect of using more appropriate shelterbelt design, and not relying only on dense trees, will produce an agricultural system that is socially and environmentally beneficial (Kock, 1990).

Studies examining the impact of shelterbelts on crop yields have generated mixed results. For example, a study in Ontario found soybean yields increased almost 30% with the use of shelterbelts (Kock, 1990), with the yield increases being attributed to a combination of reduced wind erosion damage, improved snow distribution, and microclimate modification (Kort, 1988). Other studies have found that crop yield response from shelterbelts differs among crops. In a study by Kort (1988) comparing yield responses from the literature, it was found that of crops tested, winter wheat, barley, rye, millet, alfalfa and hay (mixed grasses and legumes) were highly responsive to protection, while spring wheat, oats and corn responded at a lesser degree.

A shelterbelt study was conducted by AARD (2004-b) from 1990 to 1995 in Brown, Dark Brown, Black, and Dark Grey soil zones in Alberta. Crops examined included wheat, oats, barley, peas, canola, and hay. The study also looked at various types of tree species within the shelterbelt, including caragana, poplar, spruce, green ash, willow, and mixed shelterbelts. Overall, the study found a crop yield reduction, as a percentage of the open field yield (i.e., unaffected by the shelterbelt), in the areas directly adjacent to the shelterbelts. In the area outside of this there was an observed yield increase (Figure 2.1). It was determined that yield increases were observed in areas farther from the shelterbelt since the crops were not competing with the trees for moisture and nutrients. Further results from this study are discussed in this report in the context of the assumptions made in modelling shelterbelt adoption for the current study.

Figure 2.1 – Overall effect of field shelterbelts on annual crop yields[a]



[a] N is the number of sites in the study. For the horizontal axis, “Distance” refers to the distance from the shelterbelt measured in terms of the height of the trees.

Source: *Adapted from* AARD (2004-b) *with permission from Alberta Agriculture and Rural Development*

2.3.2.2 Buffer Strips

Buffer strips are corridors of vegetation established around waterways to filter sediment, reduce water runoff, and remove nutrients leaving upland ecosystems (Blanco and Lal, 2008; Crop Nutrients Council, 2004; Hilliard et al., 2002). Buffers can trap over 70% of sediments, over 50% of phosphorus and over 80% of nitrate runoff (AARD, 2004-a; Blanco and Lal, 2008). Buffers can also stabilize eroding banks and soil, bind soil aggregates and increase soil organic matter content (Vanderwel and Jedrych, 1997; Blanco and Lal; 2008). Finally, buffers are potentially important for wildlife habitat and protection of biodiversity (Vanderwel and Jedrych, 1997; Blanco and Lal, 2008).

Buffer strips can be as simple as grassed areas bordering waterways or as complex as an entire riparian zone (Crop Nutrients Council, 2004). For the purposes of this project buffer strips will refer to grassed filter strips around wetlands. Based on the placement of buffer strips they are an interface between terrestrial and aquatic ecosystems, making the functionality of the buffers dependent on both terrestrial and aquatic environments (Blanco and Lal, 2008).

The use of buffer strips has been gaining in popularity (Crops Nutrients Council, 2004), and buffer strips are considered a BMP for water quality management (Blanco and Lal, 2008). However, the adoption of buffer strips is still limited in Canada and the United States due to management and economic constraints (Blanco and Lal, 2008; Toma and Bouma Management Consultants, 2007). A study exploring the net changes in expected farm revenues found that losses occur in all areas considered when buffers are adopted, with the greatest net decrease observed in the Black soil zone in Alberta (Toma and Bouma Management Consultants, 2007).

Hilliard et al. (2002) reviewed previous studies on the sediment trapping ability of vegetated buffer strips. The authors found that early research reported high trapping efficiencies by vegetation, but as flow rates increased effectiveness decreased to a point where it was ineffective in removing sediment. Different buffer widths were required to effectively remove different sized particles. Hilliard et al. (2002) indicated that larger particles, such as sand, were effectively removed with a three metre wide buffer, but silt and clay were only effectively removed with 15 and 122 metre buffer strips, respectively.

While buffer strip width is an important consideration in the design of successful buffer strips, Hilliard et al. (2002) also determined that the height of the buffer strip vegetation may be more important than the strip width. In particular, greater vegetation height resulted in more effective filtering. Simulated erosion models indicated that approximately five and nine metre vegetated buffer strips could remove 63% and 78% of sediment from cropland runoff. Effectiveness of buffer strips varies due to incoming sediment load, flow rate per unit length, vegetation height and density, and filter slope and width (Hilliard et al., 2002).

A study using simulated models of a 60 hectare watershed in central Alberta by Vanderwel and Jedrych (1997) examined the effect of buffer strips on sediment retention. It was assumed in this study that the slope of the watershed ranges from 4% to 7% in upland areas and 16% to 100% in riparian areas. A 20 metre wide buffer strip reduced the sediment leaving the watershed by 11%, while a buffer strip 90 metres wide reduced the sediment leaving the watershed by 38%.

In a study on the economic impact of buffer strip adoption, Sparling and Brethour (2007) concluded that buffer strips reduce expected net revenue on model farms in various regions of Canada. Loss of revenues was attributed to high costs of buffer strip establishment and lost crop production in the area of the buffer. However, their study did not consider the environmental benefits that could be captured from buffer strips, such as reduced erosion, and as a result the benefit of buffer strips may be underestimated.

In a study using Finnish data for nutrient and sediment runoff it was discovered that, based on the private benefits of grassed buffer strips, adoption would not occur unless either producers were paid to establish buffer strips or the BMP was made mandatory; that is, regulated (Lankoski et al., 2006). The Finnish study also examined tillage technology with different crops and found that optimal buffer strip payments depend on the cropping and tillage technologies used by producers (Lankoski et al., 2006).

As is the case for shelterbelt adoption, when designing a buffer zone it is important to identify and account for any issues or problems in order to provide the most benefit (Vanderwel and Jedrych, 1997). This may require determining the appropriate buffer zone width, vegetation types (trees, shrubs, grass) and (if relevant) grazing strategies (Vanderwel and Jedrych, 1997). While the benefits of buffer strips around wetlands, such as top soil retention which improves crop production, aesthetic appearance, and harvest of trees or grass crops are important they are often difficult to quantify in terms of value (Boxall et al., 2008).

2.3.2.3 Residue Management

Crop residues are the materials left over after grain harvest (e.g., straw from cereal crops). Residues can be retained on the field or removed by baling, burning or tillage operations. Retaining crop residues on the field potentially offers many benefits, including increased snow catch and water infiltration, reduced moisture evaporation, increased soil organic matter, improved soil structure and plant nutrient cycling, reduced chance of wind and water erosion, and reduction of some weed species (AARD, 1999-b). Retention of crop residues on the soil surface has a significant effect on soil quality by increasing soil organic carbon, improving soil physical properties, and enhancing microbial activity and biomass (Krupinsky et al., 2007). Removal, incorporation or burning of residues may predispose the soil to erosion (AARD, 2000). Maintaining crop residues is particularly beneficial when combined with direct seeding technology. Standing crop residues have been shown to provide erosion control, soil and water conservation, and lead to higher grain yields (Lafond et al., 2009).

Higher levels of soil organic matter in the top layer of soils improve soil aggregation. Soils with greater aggregation have a lower risk of erosion. Aggregation is important for good soil structure, aeration, water infiltration, and resistance to erosion (AARD, 2000). Soil organic matter improves the aggregation ability of the top layer of soil, and raw plant residues on soil surfaces contribute up to 10% of soil organic matter (AARD, 2000). In Alberta the Brown soil zones have the least amount of organic matter due to lower inputs of plant residues when the soils were developing (AARD, 2000). Therefore, retaining crop residues may be more beneficial in the Brown soil zone. The Black soil zone developed under cooler and wetter conditions, which allowed for more growth and residue to accumulate, leading to higher organic matter levels (AARD, 2000). Excessive cultivation of soils leads to soil organic matter loss. This is a concern as lower levels of organic matter result in declines in crop productivity (AARD, 2000). Reducing summerfallow, incorporating forages into crop rotations, reducing tillage frequency, and returning crop residues to the soil improve the ability to maintain soil organic matter for profitable crop production (AARD, 2000).

Malhi et al. (2006) conducted a four year field study near Star City, Saskatchewan to determine the effect of tillage type and crop residue management on crop yields, nitrogen uptake, carbon removal by cropping, soil organic carbon, and soil aggregation. The study considered scenarios that included conventional and no tillage technologies and the removal versus retention of crop residues. In the study the rotation used consisted of barley, peas, wheat, and canola. There was no seed or straw yield effect from no-till or residue retention for the first three crops. However, in the fourth year, when canola is grown on wheat residue, residue retention increased seed and straw yields of canola by 33 and 19%, respectively. No-till also increased seed and straw yields by 55 and 32% in the fourth year of the study. Total soil organic carbon after four years was greater in the soils for which residue had been retained. Erodible aggregates were lower in plots with no-till and residue retention and large aggregates were more common under this treatment, indicating less potential for soil erosion when tillage practices are removed and residues are retained.

Singh and Malhi (2006) conducted a six year study on Black and Grey soils in Alberta to determine the effect of tillage type and residue management on soil aggregation and infiltration rate. As in the study conducted by Malhi et al. (2006) tillage treatments included conventional and no-till and residue management treatments included straw removal and retention. In the Black soil zone large dry aggregates were higher under no-till with straw retention, and lowest under conventional tillage with straw removal. However, it was concluded that soil aggregation benefited more from no-till practices than from residue retention. Residue retention did improve infiltration rates under both types of tillage in the Black soil zone. In the Grey soil zone tillage types and residue management had no effect on infiltration rate. Conclusions from this study included recommendations for residue management and no-till practices in western Canada in order to improve aggregation of soil particles and reduce the risk of soil erosion.

Krupinsky et al. (2007) conducted a study examining the influence of crop and crop sequencing on crop residue coverage of soils. Crops considered in the study included buckwheat, canola, chickpea, corn, dry peas, grain sorghum, lentils, sunflowers, proso millet, and hard red spring wheat. Of the crop sequences considered in the study, sequences containing wheat, millet and sorghum crops resulted in the greatest amount (i.e., by weight) of crop residues. Their study considered the effect of residue cover after two years, concluding that a first year crop of one of the three previously mentioned crops with higher residue amounts could provide sufficient residue even when the second crop had low or less durable residues (e.g., dry peas or sunflowers). Producers operating on more erodible or marginal soils were advised to grow crops with higher residues in the year before crops with lower residue amounts.

As soil organic matter differs between soil zones, so does optimal management of crop residues. In the Brown and Dark Brown soil zones of Alberta residual stubble is often left to control wind erosion and trap snow (AARD, 1999-b). In the Black and Grey soil zones larger amounts of residue may require more frequent removal to ensure that soils drain and warm in the spring (AARD, 1999-b). Crop residues must be spread evenly and removed or partially removed in some cases to avoid machinery complications, poor seed germination, disease, weed and insect infestations, and cold soils (AARD, 1999-b).

Sidhu and Beri (1988) conducted an experiment examining the effect of chopped and unchopped wheat residues on subsequent grain yields and soil properties. After four years of the study, results showed that wheat residue incorporation into the soil improved soil properties and increased grain and stover yields of subsequent corn crops significantly. However, wheat yields following the incorporation of wheat residues were depressed. This outcome is likely partially due to rotational benefits of including more diversity in crop rotations.

A study of corn and soybean residues in the Midwestern United States found that crop residues can reduce stress on crops, as compared to crops where surface residues are removed (Power et al., 1986). The authors found that increasing amounts of crop residue resulted in reduced maximum soil temperatures during the hot growing season, increased soil water storage, and improved nitrogen uptake ability of crops (Power et al., 1986). This study is specific to a geographical region where the growing season is frequently hot and dry. Therefore retained crop residues improve the growth of the crops by providing more optimal conditions for microbial activity, namely more favourable temperature and moisture conditions.

In general, changes in surface soil condition from crop residue management improve the functioning of cropping systems through increased water storage, reduced soil erosion, and improved nutrient conservation (Krupinsky et al., 2007). Improvements in soil condition through the retention of crop residues increase the resilience of cropping systems to droughts, wet periods, intense precipitation events, and extreme temperatures, all of which are common in the prairie regions of Canada (Krupinsky et al., 2007). However, when high amounts of crop residues are present with high moisture conditions, germination of crops may be delayed or reduced due to lower soil temperatures and excessive moisture.

The amount and distribution of crop residues on and near the soil surface can influence solar energy at the soil surface, the extent of protection against raindrop impact and strong winds, as well as soil biological activity (Singh et al., 1994).Therefore, active crop residue management, where producers determine whether to retain or remove crop residues based on soil conditions, is necessary for economic success of this BMP. The management of crop residue is important because of its implications on soil moisture conservation in the short term, and on soil organic matter content over the longer term (Korol, 2004). With crop residue management, well designed crop rotations are also essential as they determine the type and amount of crop residues present and the rate of residue decomposition (Lafond et al., 2009).

2.4 Literature Review on Analysis of Agricultural Beneficial Management Practice Adoption

The literature reviewed in this section represent studies that examine the economic factors of on-farm BMP or conservation practice adoption. There are numerous studies on BMP adoption that address water and soil quality. Specific issues addressed include nitrogen leaching, pollution abatement for improved soil and water quality, nutrient management, tillage and biodiversity effects.

Houston and Sun (1999) used results from farmer surveys to develop a multi-objective linear programming model to predict crop yields, water-soil pollution emissions, and farmer’s net returns for peanut and corn crop farms in the coastal areas of Georgia, USA. Their study assumes an objective of minimizing water-soil pollution levels. Farmer attitudes towards voluntary participation in government cost share subsidies for pollution abatement as a BMP are also assessed. It was determined a subsidy of approximately $1.01 per hectare would reduce nitrogen leaching by 2.7%, while net returns were reduced by approximately $4.80 per hectare. As farmer and government costs increase, nitrogen leaching from the crop growth process decreases slightly while environmental benefits increase. In this study reducing nitrogen leaching is costly, but the only control of leaching available is through changes in fertilizer applications. The authors note that stricter nitrogen abatement strategies should also consider crop rotation and other practices. It was further determined in this study that producers voluntarily participating in the subsidy program were more risk averse than average and were more likely to accept partial payments for a change in practices that may lead to lower net returns. This study demonstrates the potential of crop rotations to reduce chemical leaching and how policy can affect producer participation in practices.

Non-linear optimization methods were used in a study by Munoz-Carpena et al. (2008) to investigate the impact of summer cover crops on soil percolation and nitrogen leaching. This study used data for southern Florida sweet corn and hemp crops to develop representative simulation models. The model maximizes plant water and nitrogen uptake to simulate plant stress. After three years with a leguminous summer cover crop, organic matter content increased in corn fields. Both observed and simulated hydraulic changes were most apparent in the top ten centimetres of the soil, where increases in organic matter were also more likely to occur. Corn yields and nitrogen uptake increased when cover crops were adopted. However, nitrogen leaching into shallow aquifers also increased, diminishing water quality. While this study was concerned with biological interactions it also discusses the recommendation of combining cover crop practices with reductions in nitrogen fertilizer application rates to account for net increases in soil nitrogen, which is of interest to the current study as a potential BMP.

A study measuring farm level behaviour in response to non-point source pollution was conducted by Taylor et al. (1992). Five representative farms were defined for different geographical regions in Oregon, USA. The farms had crop mixes that included grass, small grain, vegetable, and berry crops. Non-point source pollution is stochastically modelled and is strongly influenced by weather processes (Taylor et al., 1992). This study used biophysical simulation to generate climate and weather data and optimization to measure changes in farm profit. The models maximize profits under alternative non-point pollution control policies using simulated crop yields under different tillage and soil types. To achieve a 50% reduction in total polluted water, profits were reduced by approximately $10 to $36 per hectare. However, only slight changes in operations (i.e., tillage) or application rates of nitrogen were required to attain 5 to 24% pollution abatement.

A simulation model of beneficial management practices for nitrogen fertilization on cereal and vegetable model farms in Germany was developed by Nendel (2009). Crop, soil, and environmental interactions were simulated to determine net returns and the effect of BMPs. Growing a cereal crop after a shallow-rooted and well-irrigated crop, such as lettuce, extracts nitrogen from the soil from below 90 centimetres. Also in all rotations, almost all nitrogen added as a mineral fertilizer is leached out of the system and the crop nitrogen requirements could be satisfied from mineralized nitrogen from soil organic matter and crop residues. This inclusion of specific crop rotations and crop residues has potential to reduce nitrogen fertilization rates, and increase net returns on the model operations, an outcome that is also explored in this study for cropping operations in Alberta.

BMPs to reduce water pollution from agricultural practices were examined by Centner et al. (1999). Crop yields and nutrient flows to ground and surface waters were simulated over 17 years using weather data and site specific characteristics in Germany and the United States. BMPs examined in this study to reduce erosion included cover crops, contour farming and terracing, conservation tillage, streamside vegetated buffers, filter strips and waterways, pasture management, strip cropping, and stream and water body protection. BMPs to reduce pollution from nutrients included nutrient management, irrigation water management, agricultural waste management systems and composting. The costs of agricultural pollution abatement by reducing irrigation and/or nitrogen fertilizer application rates were found to be significant. As a consequence the practices would likely not be voluntarily adopted. Intercropping was shown to reduce soil erosion and nitrate leaching. Optimal timing and reduced fertilization may increase profits if there were compensation payments provided by the government.

Field level simulation models were used by Coiner et al. (2001) to evaluate alternative landscape scenarios in Iowa. The models simulated weather, plant growth, nutrient cycling, hydrology, erosion and sedimentation, and soil temperature for commercial operations. Management of plant materials by tillage, fertilization, irrigation, and conservation practices were also simulated. Results from production, water quality, and biodiversity scenarios were compared with the baseline scenario that assumed the use of conventional tillage. In the production scenario the farms employed conservation tillage, which retains residue cover on the surface of soils, and modification of the crop rotations to incorporate more high value annual crops such as corn and soybean at the expense of alfalfa hay and grass crops. Of the three, the production scenario showed the highest returns to the land due to increased acreage and lower production costs associated with conservation tillage. In the water quality scenario the farms adopted buffer strips around water bodies and modified crop rotations to include more perennial alfalfa and grass crops. The water quality scenario resulted in the lowest returns to the land, but was also the best scenario in terms of the environment as it reduced nitrogen leaching and wind erosion. In the third scenario both water quality and biodiversity were targeted where perennial strip cropping was used to connect buffer strips and riparian areas for wildlife and the farms adopted organic agricultural practices (i.e., commercial fertilizers and chemicals were no longer used). In the biodiversity scenario returns to the land were the second highest and only slightly reduced, despite the fact that land area was reduced. The buffer strip adoption scenario resulted in reduced returns. However, this BMP also reduced nitrogen leaching and wind erosion, which may have long term implications, and may compensate for some of the initial costs associated with buffer strips.

A long term simulation model was used by Tapia-Vargas et al. (2001) to determine the effect of maize production tillage systems on runoff and sediment from agricultural operations located on sloped lands in Mexico. Soil erosion was simulated using soil moisture and runoff variables. Treatments examined included conventional tillage, no till, and no till with varying levels of residue coverage. The scenarios with conventional till and no till without residue had higher levels of runoff and sediment losses, as compared to the scenarios with the combination of no till and residue management. Fu et al. (2006) also simulated soil erosion and sediment yield models to compare no till practices to conventional tillage for farms in Washington, USA, where wheat, barley, and peas were the major crops grown. The models by Fu et al. (2006) yielded similar results as Tapia-Vargas et al. (2001) where there were reductions in soil loss and sediment yield under no-till practices. Both studies provide justification for including residue management as a BMP in the current study.

Matekole and Westra (2009) developed models to simulate surface water, nutrient, pesticide, and sediment runoff quantities. The models were used for an economic analysis of tillage and nutrient BMPs in Louisiana, USA. Farmers applied fertilizers as a type of “pseudo-insurance” against crop losses. However, in the simulation model operations would diversity nitrogen fertilizer application with tillage practices to maximize net returns. Crop acreage and fertilizer management practices were shown as a means of decreasing cropland effluent runoff in the simulated results. Reduced tillage with nutrient management was found to be a cost effective method to reduce nutrient and sediment losses in this study area. In a similar study by Matekole et al. (2009) biophysical economic models were used to evaluate benefits of implementing nitrogen fertilizer application and tillage management BMPs, also in Louisiana, USA. As was the case for the previous study, surface water, nutrient, pesticide, and sediment runoff quantities were simulated in the analysis. This study included the consideration of riparian buffers, such as trees, grasses, and shrubs, that serve as nutrient and sediment filters and help reduce nutrient erosion and sediment loss from cropland into streams and rivers. All scenarios with reduced tillage showed increases in revenue as compared to conventional tillage revenues. The results from this study correspond with the hypothesis that adoption of BMPs may also lead to financial returns to producers. This hypothesis is also explored in the current study.

Khakbazan et al. (2009) developed a dynamic programming model to examine the economic factors associated with yield function, nutrients, and water to connect agro-environmental and economic models. Potato crop rotations under irrigated production in Manitoba were of interest in this study. Khakbazan et al. (2009) compared production costs, yields, and other economic criteria to help in the selection of the best crop rotation for irrigated potato production. Including a potato rotation in these types of models allowed for the evaluation of the sustainability of production systems under a combination of high disturbance and minimal tillage management systems. A model that includes potato yield, growing season precipitation, and fertilizer and irrigation management was adapted from Belcher et al. (2003) in this study to include quantitative relationships found in the literature. Khakbazan et al. (2009) modelled costs as being both dependent on agro-environmental factors, such as fertilizer and yield dependent costs, and on base factors that are static throughout the simulation. Some potato rotations increased soil organic matter, while others slowly depleted the stock.

Cortus (2005) used simulation techniques to investigate the direct farm level impact of wetland drainage. Wetland drainage reduces the amount of EG&S available. However, drainage of wetlands has private benefits, including improved crop yields, increased land value, increased acreage under production, and production of higher value crops, and private costs, including pumping stations, and open ditches. Removing wetlands can be thought of as the opposite of BMP adoption (i.e., the opposite of the current study). Cortus (2005) developed representative farms to model wetland drainage in Saskatchewan crop production. Wetland drainage is economically feasible for Saskatchewan cropping operations, and by extension of the simulation results that it is costly for producers to maintain the current level of EG&S generated by wetlands on the farms.

The objective of the study by Koeckhoven (2008) was to determine the direct farm level impacts of BMP adoption, as is the objective in the current study. Koeckhoven (2008) also used simulation and capital budgeting techniques to determine the impact of BMP adoption. Several BMPs to address water conservation and riparian habitat were examined for a representative mixed (i.e., cattle and cropping activities) farm in southern Alberta. Of practices relevant to cropping agriculture, it was found that the establishment of buffer strips around riparian areas and the adoption of permanent cover were costly for producers in this region, largely due to reductions in the acreage for crop production. It was further concluded that producers may require some type of incentive program to encourage BMP adoption.

2.5 Chapter Summary

Responsible agricultural practices have the potential to improve the supply of EG&S. Adoption of BMPs also increases EG&S production. EG&S are beneficial to society and increasing the supply may also create a feedback system where benefits are experienced by producers. In agricultural systems soil and water quality are important factors in maintaining or improving yields and revenue of producers. However, adoption of BMPs to improve the supply of EG&S may not be at the optimal level due to real or perceived costs associated with adoption. Research into agricultural and ecological indicators provides a baseline for determining the net benefit associated with BMP adoption. To determine the optimal amount of EG&S provided by agriculture, policy programs use this information to establish appropriate methods to encourage adoption, including policies of regulation, economic incentives and/or extension.

This study is concerned with a variety of BMPs that primarily affect soil and water quality on agricultural lands. BMPs of interest include crop rotations and non-rotational BMPs to improve soil quality through reduced soil erosion, and improve water quality through reduced nitrogen leaching and soil particle runoff into water bodies. Many studies have examined the effect of altering management practices to improve soil and water quality. Some studies focus on the static assumptions of potential yield improvements and cost savings from BMP adoption while others include dynamic simulation to account for price and yield risk in agricultural production. However, research examining the impact of BMP adoption includes assumptions based on the geographical area as will be the case in this study. Many previous studies employ representative farms that are based on characteristics from actual farms in the area of interest. This approach will be considered, with the use of statistical data for the current study.

Chapter 3: The Study Areas

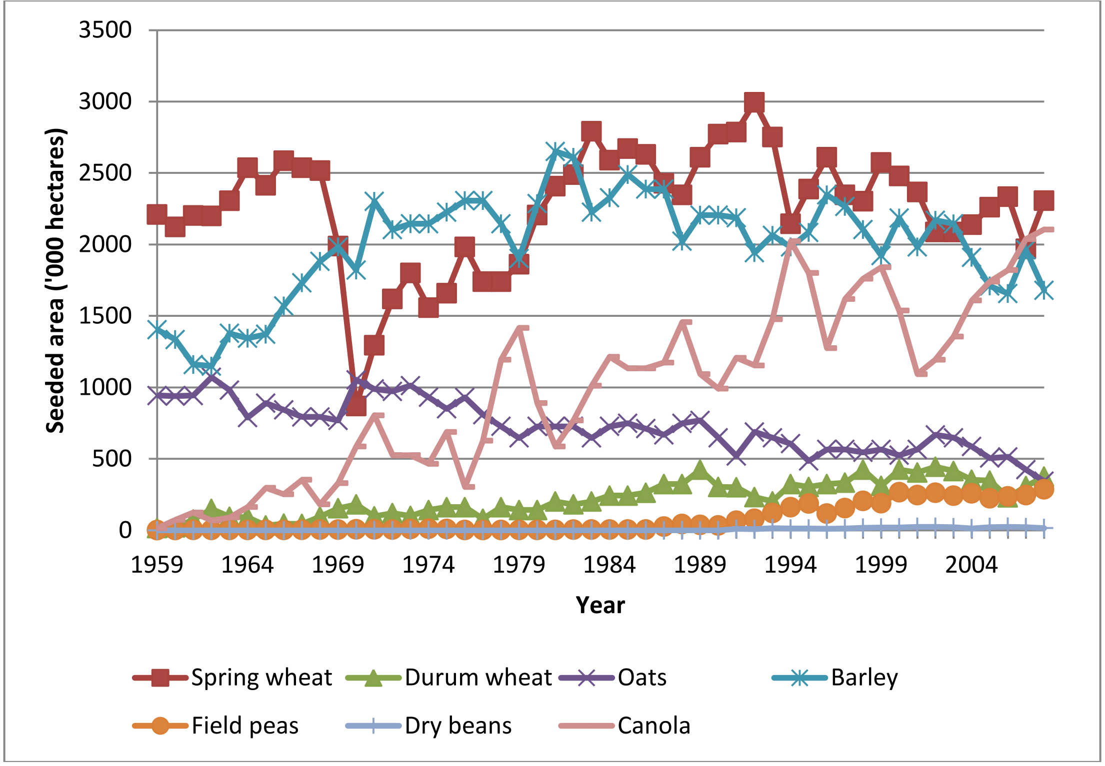
In this chapter the agricultural practices and existing and potential BMPs in Alberta agricultural regions are outlined. Cropping agriculture has a significant impact on the quality of the surrounding environment, specifically on water and soil quality. BMPs that mitigate or decrease the damage to the environment related to agricultural practices include practices that reduce wind and water erosion, reduce water runoff, improve soil organic matter, and generally improve soil health. BMPs that contribute to improving soil and water quality on agricultural lands include zero-tillage or no-tillage practices, residue management, control of crop inputs such as fertilizers, crop rotations, shelterbelts or windbreaks, and buffer zones around wetlands.

Some BMPs have had a significant uptake. For example, practices that are widely adopted in Alberta include zero-tillage or no-tillage, adjustments to crop rotations, shelterbelts to reduce erosion, and residue management. However, producers continue to use significant levels of commercial fertilizers and herbicides in Alberta, while the use of BMPs such as buffer strips around wetlands is quite low. This indicates that reduced water quality from runoff is likely an issue, along with soil quality, due to extensive input use for agricultural production in situations where the nutrients are not used by the crop.

This chapter outlines the methods taken to determine the representative soil zones and municipal districts for analysis. An overview of agriculture is also provided for each region where a representative farm is defined as well as the prevalence of BMP use in the area. Census data from Statistics Canada provide the foundation to define each representative farm and to provide an overview of the agricultural activities and current BMPs in these regions. The agricultural characteristics and the occurrence of BMPs in the areas of interest are examined to confirm the credibility of the attributes of the model farms and adoption of the practices in the analysis.

Of all agricultural land (i.e., land used for livestock, perennial and annual crops, summerfallow, or pasture) in Alberta, 45.6% was seeded to crops with an additional 4.3% allocated to summerfallow in 2006. Spring wheat, barley, canola, and alfalfa make up the four crops with the highest acreage seeded in 2006 with approximately 2.3, 1.7, 1.6, and 1.6 million hectares seeded, respectively. The fifth highest acreage was land allocated to summerfallow in 2006 with 0.9 million hectares. Historically spring wheat and barley have been the highest seeded crops in Alberta as shown in Figure 3.1. Figure 3.1 shows the crops that are considered in the crop rotations for this project with the exception of alfalfa hay. The trend in tame hay production has generally been positive from 1960 to 2001 with 2.3 million hectares of land seeded to hay in 2001 and only 0.9 million hectares seeded to hay in 1960 (Statistics Canada, 2001). Canola has gained popularity since it was introduced in the 1970s. Durum wheat is grown primarily in southern regions of Alberta and so is not one of the major crops in terms of total provincial acreage. However, it is a significant crop in southern Alberta. From the historical data shown in Figure 3.1 the area devoted to crops such as field peas and dry beans is increasing while the acreage of land seeded to oats has been decreasing. In 2006 there was approximately 0.5 and 0.2 million hectares of land seeded to oats and field peas in Alberta, respectively. In the same year there was approximately 25,000 hectares of land seeded to dry bean varieties. Beans represent a smaller portion as compared to other crops since they are produced using irrigation technology.

Figure 3.1 – Historical acreage (‘000 of hectares) of selected crops in Alberta (1959 – 2008)



Source: Statistics Canada (2009)

3.1 The Representative Regions

Representative regions are chosen primarily on the basis of Statistics Canada census data and opinions from agricultural experts in Alberta. Regions chosen as representative include soil zones with significant agricultural production and municipal districts within these regions. This section will discuss how the representative regions are determined and the agricultural characteristics of the representative regions. Representative regions are chosen from the regions illustrated in Figure 3.2. This section provides the foundation for determining the representative farms to be modelled. The process to define representative farms begins by characterizing the areas by soil zone. Following this, distinguishing agricultural production traits in the representative counties[3] are determined. Specifically, size of farms and common crops grown in each region are examined, which are discussed in Chapter 5 to further determine representative farm characteristics.

3.1.1 Soil Zones

The primary criterion used in defining representative farms for this study is soil zone. Alberta has several soil zones (see Appendix A), and in defining the representative farms it is important to begin characterizing based on soil zones. Alberta is a relatively large province and contains many types of soils that differ based on climatic, vegetative,

---

[3] Rural municipalities in Alberta are referred to by a variety of terms, including County, Municipal District (M.D.), and Special Area. The term “county” is used in this discussion as a general term to refer to all of these.

and hydrological factors (AARD, 2009-b). Human activities, such as cropping agriculture also impact the formation of soils. Different soil formation factors, temperature, and precipitation across Alberta result in soils that differ in organic material and vegetative cover.

The southeast corner of the province is generally characterized by a semiarid climate and short grass prairie vegetation (AARD, 2009-b). In this area organic matter is mainly added to the soil from plant roots, giving the soils a Brown colour that is indicative of organic material in the upper layers of soil (AARD, 2009-b). Further north and west in Alberta there is increased moisture levels, contributing to higher yielding grasses and higher organic matter contents (AARD, 2009-b). In this area darker brown and black soils are characteristic as there are increased levels of organic matter added to the soils from increased plant growth (AARD, 2009-b). Farther north and west, there are lower temperatures and natural grasslands that are mixed with deciduous trees. Lower temperatures mixed with increased organic material from tree litter and grasses form black soils in these regions (AARD, 2009-b). In the area known as the Peace Lowland, which covers the north western part of Alberta, there is a transition of deciduous trees to coniferous forest, characterizing this area with grassland and forest vegetation (AARD, 2009-b). In forested areas organic matter from leaves results in leached upper soil layers that are low in organic matter, and therefore light grey in colour (AARD, 2009-b).

In general, Mixed Grasslands are dominated by Brown Chernozemic soils, Moist Mixed Grasslands are dominated by Dark Brown Chernozemic soils, and Fescue Grasslands and Aspen Parklands are dominated by Black Chernozemic soils (AARD, 2009-b). These soils are well to imperfectly drained, making them suitable for crop production. In the Boreal Transition (i.e., forest soils) Luvisolic soils and Chernozemic soils are common with a leached grey colour (AARD, 2009-b). The soils in this region are also well to imperfectly drained (AARD, 2009-b).

The links between the soils and natural vegetation in the areas is indicative of the type of agricultural production that occurs in these regions. In the Brown soils there is little organic matter on the surface and vegetation grown is short with less residue remaining after crop harvest. Here there is less soil organic matter available to form soil aggregates and risks such as soil erosion are higher. In the Black soils higher agricultural production is possible due to increased precipitation and lower temperatures, which is more favourable to growing conditions. This results in more residues potentially being returned to the soil, increasing organic matter and improving soil aggregation. Due to the interspersion of coniferous and deciduous trees and grasslands in the Grey soils, with lower average temperatures, the large amount of organic matter that is produced does not decompose as quickly as in the Black soils. While production is high in this region, leaching from excess organic matter produces the distinctive grey soil colour.

The soil zones that have significant proportions of crop production activities are chosen to define the representative farms. Specifically, farms are defined for the Brown, Dark Brown, Black and Dark Grey soil zones. The Grey soil zone is not included as there are limited cropping operations in this region. In particular, of the four counties considered from the Grey soil zone, an average of less than 30% of farm land was used for crop production.

3.1.2 Representative Counties

To further refine the areas and farms used to define the representative farm in each soil zone, a representative county for each soil zone is chosen based on Census data. If at least (approximately) 70% of a county is deemed to be within the boundaries of a particular zone, it is included as being part of that soil zone and is taken into consideration when choosing the location of the representative farms. Any counties that were more "evenly split" between soil zones were excluded from further consideration. The counties included in the analysis by soil zones are provided in Appendix B.

From the remaining counties, representative counties in each soil zone were then chosen based on the relative significance of crop production, as measured by the proportion of agricultural land devoted to crop production. Using data from the 2006 Census of Agriculture, total area of farms, land in crops, land in summerfallow, tame or seeded pasture, and natural land for pasture are used to calculate an approximate percentage of agricultural land allocated to crops and pasture for each county in each soil zone (Table 3.1). Selection was also narrowed by accounting for counties in close proximity to metropolitan areas, and the presence and prevalence of irrigated crop production.

From the 2006 Census of Agriculture data it was determined that average farm size in counties that are in close proximity to large metropolitan areas is smaller than in counties without large metropolitan areas. It is speculated that this is most likely due to the higher incidence of small hobby farms and acreages in these areas. Therefore, counties that were in close proximity to large cities were excluded from the analysis. Counties and Municipal Districts (M.D.) of Alberta are shown in Figure 3.2

It was determined that the representative farm for the Brown soil zone should be located in either the M.D. of Taber or the County of Forty Mile. In those two counties, 53 and 41% of the agricultural land is in crops, respectively. Of the total area of crops, approximately 14.2% is in irrigated production in the County of Forty Mile, while approximately 44.8% of total crop area is irrigated in the M.D. of Taber. Given that in the other soil zones production is primarily dryland, it was decided to define a a dryland farm in the County of Forty Mile.

In the Dark Brown soil zone the County of Lethbridge has the highest proportion of land (70%) in crops. However given the presence of the City of Lethbridge within this county, it was excluded from consideration. Starland County, with 62% of farm area devoted to crops, was instead chosen as the representative county for the Dark Brown soil zone. Starland County was chosen over Wheatland County, which had a slightly higher (approximately 66%) proportion of land in crops, because of the higher proportion of irrigated acres (5% versus 0.1% in Starland County) in Wheatland.

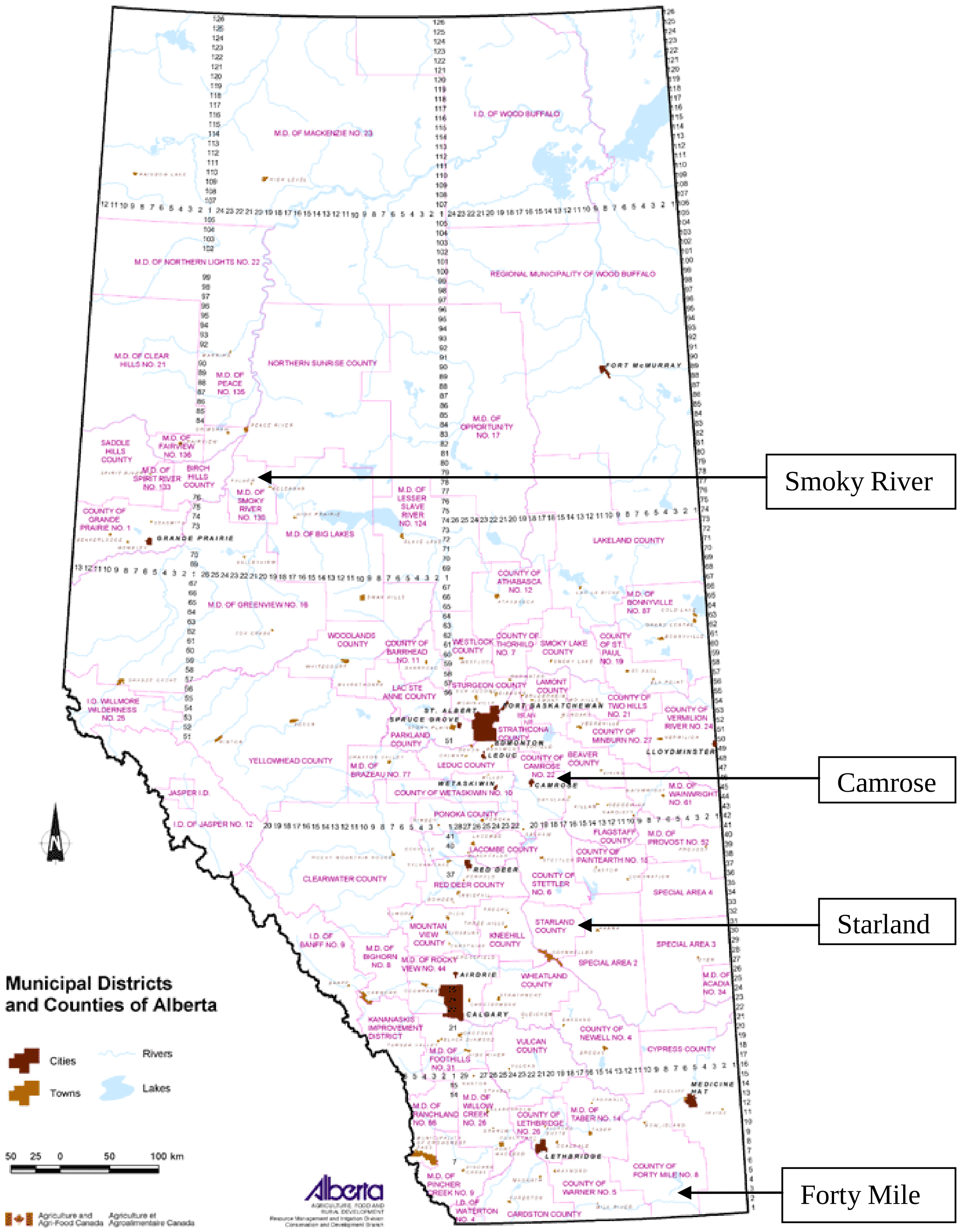
In the Black soil zone Sturgeon County has the largest proportion of land in crops with approximately 71% in crops and 19% in pasture. However, as Sturgeon County is close in proximity to the metropolitan area of Edmonton, Camrose County was chosen as the representative county, as it was the next best alternative with approximately 69% of land in crops and 22% in pasture.

The Dark Grey soil zone is made up of two ecoregions[4]: Dry Mixedwood and the Peace River Parkland. In the Dry Mixedwood region Westlock County and County of Two Hills have the highest proportion of land in crops with 57% each. In the Peace River Parkland the M.D. of Smoky River has the highest proportion of land in crops at 82%. Only one representative county is chosen for the Dark Grey soil zone, and since there is an overall higher proportion of land in crops in the Peace River Parkland as compared to the Dry Mixedwood region, the M.D. of Smoky River is chosen as the representative county for this soil zone..

---

[4] An ecoregion is a distinct region defined by its ecology, including environmental conditions and natural features.

Figure 3.2 – Municipal Districts and Counties of Alberta



Source: *Adapted from* AARD (2005-b) *with permission from Alberta Agriculture and Rural Development.*

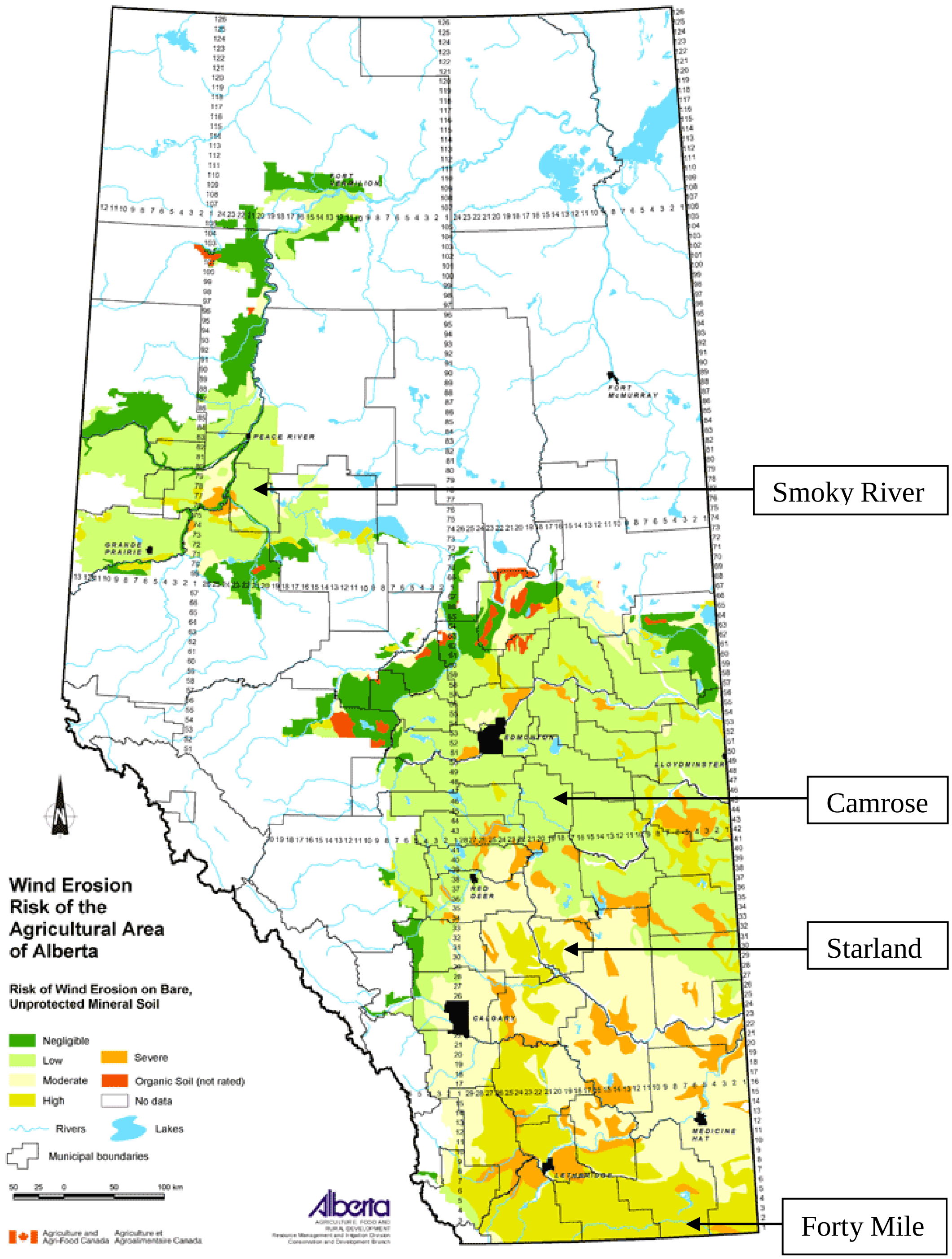
Table 3.1 – Counties and acreage of farm land (in hectares) included in choosing representative farms for each soil zone with significant cropping activities, 2006[a]

Soil Zone	County / Municipal District	Total area of farms	Area in crops and summerfallow	Area in pasture (tame and natural)
Brown	Special Area 2	836,627	196,746 (23.5%)	614,122 (73.4%)
	Special Area 3	700,475	312,964 (44.7%)	374,381 (53.4%)
	County of Newell No. 4	584,440	153,465 (26.3%)	417,681 (71.5%)
	County of Forty Mile No. 8	708,451	383,533 (54.1%)	317,760 (44.9%)
	Cypress County	999,472	229,687 (23.0%)	756,925 (75.7%)
	M.D. of Taber	403,702	241,841 (60.0%)	154,699 (38.3%)
Dark Brown	Special Area 4	401,445	155,078 (38.6%)	234,081 (58.3%)
	County of Lethbridge	296,865	237,226 (79.9%)	52,610 (17.7%)
	Vulcan County	529,712	382,039 (72.1%)	140,855 (26.6%)
	Wheatland County	456,502	333,944 (73.2%)	114,080 (25.0%)
	Starland County	248,301	173,503 (69.9%)	67,311 (27.1%)
	County of Paintearth No. 18	319,966	165,110 (51.6%)	141,835 (44.3%)
	M.D. of Provost No. 52	361,597	168,391 (46.6%)	181,369 (50.2%)
Black	Cardston County	363,438	189,918 (52.3%)	167,085 (46.0%)
	M.D of Pincher Creek	271,796	86,722 (31.9%)	172,553 (63.5%)
	M.D. of Foothills	370,081	162,933 (44.0%)	197,065 (53.2%)
	M.D. of Rocky View No. 44	435,626	245,340 (56.3%)	175,272 (40.2%)
	Red Deer County	407,584	249,931 (61.3%)	137,701 (33.8%)
	Lacombe County	279,310	172,041 (61.6%)	92,198 (33.0%)
	Leduc County	228,363	150,219 (65.8%)	62,445 (27.3%)
	County of Camrose No. 22	336,112	243,427 (72.4%)	74,815 (22.3%)
	Beaver County	291,272	190,986 (65.6%)	85,673 (29.4%)
	Minburn County No. 27	287,193	199,112 (69.3%)	72,167 (25.1%)
	Vermilion River County No. 24	555,652	314,230 (56.6%)	215,155 (38.7%)
	Strathcona County	103,709	64,645 (62.3%)	30,016 (28.9%)
	Sturgeon County	202,168	151,968 (75.2%)	38,534 (19.1%)
	Flagstaff County	399,313	290,036 (72.6%)	87,824 (22.0%)
	M.D. of Wainwright	387,159	212,335 (54.8%)	156,641 (40.5%)
Dark Grey	Lac Ste. Anne County	238,048	112,716 (47.4%)	104,130 (43.7%)
	County of Barrhead No. 11	212,370	115,111 (54.2%)	77,973 (36.7%)
	Westlock County	278,818	177,448 (63.6%)	83,925 (30.1%)
	County of Thorhild No. 7	156,695	92,051 (58.7%)	50,711 (32.4%)
	County of St. Paul No. 19	335,195	143,176 (42.7%)	168,340 (50.2%)
	Athabasca County No. 12	280,259	141,248 (50.4%)	102,266 (36.5%)
	Two Hills County No. 21	229,129	151,416 (66.1%)	62,977 (27.5%)
	M.D. of Smoky River	257,959	220,386 (85.4%)	20,068 (7.8%)
	Birch Hills County	192,277	124,669 (64.8%)	47,467 (24.7%)
	M.D. of Spirit River	68,890	58,067 (84.3%)	4,914 (7.1%)
	County of Grande Prairie No. 1	461,377	272,744 (59.1%)	143,419 (31.1%)
	M.D. of Fairview	130,976	92,577 (70.7%)	29,620 (22.6%)

[a] The values in parentheses are the percentages of total farm area for each type of use. The percentages do not sum to 100% because other land use, such as land for tree production, is not included in the analysis.

Source: Statistics Canada (2006)

Figure 3.3 – Wind erosion risks in Alberta.



Source: *Adapted from* AARD (2005-b) *with permission from Alberta Agriculture and Rural Development.*

The following sections provide summary agricultural statistics for the representative counties in each soil zone. Cropping management and land use practices are also reviewed. As noted earlier, these are later used (in Chapter 4) to define the characteristics for the representative farms that are modelled in the BMP analysis.

3.1.2.1 County of Forty Mile

The County of Forty Mile is in south eastern Alberta and lies along the Canadian and United States border (Figure 3.2). The total area of this county is 7,230 square kilometres with a population of 3,414 in 2006. Total agricultural land in this county is 7,047 square kilometres. According to Statistics Canada (2006) common crops grown in this district include spring wheat, durum wheat, oats, barley, and field peas.

The distribution of gross farm receipts in 2006 for Forty Mile is provided in Table 3.2 with the majority of farms in this region being between $100,000 and $500,000 of gross receipts. The number of farms using selected soil conservation practices, tillage practices and land inputs are provided in Tables 3.3 and 3.4. As shown in Figure 3.3, the wind erosion risk for the County of Forty Mile is moderate to severe, making this an interesting region to study for the adoption of practices such as shelterbelts and crop residue management. In 2006 approximately one quarter of farms in this region reported having shelterbelts or windbreaks while less than 50% of land had residue incorporated or retained on the surface.

Table 3.2 – Distribution of farms by gross receipts, County of Forty Mile (2006)

Gross farm receipts	Number of farms (% of total)
Under $10,000	31 (5.1%)
$10,000 to $24,999	51 (8.5%)
$25,000 to $49,999	46 (7.6%)
$50,000 to $99,999	81 (13.5%)
$100,000 to $249,999	187 (31.1%)
$250,000 to $499,999	116 (19.3%)
$500,000 to $999,999	46 (7.6%)
$1,000,000 to $1,999,999	20 (3.3%)
$2,000,000 and over	24 (4.0%)
Total	602

Source: Statistics Canada (2006)

Table 3.3 – Number of farms participating in soil conservation practices, County of Forty Mile (2006)

Soil conservation practice	Number of farms (% of total)
Crop rotation	486 (80.7%)
Ploughing down green crops	16 (2.7%)
Windbreaks or shelterbelts	167 (27.7%)
Buffer zones around water	64 (10.6%)
Total farms	602

Source: Statistics Canada (2006)

Table 3.4 – Frequency of use for specific tillage practices and land inputs, County of Forty Mile (2006)

Practices and inputs	Number of farms (% of total)	Hectares (% of total)
Most crop residue into soil	241 (47.2%)	66,810 (24.1%)
Most crop residue retained on the surface	183 (35.8%)	65,289 (23.6%)
No-till or zero till	203 (39.7%)	145,017 (52.3%)
Herbicides	411 (80.4%)	254,436 (91.8%)
Insecticides	70 (13.7%)	13,965 (5.0%)
Fungicides	121 (23.7%)	36,753 (13.3%)
Commercial Fertilizer	404 (79.1%)	230,557 (83.2%)
Total land for seeding	511	277,116

Source: Statistics Canada (2006)

3.1.2.2 County of Starland

The County of Starland is located in south-central Alberta and has a total area of 2,558 square kilometres and a population of 2,371 people in 2006. In 2006 crops were planted on over 60% of the land. In this region the crops that are most commonly grown include spring wheat, barley, canola, alfalfa, and field peas (Statistics Canada, 2006).

The distribution of farm gross receipts for Starland County is provided in Table 3.5. Most farms in this region have gross receipts between $25,000 and $500,000. Tables 3.6 and 3.7 provide information regarding soil conservation practices, tillage and land inputs in this region. Most farms use crop rotations as a soil conservation technique, but only 2.2% plough down green crops. Over a third of farms have shelterbelts or windbreaks and almost one third of the acreage seeded to crops had residue incorporated or left on the surface of the soil. According to Figure 3.3 the wind erosion risk for Starland County falls in the moderate to severe category. Therefore the analysis of management techniques to reduce soil erosion from wind may have economic importance for this region.

Table 3.5 – Distribution of farms by gross receipts, County of Starland (2006)

Gross farm receipts	Number of farms (% of total)
Under $10,000	28 (7.7%)
$10,000 to $24,999	43 (11.8%)
$25,000 to $49,999	48 (13.2%)
$50,000 to $99,999	61 (16.8%)
$100,000 to $249,999	89 (24.5%)
$250,000 to $499,999	58 (15.9%)
$500,000 to $999,999	26 (7.1%)
$1,000,000 to $1,999,999	4 (1.1%)
$2,000,000 and over	7 (1.9%)
Total	364

Source: Statistics Canada (2006)

Table 3.6 – Number of farms participating in soil conservation practices, County of Starland (2006)

Soil conservation practice	Number of farms (% of total)
Crop rotation	280 (76.9%)
Ploughing down green crops	8 (2.2%)
Windbreaks or shelterbelts	139 (38.2%)
Buffer zones around water	65 (17.9%)
Total farms	364

Source: Statistics Canada (2006)

Table 3.7 – Frequency of use for specific tillage practices and land inputs, County of Starland (2006)

Practices and inputs	Number of farms (% of total)	Hectares (% of total)
Most crop residue into soil	93 (31.6%)	20,255 (13.5%)
Most crop residue retained on the surface	75 (25.5%)	27,418 (18.3%)
No-till or zero till	157 (53.4%)	102,160 (68.2%)
Herbicides	242 (82.3%)	135,743 (90.6%)
Insecticides	13 (4.4%)	1,997 (1.3%)
Fungicides	32 (10.9%)	17,137 (11.4%)
Commercial Fertilizer	247 (84.0%)	140,993 (94.1%)
Total land for seeding	294	149,833

Source: Statistics Canada (2006)

3.1.2.3 County of Camrose

The County of Camrose is located in central Alberta, south east of Edmonton (Figure 3.2). The County of Camrose has a total area of 3,332 square kilometres with a population of 7,160 people in 2006. Of all agricultural land in this county almost 70% was under crop production in 2006. Crops that make up the bulk of cropping activities in this region include spring wheat, canola, barley, alfalfa, and field peas (Statistics Canada, 2006).

The 2006 distribution for Camrose County farm gross receipts is shown in Table 3.8. The majority of farms have gross receipts below $250,000, indicating that farm size in this area may be slightly smaller as compared to the representative counties previously discussed. Table 3.9 shows the number of farms using various soil conservation practices. Most farms use crop rotations for soil conservation and over half have windbreaks or shelterbelts on the farm. Tillage practices and land inputs for Camrose County are provided in Table 3.10. Over half the acreage seeded used no-till or zero-till technology in 2006. Erosion risk by wind is classified as low in this region (Figure 3.3).

Table 3.8 – Distribution of farms by gross receipts, County of Camrose (2006)

Gross farm receipts	Number of farms (% of total)
Under $10,000	164 (14.3%)
$10,000 to $24,999	191 (16.6%)
$25,000 to $49,999	173 (15.1%)
$50,000 to $99,999	156 (13.6%)
$100,000 to $249,999	257 (22.4%)
$250,000 to $499,999	147 (12.8%)
$500,000 to $999,999	39 (3.4%)
$1,000,000 to $1,999,999	16 (1.4%)
$2,000,000 and over	6 (0.5%)
Total	1149

Source: Statistics Canada (2006)

Table 3.9 – Number of farms participating in soil conservation practices, County of Camrose (2006)

Soil conservation practice	Number of farms (% of total)
Crop rotation	829 (72.2%)
Ploughing down green crops	34 (3.0%)
Windbreaks or shelterbelts	633 (55.1%)
Buffer zones around water	213 (18.5%)
Total farms	1,149

Source: Statistics Canada (2006)

Table 3.10 – Frequency of use for specific tillage practices and land inputs, County of Camrose (2006)

Practices and inputs	Number of farms (%of total)	Hectares (% of total)
Most crop residue into soil	317 (37.3%)	39,664 (18.8%)
Most crop residue retained on the surface	275 (32.4%)	58,322 (27.6%)
No-till or zero till	345 (40.6%)	113,030 (53.6%)
Herbicides	677 (79.7%)	182,936 (86.7%)
Insecticides	46 (5.4%)	6,023 (2.9%)
Fungicides	82 (9.7%)	17,798 (8.4%)
Commercial Fertilizer	716 (84.3%)	198,161 (93.9%)
Total land for seeding	849	211,016

Source: Statistics Canada (2006)

3.1.2.4 Municipal District of Smoky River

The M.D. of Smoky River is located in north western Alberta. This district covers an area of 2,843 square kilometres and had a population of 2,442 people in 2006. Of the total land area 2,459 square kilometres is agricultural land and 82% of the agricultural land was seeded as crops in 2006. Common crops grown in this region include canola, spring wheat, alfalfa, oats, and barley (Statistics Canada, 2006).

The distribution of farm gross receipts for the M.D. of Smoky River in 2006 is given in Table 3.11. The majority of farms in this area have gross receipts between $50,000 and $500,000. The number of farms using selected soil conservation practices is provided in Table 3.12. The number of farms and acreage of land under certain tillage practices and land inputs is provided in Table 3.13. According to Figure 3.3 the wind erosion risk in the M.D. of Smoky River is low with the exception of one small section on the central western edge of this district that has severe erosion risk. However, 42% of producers in this region indicated the presence of shelterbelts or windbreaks on the farms. There is also over half of all hectares seeded where residue is incorporated into the soil or retained on the surface in this region.

Table 3.11 – Distribution of farms by gross receipts, Municipal District of Smoky River (2006)

Gross farm receipts	Number of farms (% of total)
Under $10,000	35 (9.0%)
$10,000 to $24,999	53 (13.6%)
$25,000 to $49,999	34 (8.7%)
$50,000 to $99,999	51 (13.0%)
$100,000 to $249,999	104 (26.6%)
$250,000 to $499,999	66 (16.9%)
$500,000 to $999,999	33 (8.4%)
$1,000,000 to $1,999,999	8 (2.0%)
$2,000,000 and over	7 (1.8%)
Total	391

Source: Statistics Canada (2006)

Table 3.12 – Number of farms participating in soil conservation practices, Municipal District of Smoky River (2006)

Soil conservation practice	Number of farms (% of total)
Crop rotation	324 (82.9%)
Ploughing down green crops	33 (8.4%)
Windbreaks or shelterbelts	164 (41.9%)
Buffer zones around water	59 (15.1%)
Total farms	391

Source: Statistics Canada (2006)

Table 3.13 – Frequency of use for specific tillage practices and land inputs, Municipal District of Smoky River (2006)

Practices and inputs	Number of farms (% of total)	Hectares (% of total)
Most crop residue into soil	122 (39.4%)	26,344 (16.3%)
Most crop residue retained on the surface	115 (37.1%)	64,193 (39.8%)
No-till or zero till	129 (41.6%)	70,756 (43.9%)
Herbicides	257 (82.9%)	150,057 (92.6%)
Insecticides	83 (26.8%)	26,854 (16.6%)
Fungicides	22 (7.1%)	11,709 (7.3%)
Commercial Fertilizer	274 (88.4%)	161,971 (100.4%)
Total land for seeding	310	161,294

Source: Statistics Canada (2006)

3.2 Chapter Summary

A range of locations is considered for this project in an effort to provide a study that is representative of commercial cropping operations in Alberta. Areas are chosen based on the suitability of cropping operations to the climate and region characteristics. Summary statistics for each of the representative counties are provided in Table 3.14. Crop production is important in all four counties, with 41, 62, 69, and 82% of agricultural land being in crops in 2006 for the districts of Forty Mile, Starland, Camrose, and Smoky River, respectively.

Table 3.14 – Agricultural characteristics of the representative Municipal Districts and Counties

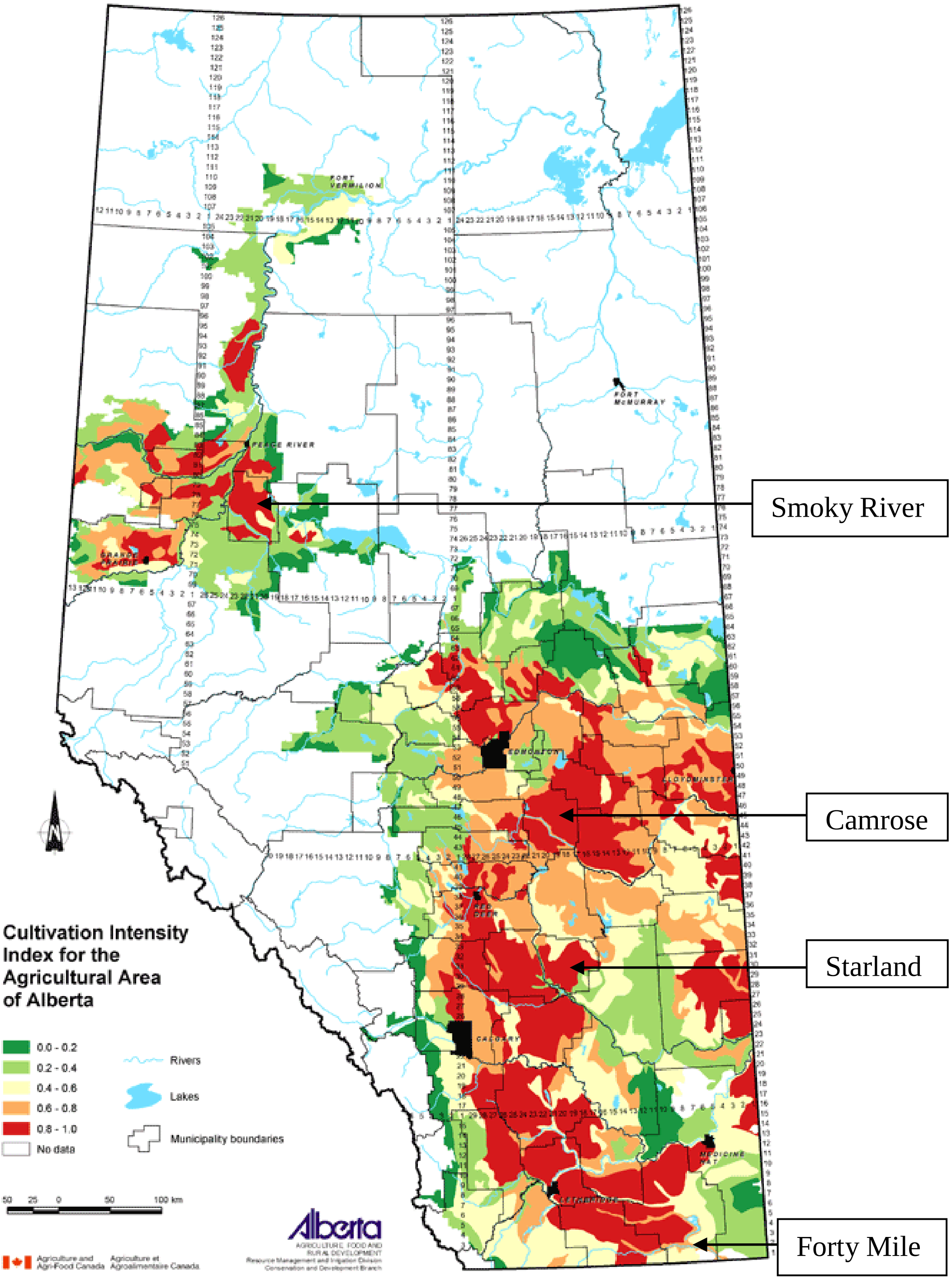
Municipal District	Number of farms	Number of farms with crops	Total agricultural area (ha)	Land in crops (ha)	Land in summer-fallow (ha)
Forty Mile	602	548	704,708	287,654	95,990
Starland	364	332	263,093	162,599	19,546
Camrose	1,149	1,001	337,830	233,059	3,461
Smoky River	391	358	245,906	200,971	4,862
Alberta	49,431	41,172	21,095,393	9,621,607	906,347

Source: Statistics Canada (2006)

Figure 3.4 illustrates the cultivation intensity index for different areas of Alberta. The cultivation intensity index measures the frequency with which different cultivation management practices (i.e., no-till, conservation tillage, conventional tillage, and summerfallow) are used. As such, the index provides a proxy of the degree to which crop production practices increase or decrease susceptibility to wind and water erosion on agricultural land (AARD, 2005-a). Higher values represent greater cultivation intensity and greater potential for erosion. According to Figure 3.4, regions chosen as representative of agriculture in Alberta have moderate to high cultivation intensity. Therefore producers in these regions could benefit from the introduction of BMPs.

The information discussed in this chapter will be used as a starting point for defining characteristics such as farm size and crop rotations for the representative farms. The environmental issues discussed in this chapter also provide the starting point for determining relevant BMPs for analysis of the representative farms.

Figure 3.4 – Cultivation intensity in Alberta.



Source: *Adapted from* AARD (2005-b) *with permission from Alberta Agriculture and Rural Development.*

Chapter 4: The Representative Farms and Simulation Model

The details of the simulation models developed to analyze the economic costs and benefits of the impact of introducing BMPs on commercial crop farms in Alberta are discussed and explained in this chapter. The simulations are run through the use of dynamic Monte Carlo modelling. Each representative farm is simulated over multiple years, with a subset of parameters being stochastic. The farm models are created in Microsoft Excel© and are simulated using *@RISK*©, which is an Excel add-in program from Palisade Corporation (2007). This program allows the models to be run through time while incorporating uncertainty with stochastic variables. In this study risk enters the analysis through stochastic crop yields and prices, as well as with the discount rate in NPV analysis. In each year of the simulation, random draws are made for each yield and price variable. Multiple iterations of the multiple year simulation are then done in order to obtain distributions of relevant outcomes.

The time horizon used for the BMP analysis is 40 years. A 40-year simulation model is chosen due to the long term nature of some of the BMPs, which are discussed later in this chapter. For example, it takes many years for shelterbelts to achieve sufficient growth to have an impact of crop yields due to reduced water supply near the trees and reduced soil erosion farther away from the trees.

Simulations are run for each representative farm first assuming no BMPs are implemented. They are then re-run for implementation of individual BMPs to determine the impact on farm performance. Finally combinations of BMPs are modelled to compare the effects of joint implementation of BMPs on each farm.

The structure of the individual farm remains relatively constant over time. In particular, the assumption is made that once producers have decided upon a machinery complement, production practices, crop insurance, safety net programs, and crop rotations, these decisions do not change over time. Crop rotation is a BMP that is analyzed in the models. However, once it is decided to implement a BMP crop rotation, this rotation is maintained through the entire simulation time horizon.

The Net Present Value (NPV) for each farm is calculated over a period of 40 years and is used to compare the costs and benefits before and after BMP adoption. The comparison of NPV in each case (without BMPs, individual BMPs, and BMP combinations) provides insight for the economic feasibility of the adoption of BMPs on commercial crop farms in Alberta.

4.1 Conceptual Representative Farm Model

This section provides a discussion of modeling concepts used in this study; specifically, simulation and capital budgeting. Simulation analysis is the best choice for modelling the farm systems because flexibility in variables is permitted as BMPs are adopted. Crop prices, yields and BMP effects can be modelled assuming non-linear distributions, which is more realistic. Capital budgeting techniques are used to evaluate the impact of BMP adoption in terms of wealth.

4.1.1 Net Present Value

NPV is defined as the present value of future cash flows minus the costs of investment (Ross et al., 2003). Present values are calculated by discounting future cash flows using the opportunity cost of capital, or discount rate. In this way, time value of money[5] is accounted for in evaluating investments.

Projects with positive NPV are deemed to be "acceptable" in that they will result in increased wealth. If two mutually exclusive investments are being compared, the one with the greatest NPV will result in the greatest increase in wealth. NPV is calculated using equation 4.1 from Copeland and Weston (1988):

$$\text{NPV} = \sum_{t=0}^{N} \frac{CF_t}{(1+r)^t} - I_0 \qquad (4.1)$$

In equation 4.1 Copeland and Weston (1988) define CF_t as the net cash flow in a time period t, I_0 as the initial cash expenditure, r as the market discount rate, and N as the number of years considered for the investment. The discount rate should reflect the market-determined opportunity cost of capital in order to be consistent with the wealth maximization principle (Copeland and Weston, 1988). In situations where cash flows for potential investments are uncertain, the discount rate should also reflect the level of risk. NPV analysis also allows for the possibility of changes in the opportunity cost over the course of the investment (Copeland and Weston, 1988). In other words, if the discount rate changes from one period to the next, cash flows can be discounted accordingly.

As noted above, discount rates reflect the relative riskiness of an operation. Adoption of BMPs is an investment decision that may be risky for producers. Adoption will only occur if the expected return from adoption is sufficiently high to compensate for risk (Ross et al., 2003). Therefore, the discount rate used in NPV analysis should reflect the level of risk involved in investment in the project, in this case BMP adoption.

4.1.2 Monte Carlo Simulation

Evans and Olson (2002, p. 2) define simulation as "the process of building a mathematical or logical model of a system or a decision problem, and experimenting with the problem to obtain insight into the system's behaviour or to assist in solving the decision problem." Simulation models are useful for representing agricultural systems as they can be used to test hypotheses and explore alternative management scenarios in agriculture, which aids in the development of innovative practices and policy and extension (Bechini and Stöckle, 2007).

Simulation models may be static or dynamic over time and may contain deterministic or stochastic variables (Carson, 2003). A static model considers only one period in time while a dynamic model may evolve over time. Deterministic models do not contain random variables, while stochastic models allow for one or more parameters to be random. A simulation model is often thought of as a mechanism that converts input parameters into output performance measures (April et al., 2003). The typical structure of a simulation model is provided in Figure 4.2.

Simulation analysis is an advantageous method of modelling agricultural systems because it allows for flexibility to model complex relationships. Many relationships in agricultural production are non-linear, but can still be estimated using distributions with

---

[5] The time value of money refers to an assumption regarding investor preferences; that is, all other things being equal, an investor prefers to receive returns (i.e., positive cash flows) earlier rather than later. The discounting done in NPV calculations puts all cash flows associated with an investment on an equivalent time basis.

stochastic parameters, an approach that is feasible with simulation analysis. However as agricultural models are made more flexible they typically become more complex and it is difficult to develop models that are realistically flexible. Also, with simulation analysis there is no guarantee of an optimal solution being found. However, with the ability to predict a distribution of outcomes it is likely that the optimal solution is represented within the range of outcomes that are calculated from simulation analysis.

This study considers stochastic simulation in order to incorporate uncertainty and risk using random variables. In particular, Monte Carlo simulation is employed. Monte Carlo simulation uses repetitive random sampling from one or more parameter distributions to compute outcomes that are dependent on the values selected for the distributions (Vlahos, 1997). This study uses the Microsoft Excel add-in program *@RISK©* (Palisade Corporation, 2007) for Monte Carlo simulation, which is relatively simple to use as an addition to Excel spreadsheets and is powerful enough to compute up to 10,000 iterations per simulation.[6] Since Monte Carlo simulation is based on random sampling, results may contain sampling errors (Evans and Olson, 2002). However, increasing the number of iterations for results minimizes this error (Evans and Olson, 2002).

Stochastic model inputs are predefined distributions, and outcomes from Monte Carlo simulation analysis are also distributions. For the purposes of this study the outcome that is used as a measure of wealth for cropping operations is NPV. NPV outcomes from BMP adoption are compared in terms of differences in means and standard deviations associated with distributions of performance measures. In particular, crop yields and prices are modelled stochastically and used to calculate distributions of NPVs for the representative crop farms.

4.1.3 Representative Farms Simulation Model Structure

In this study cropping operations consider adoption of BMPs based on wealth maximization. NPV from baseline scenarios are compared to NPVs after BMP adoption. If BMPs produce a net positive effect then the practices are considered beneficial for the operation. Conversely, practices where net losses are observed are considered to result in a net cost for producers and would likely not be adopted without incentives. Cash flow and stochastic simulation are combined in this study to develop representative, farm-level models for cropping operations. Monte Carlo simulation is used, which allows incorporation of historical price and yield models to model uncertainty and risk of these variables. Monte Carlo simulation is also used to account for uncertainty effects from BMP adoption.

To begin, simulation models are developed that incorporate representative farm characteristics such as location, size, crop choice, and crop yields. Input costs such as seed, fertilizer, and herbicides, are added to the models according to the choice in crops grown and area of land allocated to each crop. There are many risks associated with agricultural production. Stochastic crop yield and price models are developed using historical data, accounting for risk from weather (i.e., weather affects yields) and markets. These stochastic yield and price models are incorporated into the farm level simulation models and used to determine net revenue of the operations. Agricultural risk is also incorporated via the discount rate, as cash flows are discounted in NPV analysis.

In modelling BMP adoption, both rotational and non-rotational BMPs are considered. Rotational BMPs affect the amount of land allocated to certain crops, and

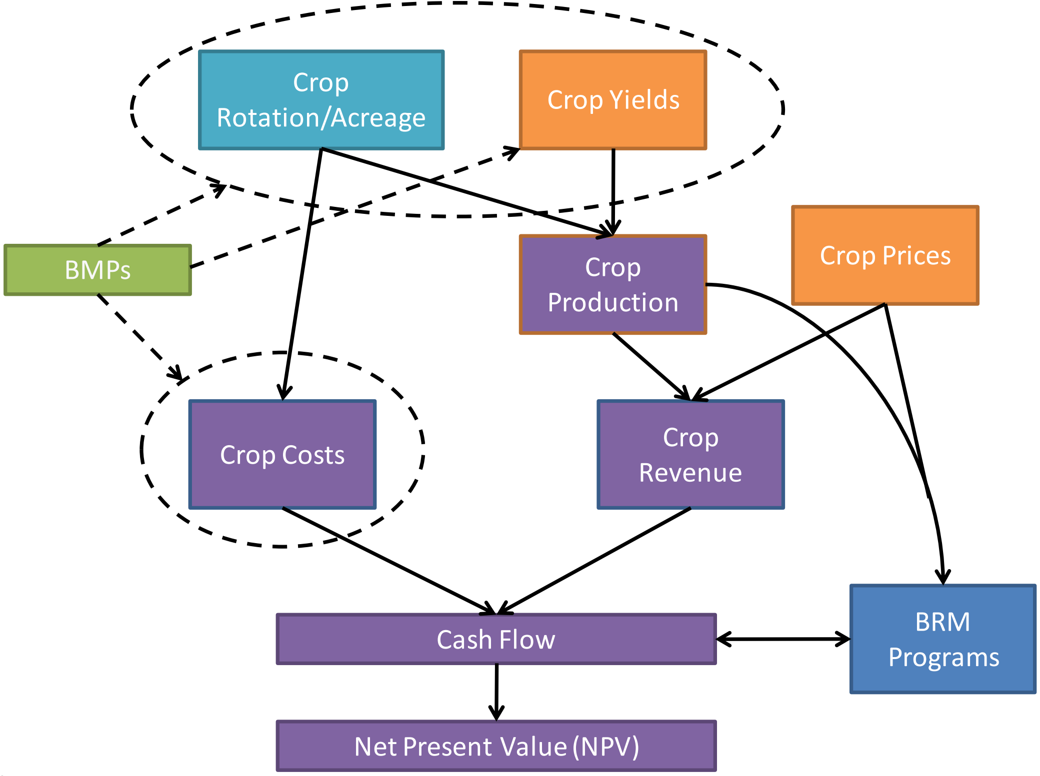
---

[6] An iteration is a set of random draws from a pre-defined probability distribution which are then used to calculate model variables. Monte Carlo programming is an iterative process in that these draws and resulting calculations are repeated to create a distribution of model outcomes.

therefore affect the revenue of the farms. There are also yield effects from adoption of most cropping BMPs. These yield effects affect crops following BMP crops and are modelled stochastically. The yield effects are drawn from distributions with minimum and maximum values, as determined from the literature. Non-rotational BMPs do not result in any change in crop rotations. However, in some cases adoption results in a change in total land available for crop production (e.g., establishment of a buffer strip). More information on BMP yield and acreage effects is provided in Chapter 5. In some cases effects from BMP adoption evolve or develop over time and in many cases all costs and benefits of BMP adoption are not apparent after just one period. Therefore dynamic modelling that considers many time periods is used to determine if BMP adoption is feasible.

Figure 4.1 is a schematic of the modelling techniques for the representative farms. Crop yields and prices are variables that are measured stochastically. It should also be noted that subsequent crop yield from BMP adoption are modelled stochastically. Business Risk Management (BRM) programs include AgriStability, AgriInvest, and crop insurance programs. Variables directly affected by BMP adoption include crop acreage, crop yields, and crop costs, as indicated by the dashed circles in Figure 4.1. The remaining boxes in the schematic including crop production, crop costs, crop revenues, cash flow, and NPV make up the basics of the cash flow relationships.

Figure 4.1 – Diagram of modelled farm relationships[a]



[a] The dashed circles enclose those parts of the model that are directly affected by adoption of BMPs.

4.2 Representative Farm Characteristics

This section discusses the characteristics that are representative of a typical farm in each region of interest. The representative farms considered for this study are commercial crop farms in Alberta. Farms are defined based on size as well as types of crops typically grown in each region. Commercial cropping operations have land bases that are larger than for an "average" farm (i.e., as would be suggested from Census data) and this is reflected in the representative farms for this project. The information presented in this chapter is determined using Census of Agriculture (2006 and 2001) data and expert opinion from Alberta Agriculture and Rural Development (AARD).

4.2.1 Farm Size

Farm size (i.e., hectares of land per operation) was determined based on the assumption that the modelled farms should be representative of commercial operations in each of the counties being used in the analysis. According to AARD (1999-a) commercially viable farms are at least 648 hectares (1600 acres). On this basis it was assumed that all representative farms will be at least this large. Using 2006 Census of Agriculture data, farms classified by total farm area are separated into the following four categories: 648 to 906 hectares (1600 to 2239 acres), 907 to 1165 hectares (2240 to 2879 acres), 1166 to 1425 hectares (2880 to 3519 acres), and 1426 hectares (3520 acres) and greater. These categories are chosen as they include farms that meet the minimum size requirement and they correspond to groupings in the Statistics Canada census data. The proportion of each grouping, relative to the total number of "commercial sized" farms in each County/Municipal District is used to determine the size of farm that is most common among commercial operations (Table 4.1).

Table 4.1 – Distribution of farms by size, representative Alberta counties (2006)

Farm Size (hectares)	Forty Mile	Starland	Camrose	Smoky River
648 – 906	50	47	79	39
907 – 1165	64	34	28	30
1166 – 1424	42	28	13	14
1425 +	128	34	24	29
Total Commercial Farms	284	143	144	112
Total Farms	602	364	1149	391

In establishing representative farm size for the various soil zones, individual Counties/Municipal Districts and the overall average farm size for the soil zone is considered. , In the County of Forty Mile (Brown soil zone) approximately 60% (42 and 128 farms) of commercial operations are in the larger two size categories and only 40% (50 and 64 farms) are in the smaller two size categories. The acreage for the farm in the Brown zone is thus set at 1295 hectares (i.e., 3200 acres or 20 quarter sections). In the Dark Brown soil zone and in Starland County approximately 57% and 43% of commercial farms are in the lower two and upper two size categories, respectively. However, the decision is made to have the Dark Brown soil zone farm the same size as the Brown soil zone farm at 1295 hectares (i.e., 3200 acres or 20 quarter sections). This decision was made to allow for easier comparisons between farms in the Brown and Dark Brown soil zones and is justified on the basis that if the smallest size category (i.e., 648-906 hectares) is excluded from consideration, the distribution of farms in the other three size categories is relatively even. In the Black soil zone, approximately 74% of farms are in the smaller two size categories, while only 26% are in the larger two soil categories. Therefore, the size of the representative farm in Camrose County (i.e., Black soil zone) is set at 1036 hectares (i.e., 2560 acres or 16 quarter sections). In the Dark Grey soil zone and in the M.D. of Smoky River approximately 38% of farms are in the larger two size categories and 62% of farms are in the smaller two size categories. Therefore the representative farm in the Dark Grey soil zone, in the M.D. of Smoky River is set at 777 hectares (i.e., 1920 acres or 12 quarter sections).

4.2.2 Crop Production and Rotation

An important consideration in defining the representative farms for this study is the set of crops to be produced and the associated crop rotations. According to the 2006 Census of Agriculture there were 2,334,512, 1,657,062, and 1,646,468 hectares of spring wheat, barley, and canola, respectively, grown in Alberta. These represent the top three annual crops under production in terms of area. However, growing conditions (i.e., soil quality, temperature and moisture conditions, etc.) vary across the province and so it might be expected that typical crop rotations will also vary for the representative farms. Crops and associated rotations are therefore chosen based on a) crop area in each representative county and soil zone using 2001 and 2006 Census of Agriculture data, and b) expert opinion from AARD.

Table 4.2 provides a summary of areas grown for common crops in each representative county, based on 2006 Census of Agriculture data. As is evident from the values in Table 4.2, in several of the counties alfalfa hay and other tame hay represent a significant proportion of crop area. It is likely that most of this hay production occurs on farms that have cattle. Since this study focuses on operations where the primary source of revenue is from sale of annual crops, hay is not considered for the baseline representative rotations.[7]

The information in Table 4.2 may be used to identify the “top” annual crops for each representative county, defined in terms of area grown. For the County of Forty Mile, the predominant crops grown, on an area basis, are spring wheat, durum wheat, oats, barley, and field peas. In the County of Starland spring wheat, barley, and canola represent the most prevalent crops. The same three crops (i.e., spring wheat, barley and canola) are also the top annual crops grown in the County of Camrose, with field peas and oats having smaller but still significant areas. Finally, canola and spring wheat are the dominant annual crops grown in the Municipal District of Smoky River, with oats and barley representing lesser (but still significant) areas.

---

[7] While hay is not part of the base rotations for any of the representative farms, it is included in the crop rotation BMPs for some of the farms, as a cash generating activity.

Table 4.2 – Areas of crops grown in representative counties in 2006

Crop	Forty Mile	Starland	Camrose	Smoky River
	Acreage (ha)[a]			
Alfalfa and alfalfa mixes	12,145	11,763	19,261	34,412
All other tame hay and fodder	4,564	4,424	11,591	6,450
Barley	28,329	30,011	33,619	7,785
Canola	8,117	28,227	72,266	76,447
Chick peas	7,041	N/A	N/A	N/A
Dry field peas	24,332	6,137	8,594	3,864
Durum wheat	46,155	550	N/A	N/A
Mixed grains	538	950	3,802	N/A
Oats	37,084	3,465	6,743	8,266
Other dry beans	6,545	N/A	N/A	N/A
Potatoes	1,263	3	N/A	N/A
Spring wheat	122,957	72,964	72,336	51,910
Sugar beets	N/A	N/A	N/A	N/A
Other crops	13,081	3,532	3,115	1,869

[a] N/A is used to denote crops for which acreages are not available due to the crop not being grown in the area or only being grown by a small number of producers (i.e., withheld due to confidentiality).

Source: Statistics Canada (2006)

As noted earlier, expert opinion from AARD is also used to establish crop rotations for the representative cropping operations. Expert opinion (Bergstrom, 2009) indicates that typical crop rotations for Alberta crop farms are comprised of approximately one-third wheat, one-third canola, with the remaining one-third being some combination of barley, peas, silage/forages, and specialty crops. As well, farms typically alternate cereals and broadleaf annuals from year to year within individual fields (Bergstrom, 2009) as a method to deal with potential diseases and reduced yields that may be associated with continuous cropping practices. Besides these general patterns, AARD crop experts also made suggestions as to the specific crops to include for farms in Southern Alberta, including the Brown and Dark Brown soil zone farms (Dunn, 2009).

One other source of information taken into account when deciding on crop rotations is the USDA's Crop Sequence Calculator (CSC) (USDA ARS, 2008). The CSC utilizes information on crop production, economics, plant diseases, weeds, water use, and surface soil properties to generate advice/recommendations for producers to use in evaluating risks associated with different crop sequences (USDA ARS, 2008). Research for the CSC was done at the Northern Great Plains Research Laboratory in Mandan, North Dakota from 1998 to 2005. The results provided by the CSC that are taken into consideration for the crop rotations include a) trends towards lower yields when a crop is grown on the residue from the same crop (i.e., two or more subsequent years of the same crop in the same field), and b) trends towards higher cereal grain yields and net returns when a cereal crop follows a pulse or oilseed crop.

A summary of the resulting base crop rotations for each of the representative farms is provided below. In presenting the crop rotation, abbreviations are used for each crop, as follows:

B - Barley
C - Canola
DB - Dry Beans
DW - Durum Wheat
SF - Summerfallow
SW - Spring Wheat

4.2.2.1 Brown Soil Zone

The base rotation for the farm in the Brown soil zone was an eight-year rotation consisting of SF – SW – C – DW – SF – B – C – SW. As with the irrigated farm, this rotation is based on expert opinion (Dunn, 2009). Dunn (2009) had indicated that actual rotations in this area would not include barley and would have a smaller proportion of summerfallow than is incorporated into the representative farm rotation. However, Census data (Table 5.2) suggest that barley is frequently included in crop rotations, and approximately one quarter of land used for cropland in this region is allocated to summerfallow. On the basis of Census data evidence, the eight year rotation provided above is used for this farm.

4.2.2.2 Dark Brown Soil Zone

For the Dark Brown soil zone the base rotation is a four year rotation consisting of SW – C – B – SF. Again, opinion from AARD (Dunn, 2009) suggested that summerfallow should be reduced or excluded for the rotation for this farm and that barley should perhaps be replaced with winter wheat. However, as was the case for the Brown soil zone farm, Census data indicate a significant portion of cropland was allocated to summerfallow in 2006. Barley had the second greatest area among annual crops in Starland, after spring wheat. As a result, the four year rotation provided above is used for this farm.

4.2.2.3 Black and Dark Grey Soil Zones

The base rotation for the Black and Dark Grey soil zones is a five-year rotation consisting of SW – C – B – SW – C. This is consistent with the 2006 Census of Agriculture data, as spring wheat, barley, and canola are the most common crops in the representative counties for these soil zones. The rotation is also consistent with the recommended alternating pattern of cereal/broadleaf crops. It was suggested by AARD expert opinion (Bergstrom, 2009) that field peas should be included in the base rotation in the Black soil zone. However, peas have a significantly lower area of production than the other three crops in the County of Camrose (Table 5.2). As a result, field peas are included only as part of a BMP crop rotation, as discussed later in this chapter.

4.2.2.4 Crop Rotation Summary

The crop rotations for each representative farm are “combined” with the area of cropland discussed earlier in this chapter (i.e., farm size), to arrive at the areas of crops grown each year by each farm. The area allocated annually for each crop is given in Table 4.3. Since they are grown in rotation, the crops grown on specific fields will change from year to year. However, the total area for each crop on each representative farm is assumed to be constant each year.

Table 4.3 – Annual crop production (in hectares) for base crop rotation, by representative farm

Crop	Brown Soil	Dark Brown Soil	Black Soil	Dark Grey Soil
Barley	162	324	208	155
Canola	324	324	414	311
Durum Wheat	162	0	0	0
Spring Wheat	324	324	414	311
Summerfallow	324	324	0	0
Total	**1295**	**1295**	**1036**	**777**

4.2.3 Machinery Complements

Each of the representative farms is assumed to have a machinery complement that is unique to farm location and size, and types of crops grown. The complement is defined in terms of the types and sizes of individual pieces of machinery required to complete cropping operations such as tillage, seeding, harvesting, etc. Activities associated with the machinery complement contribute to farm cash outflows and thus need to be considered explicitly within the modelling process. In particular, day-to-day use of machinery results in variable costs associated with fuel use, maintenance and repairs.[8] As well, machinery replacement decisions result in significant net cash outflows although these are irregular in terms of timing.

Modelling replacement decisions for farm machinery is problematic as factors such as economic feasibility would need to be considered in terms of the timing of the decisions. However, if machinery replacement or maintenance of the machinery asset base is not considered, the ability of producers to maintain normal cropping activities would be impaired. A compromise is used in this simulation analysis; specifically, a constant annual cost is calculated to account for machinery replacement. This annual value is the amount required to maintain the machinery complement at its initial asset value (i.e., at the beginning of the simulation time period). Similar approaches have been used in previous studies with cash flow modelling structures (Cortus, 2005; Koeckhoven, 2008). Other variable costs associated with machinery, such as repairs, are accounted for using input costs per crop per hectare, and are discussed in the crop input costs section of this chapter.

In order to determine the annual machinery maintenance cash flow amount, machinery complement information is required. This includes the types and sizes of machines present on each representative operation, the machinery book value as of the beginning of the simulation time period, and the annual loss in value (i.e., depreciation rate). This information is used to calculate the annual cash flow that is treated as a proxy for machinery replacement expenditures.

In this study, machinery complements are developed based on assumptions regarding required field operations for each representative farm and identifying appropriate machine types and sizes. Adjustments are made to allow for different soil zones, weather patterns, crops in rotation, farm size, and time available to perform

---

[8] Besides these costs, there would be additional potential machinery-related cash outflows in the form of debt servicing or lease payments. However, these are not explicitly considered in the analysis.

cropping operations. This approach to designing representative machinery complements is consistent with what has been used in other recent studies, such as Cortus (2005) and Koeckhoven (2008). The resulting machinery complements are then validated using expert opinion from AARD cropping specialists (Papworth, 2010).

In developing the machinery complements, the assumption is made that the farms use no-till practices. In particular, seed and fertilizer are placed in the soil with minimal disturbance to the previous year's stubble. Reducing soil disturbance allows for benefits such as reduced soil erosion, conservation of soil moisture and reduced likelihood of the emergence of weed species in the crop (AARD, 2004-a). One pass that places both the seed and fertilizer in the soil also improves the timeliness of seeding (Rotz et al. 1983) allowing more time to be allocated to other practices. Gray et al. (1996) also note that by reducing seeding time, machinery depreciation is slowed due to reduced hours on the tractors. As discussed earlier, no-till practices are recognized as a type of cropping BMP and so it would be possible to model this as one of the BMP scenarios in the current analysis. However, the number of producers using no-till or zero-till production practices has increased over time to a point where it may almost be considered the standard practice. In Alberta the use of no-till or zero-till seeding practices has increased from 27% of total land for seeding in 2001 to 48% of total land for seeding in 2006. In some specific regions of the province, this percentage is greater than 50%, as suggested in the discussion of representative counties in Chapter 3.

In developing machinery complements for each farm it is assumed that there are time constraints to cropping operations such as seeding, spraying and harvesting. Assumptions are made regarding the amount of time that is possible for each practice taking uncertainties such as weather into consideration. The size of implement required to complete the activity in the allocated time is determined next, beginning with the seeding implement. Cortus (2005) and Koeckhoven (2008) observed, based on information from sources such as the AARD Machinery Cost Calculator (2008) and SAF Farm Machinery Custom Rates (2008), that seeding implements require the most tractor horsepower. Therefore the size of the tractor (i.e., horsepower) is based on what is needed for the size of the seeding implement that allows for completion of seeding in a timely manner. Equation 4.2, from Edwards (2009) is used to calculate the required seeding implement width. Equation 4.3 (Edwards, 2009) is then used to calculate the required tractor horsepower. Determination of implement width and tractor horsepower requires some information about soil type and typical field efficiencies for different operations. Field efficiency represents the degree (in percentage terms) of maximum theoretical capabilities of machinery that is achieved in practice, accounting for overlap, slowing for turning in fields, and minor repairs. The assumed values used in these calculations are provided in Tables 4.4 and 4.5.

$$\text{Implement Width} = \frac{\text{Farm size (ha)}*10}{\text{Available time (hr)}*\text{speed}\left(\frac{\text{km}}{\text{hr}}\right)*\text{Efficiency coefficient}} \qquad (4.2)$$

$$\text{Tractor Horsepower} = \frac{\text{Implement width(ft)}*\text{Speed}\left(\frac{\text{km}}{\text{hr}}\right)*\text{Draft}\left(\frac{\text{lb}}{\text{ft}}\right)*\text{Soil factor}}{375} \qquad (4.3)$$

Table 4.4 – Values for soil factors

Soil Type	Type of Tractor[a]		
	2WD	*4WOA*	*4WD*
Firm soil	1.64	1.54	1.52
Tilled soil	1.75	1.61	1.56
Sandy or Soft soil	2.13	1.82	1.67

[a] 2WD, 4WOA and 4WD refer to two wheel drive, four wheel drive with optional assist, and four wheel drive tractors, respectively.

Source: Edwards (2009)

Table 4.5 – Values for field efficiency

Field Efficiency	Range	Efficiency Used
Tillage	70 - 85	0.8
Planting	65 - 85	0.75
Harvesting	60 - 80	0.7
Spraying	50 - 70	0.65

Source: Powell (2000)

Soil factor values represent index values reflecting the relationship between soil type/condition and tractor horsepower requirements. As indicated in Table 4.4, horsepower requirements increase with less firm soil. The representative farms in the Brown and Dark Brown soil zones are assumed to have sandy or soft soil.[9] Given that these farms are also assumed to have a four wheel drive tractor, a soil factor value of 1.82, as determined by Edwards (2008) for sandy or soft soils, is used in the tractor horsepower calculation. For the farms in the Black and Dark Grey soil zones it is assumed that soil is tilled. The Black soil zone farm is assumed to have a four wheel drive tractor, while the Dark Grey soil zone farm is assumed to have a four wheel drive tractor with optional assist. It was decided to use the tilled coefficients in estimating soil factors on the farms in the Black and Dark Grey soil zones as a middle ground between the coefficients since the referenced study from which these values were obtained was based on conditions in Iowa. Differences may be apparent for soils in Alberta, so to avoid going from one extreme to the other, from sandy to firm soil, the tilled coefficient is used even though the present analysis assumes no-till seeding technology is used.

Similar methods are used to determine the size of combine harvester, swather and harrows. The approximate time available to harvest is estimated based on the soil zone. The speed of the equipment is then used to determine the width of the combine header, swather header and harrow. The combine header width is used to choose the size of combine. This is done using SAF (2008) Farm Machinery Custom Rates, which places combines in Classes 5 to 7+ based on grain hopper size and horsepower. Additional equipment added to the machinery complement include farm and grain trucks, grain auger, different combine headers for certain crops, and machinery for specialty crops such as dry beans.

After the machinery complements are built according to the above criteria, opinion from farmers and government analysts is considered and changes are made regarding the size and type of machinery. For instance, it is suggested (Papworth, 2010)

---

[9] Soft or sandy soil is assumed in the Brown and Dark Brown soil zones as these regions have lower soil aggregates and lower soil organic matter, as compared to Black and Dark Grey soil zones (AARD, 2004-a).

that farmers would only own a self propelled, high clearance sprayer if more than 4,047 hectares are sprayed annually. As a result, it is assumed that custom spraying is used by all representative farms. The machinery complements for each representative farm are provided in Table 4.6.

Once the machinery complement for a representative farm is established, the book value at the beginning of the simulation period is determined. As discussed earlier, this represents the machinery asset value to be maintained through the simulation analysis. To establish this value, the age of each piece of machinery as of the beginning of the simulation period is required. For the purposes of this study, machinery for each farm is assumed to be five years of age.[10]

Given the machinery age, two alternative approaches are considered for calculating the initial machinery book values. The first approach involves obtaining new machinery values and depreciating them to five years of age. New machinery values are taken from SAF (2008) *Farm Machinery Custom and Rental Rate Guide 2008-09*. These values are depreciated to five years of age using depreciation rates of 8.5% for combines, 5.5% for tractors, and 7.5% for all other machinery (Unterschultz and Mumey, 1996). The annual average reduction in market value for irrigation systems is assumed to be 10% (MSUE, 2009).

These machinery book values are compared to results using machinery prices available for used machinery in Alberta through *IronSearch.com*, a web site for North American used machinery. A simple linear relationship between machinery price and machinery characteristics such as total machine hours, year of production, and horsepower is estimated using the linear regression function in Excel. The regression results are used to predict prices for machinery assumed to be present on the representative farms. These values are then compared to values obtained using the depreciated values based on Saskatchewan Agriculture and Food new machinery prices.

Only slight differences were apparent between the estimated book values calculated using the two methods. Therefore the estimates based on SAF (2008) new machinery values are used in the simulation analysis. The annual machinery replacement/maintenance cash flow expenditure per year is calculated by summing the total book value of the machinery and multiplying by an assumed depreciation rate of 8%. The complete list of all machinery and combined annual costs of machinery, assuming an average age of five years, are provided Table 4.6 and 4.7.[11]

---

[10] In practice, the machinery present on any particular farm will vary in age. However, in defining the representative farms it was decided to use five years as an average, for reasons of simplicity.

[11] Original new machinery values and initial simulation period book values used in these calculations are available from the authors on request.

Table 4.6 – Machinery complement for the representative farms

Soil Zone	Powered Equipment		Drawn Equipment		Attachments & Misc. Equipment	
	Description	**Size**	**Description**	**Size**	**Description**	**Size**
Brown, dryland	4WD Tractor	425 h.p.	Air Hoe Drill	50 ft.	Combine header - pick up	14 ft.
	S.P. Swather	30 ft.	Harrows	60 ft.	Combine header - flex	25 ft.
	Combine	Class 6			Grain Auger	10 "
	Grain Truck 1	350 h.p.				
	Grain Truck 2	350 h.p.				
	Farm Truck	3/4 ton				
Dark Brown	4WD Tractor	425 h.p.	Air Hoe Drill	50 ft.	Combine header - pick up	16 ft.
	S.P. Swather	30 ft.	Harrows	80 ft.	Combine header - flex	36 ft.
	Combine	Class 7+			Grain Auger	10 "
	Grain Truck 1	350 h.p.				
	Grain Truck 2	350 h.p.				
	Farm Truck	3/4 ton				
Black	4WD Tractor	325 h.p.	Air Seeder	50 ft.	Combine header - pick up	16 ft.
	S.P. Swather	30 ft.	Cultivator	50 ft.	Combine header - flex	36 ft.
	Combine	Class 7+	Harrows	80 ft.	Grain Auger	10 "
	Grain Truck 1	350 h.p.				
	Grain Truck 2	350 h.p.				
	Farm Truck	3/4 ton				
Dark Grey	4WOA Tractor	225 h.p.	Air Seeder	40 ft.	Combine header - pick up	14 ft.
	S.P. Swather	24 ft.	Cultivator	40 ft.	Combine header - flex	30 ft.
	Combine	Class 7	Harrows	50 ft.	Grain Auger	10 "
	Grain Truck 1	350 h.p.				
	Grain Truck 2	350 h.p.				
	Farm Truck	3/4 ton				

Table 4.7 – Total annual machinery replacement cost by representative farm

Farm	Dryland Brown	Dark Brown	Black	Dark Grey
per acre	$16.82	$17.95	$21.86	$25.64
per hectare	$41.56	$44.37	$54.02	$63.35

4.3 Stochastic Simulation Model Parameters

This section provides a discussion of the information, estimations, and calculations involved in developing the simulation model parameters that are assumed to be stochastic for the representative cropping operations. As noted earlier, Monte Carlo simulation techniques are used in this analysis in order to allow for stochastic parameters to be modelled for the representative farms. In this way, the simulation analysis accounts for sources of risk in agricultural production. Major sources of production risk in cropping agriculture include uncertainty regarding weather, pests and disease, and the quality of inputs. There is also often market risk arising from uncertain commodity prices. Moss and Shonkwiler (1993) stated that the distributions of commodity prices and yields that represent risk are critical in firm level analysis. Given their potential importance production and price risks are incorporated in the modelling to examine the impact of cropping BMPs for the representative farms. These stochastic elements interact with other variables in the models including crop insurance, safety net programs, and other costs and revenues. Details on how the yield and price relationships are estimated and validated and then included in the cash flow models are also provided in this section.

4.3.1 Crop and Forage Yield Models[12]

Crop yields are modelled in the simulation analysis using yield distributions that are based on historical crop yield data from the counties used to define the representative farms. Crop yield data (1978 to 2008) for the defined representative counties, were obtained from Agriculture Financial Services Corporation (AFSC) for the crops that are included in the base rotations, discussed earlier in this chapter. The data obtained were for dryland crop production in all counties. Historical yields were also obtained for additional crops that are included in some of the crop rotation BMPs; specifically, alfalfa hay, field peas, and legume green manures.

4.3.1.1 Estimation of Crop and Forage Yield Variables

Before the yield data can be used to estimate distribution parameters, they must first be tested for a time trend. Variability in yields over time may arise from production risk, but may also be due to changes in technology or technical change. Year-to-year variability may be overstated if the effects of technical change are not "removed". This is done by de-trending the yield data. First, the yield data are tested for a time trend using a simple regression of yield (Y) on time (t) as shown in Equation 4.4. A statistically significant positive slope may be an indication of progressive technical change. In that case, the yield data are de-trended using the residuals (i.e., observed minus predicted) from the regression. The residuals are added to the predicted yield value for the base year (2008) to obtain a de-trended yield series. The year 2008 is used as the base year as it represents the most recent yields available at the time of the analysis. This is important in order to be as consistent (time-wise) as possible with the base year for crop costs. A t-test is used to test for the presence of a time trend, with the null hypothesis that $\beta = 0$ in equation 4.4 (i.e., no time trend).

$$Y_t = \alpha + \beta t + \varepsilon_t \tag{4.4}$$

The time trend results are mixed, with several of the crop yields having a significant positive time trend (i.e., rejection of the null hypothesis using a 5% level of

---

[12] Crop yield data, summaries of statistical testing using these data, and the crop correlation coefficients used in the simulation analysis are available from the authors upon request.

significance). These are canola in the County of Forty Mile[13], spring wheat and canola in the County of Camrose, and spring wheat, barley, canola and oats in the Municipal District of Smoky River. For the purposes of this study when yields are required to be de-trended based on the time trend test results, the 2008 predicted yield values are used as the basis for calculating the de-trended yield series.

Once the necessary time series are de-trended, the yield data are fitted to distributions; that is, the distribution parameter estimates to be used in the simulation model are calculated. This is done using the “Fit Distributions” option in *@RISK*. Goodness-of-fit tests are used to determine the best fitting distributions for a given set of data. A wide range of potential distributions are available for consideration in this analysis, including symmetrical and asymmetrical distributions, truncated distributions, etc.

An important consideration in modelling crop yield distributions is the fact that the distribution should be truncated at zero; that is, it should exclude the possibility of negative yields. This excludes the normal distribution (along with many other distributions) from consideration. Distributions that have the property of potentially being truncated at zero include the Exponential, Gamma, LogNormal, Triangle, Uniform, and Weibull distributions. These distributions are then considered for possible use in modelling crop yields for the current study.

For the purposes of this analysis goodness-of-fit is established using the Kolmogorov-Smirnov (K-S) test statistic. The goodness-of-fit test results indicate that the Weibull distribution is, in most cases, the “best fitting” distribution of those that meet the truncation requirement. The only exceptions to this are durum wheat (i.e., third best fit after the Gamma and LogNormal distributions) and spring wheat (i.e., third best fit after the LogNormal and Gamma distributions) in Taber, and spring wheat (i.e., second best fit after the Gamma distribution) in Smoky River.

Based on these results it was decided to use the Weibull distribution to model crop yields. A single type of distribution is used for all crops and farms in order to be consistent across the crops and to allow comparison between representative farms. The Weibull distribution is characterized by being bound at zero, non-symmetrical, and permits a wide range of skewness and kurtosis. The Weibull distribution is characterized by the probability density function:

$$f(x) = \alpha x^{\alpha-1} \frac{\alpha x^{\alpha-1}}{\beta^{\alpha}} \exp\,[-(\frac{x}{\beta})^{\alpha}] \tag{4.5}$$

Source: Palisade Corporation (2007)

where α represents the shape parameter and β represents the scale parameter.

Besides the individual crop yield distributions, correlations are also required in order to model stochastic crop yields in the simulation analysis. Environmental factors such as weather affect crops in a similar fashion and as a result it is likely that in many cases yields for crops on a given farm are positively correlated. The program *@RISK* has a built in correlation function that allows for stochastic variables to be correlated in a simulation analysis.[14] Correlation coefficients between crops, based on 2004 to 2006 field

---

[13] The canola yield data for the County of Forty Mile include years where a zero yield is recorded. The zero(s) are assumed to represent missing data and so are removed from the time series prior to testing for the time trend.

[14] The *@RISK* function “CORRMAT” is used to correlate crop yield values that are sampled from different distributions. This function allows the variables to be correlated but still have the uncertainty from the stochastic Weibull distributions. The formulae used in *@RISK* combines the

level data from Alberta crop insurance risk regions[15], were obtained from AARD. These correlations are used in modelling stochastic crop yields in the simulation analysis, versus correlations based on municipal level yield data, because the modelling is performed at the farm level. As such, correlations calculated at the field level are more appropriate, since the level of aggregation of yield variability is closer in magnitude than is the case for municipal level values.

Crops that did not have data available for a reasonable and/or continuous period of time include field peas, legume green manures, and alfalfa hay. For these crops, variability (i.e., risk) in yields is modelled using the correlation between these yields and a reference crop. In this case, barley is used as the reference crop for all farms as it has been shown to be appropriate for this purpose in previous studies (Koeckhoven, 2008). Field-level correlations from AARD (2007-b) are also used for these crops.

The yields for field peas, legume green manures and alfalfa hay (i.e., the unknown crop yields) in any period are based on their average yields, the change in barley (or spring wheat) yield from the previous to the current period and the yield correlations from AARD. Equation 4.6 shows this relationship where $Y_{unknown,t}$ is the calculated yield (in kg/ha) of the unknown crop, $E[Y_{unknown}]$ is the estimated yield of the unknown crop, ΔY_{barley} is the change in barley (or spring wheat) yield from the previous to current period, and $\rho_{barley,,unknown}$ is the AARD correlation coefficient between barley (or spring wheat) and the unknown crop. The barley-legume green manure correlation used in the analysis for all representative farms is 0.3. For barley-field peas, correlation coefficients of 0.631, 0.757, and 0.429 are used for Forty Mile/Starland, Camrose and Smoky River, respectively. The yield correlation used for barley-alfalfa/grass hay (and spring wheat-alfalfa/grass hay) for all representative farms is 0.3.

$$Y_{unknown,t} = E[Y_{unknown}] * [1 + (\Delta Y_{barley} * \rho_{barley,unknown})] \qquad (4.6)$$

4.3.1.2 Maximum Crop Yield Limits

Given the stochastic nature of crop yields in the simulation analysis and the distributional assumption for crop yields, there is potential for simulated crop yields that are unrealistically high. As well, some of the BMPs modelled in this study are assumed to have positive yield effects, as discussed later in the chapter. This also contributes to the possibility of having simulated crop yields that are unrealistic in magnitude, as in some cases the BMPs are considered in combination which further increases the potential for higher yields.

To account and correct for this possibility, a maximum restriction is imposed on final simulated crop yields. Maximum yields are determined using the municipal crop yield data that were available. In each case, the maximum was set at the maximum observed yield from the municipal data, plus one standard deviation from historical yield data to account for increased variability at the farm level. The maximum yields, in kilograms per hectare, are displayed in Table 4.8. Maximum yield for the farm in the Brown soil zone is not necessary as it is assumed that of crops adopted as a BMP that may improve subsequent crop yields this representative farm only considers field peas.

"RISKWEIBULL(a,b)" and "RISKCORRMAT(c,d)" functions where the variables in the latter, c and d are drawn from correlation matrices from AARD.

[15] There are 22 crop insurance risk regions in Alberta (AFSC, 2011). The Brown (dryland) representative farm is located in crop risk area 3. The Dark Brown representative farm is located in crop risk area 8. Finally, the Black and Dark Grey representative farms are located in crop risk areas 12 and 19, respectively.

The potential subsequent yield increase from this crop in this region is maximized at 10%, which is below any set maximum values using the above criteria.

Table 4.8 – Crop yields with maximum restrictions (kg/ha)

Soil zone	Alfalfa Hay	Barley	Canola	Durum Wheat	Spring Wheat
Dark Brown	6,000.00	4,415.21	2,464.57	N/A[a]	3,644.96
Black	6,358.00	4,786.53	2,900.29	N/A[a]	4,456.14
Dark Grey	5,081.50	4,846.27	2,871.00	N/A[a]	4,618.41

[a] N/A denotes "not applicable" as these crops were not considered in the corresponding soil zone.

4.3.1.3 Validation and Adjustment of Crop and Forage Yield Variables

The estimated crop yield distributions and correlations are tested using *@RISK* to determine if they generate simulated yields that match the historical data in terms of means, variance and correlations. This is referred to as validation of the yield models. To test if the estimated crop and forage yield variables accurately estimate the historical correlations, a simulation is run for each farm using *@RISK*. The model is run for 1,000 iterations and the resulting sample correlations calculated from the simulation results are tested for equivalence with the correlation coefficients obtained from AARD. While the calculated correlation coefficients are not exactly the same as the historical values there is no statistically significant difference (based on a 5% level of significance) between the simulated means of the yield data and the de-trended historical yields, for all districts and crops considered. For all crops in all regions the p-value for t-tests assuming unequal variances between de-trended historical yields and simulated yields was greater than 0.42.

Yield data are often recorded and available at a more aggregate level that may not be representative of farm level yields (Just and Weninger, 1999). This presents a problem in terms of aggregation bias related to yield variability. Farm level yield variability is greater than the variability of yields measured at an aggregate level (Marra and Schurle, 1994). To correct for aggregation bias Marra and Schurle (1994) identify an adjustment process. In their study, which compared farm level and county level yield data, they adjusted the county level variability upwards by 0.1% for each percentage difference in county acreage and average farm acreage within the county. This method is also used by Cortus (2005) and Koeckhoven (2008) to correct for biases in yield variability.

In this study, yields are available at a county level, while the simulation is conducted at the farm level. For the crop yield models in this study the variability is adjusted in a similar manner, but rather than using the total county acreage and total farm acreage, the total acreage grown for each crop and the acreage grown on the representative farms for the same crop is used. Once the appropriate standard deviation is calculated using the Marra-Schurle method the α and β parameters (i.e., the shape and scale parameters) in the Weibull distributions are adjusted in an ad hoc manner so that the variance reflected by the distribution is increased to match the value obtained from the Marra-Schurle adjustment, without changing the distribution mean. Tables 4.9 to 4.12 provide the different standard deviations for each crop in each representative county where "Actual" is the standard deviation calculated from the historical (aggregate) data, "Weibull fitted" is the standard deviation from the original Weibull distribution fitted to the data, and "Marra-Schurle (M-S) Corrected" is the adjusted standard deviation that is used in the analysis.

Table 4.9 – Standard deviation adjustments for estimated crop yields in the County of Forty Mile

	Crop			
Standard Deviation[a] (kg/ha)	Barley	Canola	Durum wheat	Spring wheat
Actual	653.49	350.38	606.51	531.35
Weibull fitted	581.86	345.78	564.5	478.27
Marra-Schurle (M-S) Corrected	767.21	358.82	778.83	732.62
% Difference (Fitted and M-S)	31.85%	3.77%	37.97%	53.18%

[a] Actual is the standard deviation calculated from the historical (aggregate) data, Weibull fitted is the standard deviation from the original Weibull distribution fitted to the data, and Marra-Schurle (M-S) Corrected is the adjusted standard deviation that is used in the analysis.

Table 4.10 – Standard deviation adjustments for estimated crop yields in the County of Starland

	Crop			
Standard Deviation[a] (kg/ha)	Barley	Canola	Durum wheat	Spring wheat
Actual	636.71	383.11	670.99	493.21
Weibull fitted	587.33	378.93	646.68	471.62
Marra-Schurle (M-S) Corrected	754.11	416.13	672.60	603.87
% Difference (Fitted and M-S)	28.40%	9.82%	4.01%	28.04%

[a] Actual is the standard deviation calculated from the historical (aggregate) data, Weibull fitted is the standard deviation from the original Weibull distribution fitted to the data, and Marra-Schurle (M-S) Corrected is the adjusted standard deviation that is used in the analysis.

Table 4.11 – Standard deviation adjustments for estimated crop yields in the County of Camrose

Standard Deviation[a] (kg/ha)	Crop			
	Barley	Canola	Oat	Spring Wheat
Actual	733.65	354.31	651.18	543.87
Weibull fitted	654.35	310.12	594.77	471.92
Marra-Schurle (M-S) Corrected	766.63	367.35	627.05	559.10
% Difference (Fitted and M-S)	17.16%	18.45%	5.43%	18.47%

[a] Actual is the standard deviation calculated from the historical (aggregate) data, Weibull fitted is the standard deviation from the original Weibull distribution fitted to the data, and Marra-Schurle (M-S) Corrected is the adjusted standard deviation that is used in the analysis.

Table 4.12 – Standard deviation adjustments for estimated crop yields in the Municipal District of Smoky River

Standard Deviation[a] (kg/ha)	Crop			
	Barley	Canola	Oat	Spring Wheat
Actual	535.37	285.84	670.70	515.27
Weibull fitted	501.45	297.92	621.98	512.51
Marra-Schurle (M-S) Corrected	527.34	375.16	663.51	603.24
% Difference (Fitted and M-S)	5.16%	25.93%	6.68%	17.70%

[a] Actual is the standard deviation calculated from the historical (aggregate) data, Weibull fitted is the standard deviation from the original Weibull distribution fitted to the data, and Marra-Schurle (M-S) Corrected is the adjusted standard deviation that is used in the analysis.

Table 4.13 – Crop yield means from historical data, Weibull distribution crop yield means, and Weibull parameters, by county and crop

County	Crop	Yield Mean (kg/ha)[a]	Weibull Mean (kg/ha)	Weibull α	Weibull β
Forty Mile	Barley	2260.45	2258.52	4.39	2478.30
	Canola	938.79[b]	937.87	2.95	1051.00
	Durum wheat	1970.45	1968.54	3.90	2174.80
	Spring wheat	1835.22	1835.62	4.34	2015.70
Starland	Barley	2656.57	2635.87	5.15	2865.80
	Canola	1272.80	1268.64	3.73	1405.10
	Durum wheat	2295.63	2276.46	3.95	2513.50
	Spring wheat	2369.40	2158.99	5.27	2344.40
Camrose	Barley	2981.82	2971.59	5.22	3228.40
	Canola	1940.66[b]	1933.55	7.36	2061.70
	Oat	2430.41	2411.68	4.61	2639.00
	Spring wheat	3044.40[b]	3036.66	7.61	3232.40
Smoky River	Barley	3556.14[b]	3566.26	8.47	3776.50
	Canola	1830.38[b]	1826.35	7.23	1949.20
	Oat	3536.55[b]	3548.00	6.69	3802.00
	Spring wheat	3088.76[b]	3092.79	7.11	3303.70

[a] Yield means are from historical data and are detrended if a significant trend is present. [b] Denotes crop yields that are detrended prior to further analysis.

Mean yields in the Weibull distributions were also affected slightly by adjusting the standard deviations. Table 4.13 provides the yield mean for each relevant crop by county, the adjusted mean from standard deviation corrections, and the associated Weibull shape (α) and scale (β) parameters.

4.3.2 Crop and Forage Price Models[16]

Along with crop yields, crop prices are also modelled as stochastic parameters in the simulation analysis. Price data for barley, canola, oats, field peas and tame hay were obtained from AARD. Price data for Canadian hard red spring and durum wheat were obtained from the Canadian Wheat Board (CWB) and assumed to be of No. 1 grade with 13.5% protein for both types of wheat. It is assumed that a common crop commodity price is applicable for all crops in all regions of Alberta. As a result the same price data and resulting price models are used for all representative farms.

Price data from 1984 to 2008 are used in estimating the price models. While longer price series are available for some crops, there are limited data available for field peas because this crop has a shorter history of significant production in Alberta. Prior to use in statistical analysis the crop price data were adjusted for inflation using Consumer Price Index (CPI) from Statistics Canada (2009).

4.3.2.1 Price Model Estimation Procedures

In this study, crop prices are simulated using time series modelling. In particular, current prices are a function of lagged prices.[17] The crop price model is estimated using Seemingly Unrelated Regression (SUR) using the software *SHAZAM* (*SHAZAM* User Manual, 2008). Each equation in the SUR model can be estimated independently. However, estimating them as a system allows for consideration that there may be exogenous (i.e., non-modelled) variables affecting all of the dependent variables (i.e., the prices) in a similar way. This would result in error terms for the individual price equations being correlated. SUR recognizes and incorporates the correlation of the errors between the equations. For historical price series this type of estimation is important as it is possible that an event that causes price fluctuations in one crop may also affect other crop prices.

In order to proceed with the SUR estimation, it is first necessary to determine the appropriate number of lagged prices to use as explanatory variables in the price equations. The Akaike Information Criterion (AIC) and Schwarz Criterion (SC) are used to determine the appropriate lag length for each crop price, prior to SUR estimation. AIC and SC are measures of goodness of fit for statistical models used to determine optimal lag length. Each commodity price equation is estimated individually using Ordinary Least Squares (OLS) with one to five lags. A maximum of five lags was chosen as there are only 24 years of price data available. Including too many lags reduces the degrees of freedom, which may cause low model significance. AIC and SC statistics are calculated for each estimation. The results are compared and the optimal lag length is defined by the

---

[16] Crop price data, along with summaries of statistical testing using these data, are available from the authors upon request.

[17] The use of this approach requires prices to be stationary; that is, variances and covariances are finite and independent of time. This assumption is tested using Augmented Dickey Fuller and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests. A majority of prices were deemed to be stationary based on the results from these two tests. Given these results, it was decided to use time series modeling for all crop prices in this study.

lowest AIC or SC value. In cases where the two criteria differ in terms of optimal lag length the AIC result is used to determine optimal lag length as it has been shown to be a superior measure in some infinite and finite Vector Autoregression (VAR) models (Kilian, 2001).

The AIC and SC results are shown in Table 4.14. The optimal lag length for spring wheat, durum wheat, barley, and field peas is determined to be three years, while the lag length is two years for the crops canola and oats. Tame hay has an optimal lag length of five years and there is indication that the AIC would decrease further if the equations were estimated with more than five lags. However, due to diminishing degrees of freedom with additional lags it is decided to use five lags for tame hay price.

Table 4.14 – AIC and SC values for lagged price equations

	Lags	1	2	3	4	5
Spring Wheat	AIC	0.00351	0.00264	0.00242	0.00254	0.0027
	SC	0.00357	0.00306	0.00294	0.00324	0.0037
Durum Wheat	AIC	0.00641	0.00533	0.00521	0.00554	0.0059
	SC	0.00707	0.00617	0.00633	0.00707	0.00791
Barley	AIC	0.00147	0.00102	0.00010	0.00108	0.00112
	SC	0.00162	0.00118	0.00121	0.00138	0.0015
Canola	AIC	0.00891	0.00713	0.00753	0.00777	0.00798
	SC	0.00982	0.00825	0.00916	0.00991	0.0107
Oats	AIC	0.00149	0.00132	0.00143	0.00155	0.00156
	SC	0.00164	0.00153	0.00175	0.00198	0.00209
Field Peas	AIC	0.00512	0.00465	0.00453	0.00468	0.00436
	SC	0.00564	0.00538	0.0055	0.00597	0.00585
Tame Hay	AIC	0.00093	0.00067	0.00065	0.00056	0.0005
	SC	0.00103	0.00078	0.00079	0.00072	0.00066

The resulting price equations for SUR analysis are provided in Equation 4.7 to 4.13, where P_t^{SW}, P_t^{DW}, P_t^{B}, P_t^{C}, P_t^{O}, P_t^{FP}, P_t^{AH} are the prices of spring wheat, durum wheat, barley, canola, oats, field peas and alfalfa hay respectively. P_{t-n}^{i} is the price in period *t-n* for crop *i*, ε_t^{i} is the error term in time *t* for crop *i*, and $\beta^{i}{}_{1}$ to $\beta^{i}{}_{n}$ are the coefficients on the lagged price variables.

$$P_t^{SW} = \beta^{SW}{}_0 + \beta^{SW}{}_1\, P_{t-1}^{SW} + \beta^{SW}{}_2\, P_{t-2}^{SW} + \beta^{SW}{}_3\, P_{t-3}^{SW} + \varepsilon_t^{SW} \tag{4.7}$$

$$P_t^{DW} = \beta^{DW}{}_0 + \beta^{DW}{}_1\, P_{t-1}^{DW} + \beta^{DW}{}_2\, P_{t-2}^{DW} + \beta^{DW}{}_3\, P_{t-3}^{DW} + \varepsilon_t^{DW} \tag{4.8}$$

$$P_t^{B} = \beta^{B}{}_0 + \beta^{B}{}_1\, P_{t-1}^{B} + \beta^{B}{}_2\, P_{t-2}^{B} + \beta^{B}{}_3\, P_{t-3}^{B} + \varepsilon_t^{B} \tag{4.9}$$

$$P_t^{C} = \beta^{C}{}_0 + \beta^{C}{}_1\, P_{t-1}^{C} + \beta^{C}{}_2\, P_{t-2}^{C} + \varepsilon_t^{C} \tag{4.10}$$

$$P_t^{O} = \beta^{O}{}_0 + \beta^{O}{}_1\, P_{t-1}^{O} + \beta^{O}{}_2\, P_{t-2}^{O} + \varepsilon_t^{O} \tag{4.11}$$

$$P_t^{FP} = \beta^{FP}{}_0 + \beta^{FP}{}_1\, P_{t-1}^{FP} + \beta^{FP}{}_2\, P_{t-2}^{FP} + \beta^{FP}{}_3\, P_{t-3}^{FP} + \varepsilon_t^{FP} \tag{4.12}$$

$$P_t^{AH} = \beta^{AH}{}_0 + \beta^{AH}{}_1\, P_{t-1}^{AH} + \beta^{AH}{}_2\, P_{t-2}^{AH} + \beta^{AH}{}_3\, P_{t-3}^{AH} + \beta^{AH}{}_4\, P_{t-4}^{AH} + \beta^{AH}{}_5\, P_{t-5}^{AH} + \varepsilon_t^{AH} \tag{4.13}$$

4.3.2.2 Crop Price Model Results and Incorporation

The SUR crop price model results are provided in Table 4.15. All estimated constants are statistically significant at the 1% level. All first lag price coefficients are also significant. However, some lagged prices are not statistically significant. As well, some individual R-squared goodness-of-fit measures are relatively low and range from 0.1249 to 0.6194. However, the overall model R-squared is 0.9358 with a Log-Likelihood Function (LLF) of 398.50, indicating that together the equations provide a relatively reliable model to predict crop commodity prices.

Table 4.15 – SUR model estimated coefficients

Variable	Spring Wheat	Durum Wheat	Barley	Canola	Oats	Field Peas	Alfalfa Hay
Lag 1	0.5256***	0.4366**	0.4785***	0.9167***	0.2961**	0.9353***	0.6157***
	(0.2027)	(0.2000)	(0.1241)	(0.1371)	(0.1408)	(0.1410)	(0.1767)
Lag 2	-0.6901***	-0.5414**	-0.4152***	-0.5677***	-0.3017**	-0.6712***	0.0074
	(0.1961)	(0.2399)	(0.1309)	(0.1371)	(0.1394)	(0.1820)	(0.2197)
Lag 3	0.1168	-0.1188	-0.1229			0.1378	-0.3914*
	(0.1854)	(0.2101)	(0.0983)			(0.1240)	(0.2167)
Lag 4							0.0922
							(0.1778)
Lag 5							0.0054
							(0.1378)
Constant	0.2236***	0.2800***	0.1476***	0.2559***	0.1461***	0.1274***	0.0673***
Std. Error	0.0422	0.0636	0.0230	0.0435	0.0323	0.0289	0.0148
R-sq'd	0.1918	0.2804	0.4362	0.6194	0.1249	0.6149	0.4974

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

Annual prices used in the simulation are determined using the estimated SUR system of equations; that is, using lagged prices. The stochastic aspect of the price modelling is introduced through the error term for each equation. The error terms for the commodity price models are estimated in *@RISK* assuming a standard normal distribution (i.e., ~N(0,1)). However, since it is assumed that the price equation errors are correlated, they must be adjusted accordingly and scaled by the standard deviation (Hull, 2003). The error correlations are calculated using the following formulae from Hull (2003):

$$\varepsilon_m = \sum_{k=1}^{k=m} \delta_{mk}\, x_k, \text{ subject to:}$$
$$\sum \delta_{mk}^2 = 1,$$
$$\sum_k \delta_{mk}\, \delta_{jk} = \rho_{m,j} \qquad (4.14)$$

where ε_m is the corrected error term for the commodity 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 price m and j, and δ_{mk} are the terms estimated from the constraints.

There are seven crop prices to be estimated. However, if more than four prices are considered simultaneously, the correlated error equations become extremely complicated to estimate using the above formula.[18] As a result, the crop prices are divided into groups, which are considered separately. The error correlations for crop prices from the SUR estimation are used to decide which crop errors are grouped together to be correlated with each other. The correlation estimates are examined and an ad hoc procedure is used to identify sub-groupings where there are strong positive correlations between the error terms for the different crops. These are used as an indication that the exogenous factors tend to have a common effect on the error term in terms of magnitude and sign, and so are likely candidates to have their error terms correlated with each other.

The SUR estimated error correlations are shown in Table 4.16. Based on the correlation estimates, it is decided that barley and oat prices are grouped together and their errors correlated, canola and field pea prices represent another grouping for error correlation, spring wheat and durum wheat prices are grouped together, and hay prices will be estimated independently of the other crop prices.

Table 4.16 – SUR estimated error correlations.

	ε^{SW}	ε^{DW}	ε^{BAR}	ε^{CAN}	ε^{OAT}	ε^{FP}	ε^{AH}
ε^{SW}	1.0000						
ε^{DW}	0.8539	1.0000					
ε^{BAR}	0.1241	0.4180	1.0000				
ε^{CAN}	0.2682	0.4380	0.3399	1.0000			
ε^{OAT}	-0.0508	0.1940	0.8269	0.0756	1.0000		
ε^{FP}	0.3231	0.3117	0.4237	0.6989	0.0804	1.0000	
ε^{AH}	0.0486	0.0543	0.0214	0.0651	0.3554	-0.1111	1.0000

Given the sub-groupings identified for the crop prices, the corrected error terms are found by solving for the δ_{mk} terms, as follows:

$$\varepsilon_B = x_B \tag{4.15}$$

$$\varepsilon_O = \rho_{B,O} x_B + \left(\sqrt{1-\rho_{B,O}^2}\right) x_O \tag{4.16}$$

$$\varepsilon_C = x_C \tag{4.17}$$

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

$$\varepsilon_{SW} = x_{SW} \tag{4.19}$$

$$\varepsilon_{DW} = \rho_{SW,DW} x_{SW} + \left(\sqrt{1-\rho_{SW,DW}^2}\right) x_{DW} \tag{4.20}$$

$$\varepsilon_{AH} = x_{AH} \tag{4.21}$$

where subscripts *B*, *O*, *C*, *FP*, *SW*, *DW*, and *AH* represent barley, oat, canola, field pea, spring wheat, durum wheat, and alfalfa hay commodity price respectively.

---

[18] More than four correlated error equations are simple to calculate using the Cholesky Decomposition. However this approach was not used to be consistent with similar previous studies (i.e., Cortus, 2005 and Koeckhoven, 2008).

4.3.2.3 Validation of Crop Price Models

Since crop prices were assumed to be stationary, simulated results are tested with historical prices to confirm crop prices are modelled accurately and that the assumption of stationarity is reasonable. Historical mean prices (1984 – 2008) are compared with simulated mean prices (40 year simulation period). To compare the results t-tests assuming unpaired samples were conducted for each crop with the null hypothesis that the historical means are equal to the simulated means. Results of the mean prices and t-test p-values are provided in Table 4.17. In all cases the p-value is greater than 0.05 and there is failure to reject the null hypothesis that the means are assumed to be equivalent. Therefore, the assumption of price stationarity is reasonable as there are no significant differences between historical crop prices and simulated crop prices.

Table 4.17 – Comparison of historical price data and @*RISK* simulated values for crop prices ($/kg)

Crop	Historical Mean	@*RISK* Simulated Mean	t-test p-value
Barley	0.1460	0.1390	0.3490
Canola	0.4095	0.3948	0.4235
Durum Wheat	0.2403	0.2296	0.5084
Field Pea	0.2398	0.2137	0.0826
Hay	0.1087	0.1007	0.1904
Oats	0.1503	0.1452	0.4880
Spring Wheat	0.2244	0.2144	0.3900

4.4 Economic Relationships

The farm simulation models are calculated using cash flow analysis to determine the NPV of each representative farm. A modified net cash flow (MNCF) is calculated annually for each representative farm. The MNCFs are discounted and summed to obtain an NPV for each operation. This section provides an explanation of the cash flow calculations and the connections between revenues and costs in crop production. Revenues arise largely from crop sales which in turn depend on stochastic crop yields and prices and as such annual variability in revenues is expected. The costs associated with crop production include input costs such as seed, fertilizer, fuel, etc. Input costs vary between the farms based on spatial location and are calculated based on average current production costs by soil zone in Alberta (AARD, 2010-b). Other sources of cash flows include crop insurance, the safety net programs AgriStability and AgriInvest, and machinery costs. These are also discussed in this section.

4.4.1 Revenues

Revenues from crop production are calculated from the simulated crop yields and prices. As discussed previously, crop yields are estimated directly from the fitted and adjusted Weibull distributions, incorporating yield correlations between crops. Crop yields are based on independent draws from distributions for each crop in each year for the individual farms. As such annual variability representing crop yield differences due to weather effects is captured. Crop prices, while based on lagged prices, are also stochastic stemming from independent error term draws each year. This introduces further variability into the farm revenue. The bulk of farm revenue is from the sale of crops calculated by multiplying annual crop production in kilograms with commodity price in dollars per kilogram.

Other sources of revenues potentially available to crop producers include payments from safety net programs; specifically, crop insurance and AgriStability and AgriInvest. Payments from these sources are accessible to producers in the event of a significant yield or revenue loss, assuming producer participation in the program(s) in the corresponding year. The calculation of payments from these programs is discussed later in this section.

4.4.2 Input Costs

Input costs for crop production on the representative farms are based on information from Alberta Agriculture's *AgriProfit$* Cropping Alternatives (AARD, 2010-b) program. *AgriProfit$* forecasts are in turn based on current cost of production information obtained from various sources. Input costs relevant to the farms of interest include seed, fertilizer, chemical, trucking and marketing, fuel, oil, and lube, machinery and building repairs, and utilities and miscellaneous costs.

Seed costs in *AgriProfit$* (AARD, 2010-b) are determined from the Alberta Farm Input Prices survey, combined with a seed cost multiplier to account for a blend of certified and common seed that is cleaned and treated (Bergstrom, 2010). Assumptions regarding germination, emergence mortality, and seed spacing are also taken into consideration when determining seed cost. *AgriProfit$* (AARD, 2010-b) assumes a 90-95% germination rate, 3-5% emergence mortality, and nine inch spacing.

Fertilizer costs in *AgriProfit$* (AARD, 2010-b) are based on a blend of nitrogen (N), phosphorus (P), potassium (K), and sulphur (S), abbreviated with NPKS. The price of the fertilizer blend is made up of fall 2009 and spring 2010 prices (Bergstrom, 2010). Prices of $1.04/kg, $0.77/kg, $0.90/kg, and $0.62/kg for nitrogen, phosphorus, potassium, and sulphur, respectively, are used in the calculations. Chemical costs include pre-seed chemical, in-crop chemical, and/or fungicide/insecticide/pre-harvest/desiccation chemicals that are applied as applicable to the crop and region (AARD, 2010-b).

Trucking and marketing costs are from *AgriProfit$* data and range from $5 to $12 per 1,000 kilograms of crop commodity. Other expenses, including fuel, oil and lube, machinery repairs, building repairs, utilities and miscellaneous, and pumping (irrigation only) costs are calculated from *AgriProfit$* data and Alberta Farm Input Prices survey. Many of these input costs vary due to differences in regional farming practices in Alberta and this is accounted for in the different input costs by region, shown in Tables 5.21 to 5.25.

In place of the custom work accounted for by *AgriProfit$* the cost of custom spraying is used in the analysis. This is calculated by multiplying the custom cost of spraying of approximately $7.34 per hectare (SAF, 2008) by the acreage to be sprayed annually. It is assumed, based on expert opinion (Dunn, 2009), that fields are sprayed an average of two times per year.

The machinery costs provided in Tables 4.18 to 4.21 represent costs for repair and maintenance. Besides these costs, an annual expenditure to account for machinery replacement (i.e., maintenance of the machinery asset base) is also included in the calculation of total crop costs used in cash flow calculations. This expenditure, calculated as the annual amount spent on machinery replacement/maintenance required to offset the loss in value due to depreciation, is discussed earlier in this chapter.

Table 4.18 – Input costs by crop for farm representing Brown soil zone, dryland production ($/ha)

	Spring wheat	Durum wheat	Feed Barley	Canola	Field Peas	Mixed Hay	Summer -fallow
Seed	37.19	31.78	25.99	59.18	70.28	5.29	0.00
Fertilizer (NPKS)	81.54	81.54	97.60	116.14	33.36	21.00	0.00
Chemical	69.19	69.19	34.59	67.83	58.07	3.41	40.77
Trucking & Marketing	16.14	16.14	20.98	8.40	16.14	14.83	0.00
Fuel, Oil & Lube	26.81	26.81	29.65	31.36	26.81	19.77	19.77
Machinery Repairs	22.24	22.24	21.62	21.00	21.00	18.53	21.00
Building Repairs	2.47	2.47	2.47	2.47	2.47	1.24	1.24
Custom Work	7.34	7.34	7.34	7.34	7.34	0.00	7.34
Utilities & Misc.	21.00	21.00	21.00	21.00	21.00	14.83	9.88
Total	283.92	278.51	261.24	334.72	256.47	98.9	100.00

Source: AARD (2010-b).

Table 4.19 – Input costs by crop for farm representing Dark Brown soil zone, dryland production ($/ha)

	Spring wheat	Durum wheat	Feed Barley	Argentine Canola	Dry field peas	Mixed Hay	Summer-fallow
Seed	37.19	31.78	29.70	73.96	70.28	5.29	0.00
Fertilizer (NPKS)	97.60	97.60	109.96	134.67	33.36	24.71	0.00
Chemical	77.84	77.84	34.59	75.37	95.13	3.41	40.77
Trucking & Marketing	18.16	18.16	22.58	10.08	18.16	17.30	0.00
Fuel, Oil & Lube	27.01	27.01	29.65	33.04	33.36	19.77	19.77
Machinery Repairs	21.62	21.62	21.62	21.62	21.62	18.53	21.00
Building Repairs	2.47	2.47	2.47	2.47	2.47	1.24	1.24
Custom Work	7.34	7.34	7.34	7.34	7.34	0.00	7.34
Utilities & Misc.	24.71	24.71	24.71	24.71	24.71	17.30	9.88
Total	313.94	308.53	282.62	383.26	306.43	107.55	100.00

Source: AARD (2010-b).

Table 4.20 – Input costs by crop for farm representing Black soil zone, dryland production ($/ha)

	Spring wheat	Feed Barley	Milling Oats	Argentine Canola	Dry field peas	Mixed Hay	Alfalfa Hay
Seed	42.50	29.70	26.69	73.96	76.68	5.73	16.93
Fertilizer (NPKS)	130.96	130.96	108.72	181.62	48.18	30.89	28.42
Chemical	86.49	43.24	28.42	75.37	95.13	3.41	4.25
Trucking & Marketing	26.22	29.06	26.29	15.12	20.16	33.36	37.07
Fuel, Oil & Lube	37.07	38.30	33.36	38.30	38.30	33.36	33.36
Machinery Repairs	32.12	32.12	30.89	33.36	33.36	23.47	23.47
Building Repairs	2.47	2.47	2.47	2.47	2.47	1.24	1.24
Custom Work	7.34	7.34	7.34	7.34	7.34	0.00	7.34
Utilities & Misc.	28.42	28.42	28.42	34.59	34.59	17.30	17.30
Total	393.59	341.61	292.6	462.13	356.21	148.76	169.38

Source: AARD (2010-b).

Table 4.21 – Input costs by crop for farm representing Dark Grey (Peace region) soil zone, dryland production ($/ha)

	Spring wheat	Feed Barley	Milling Oats	Argentine Canola	Dry field peas	Mixed Hay	Alfalfa Hay
Seed	37.19	25.99	21.35	59.18	70.28	5.73	16.93
Fertilizer (NPKS)	109.96	109.96	93.90	156.91	38.30	30.89	23.47
Chemical	86.49	43.24	28.42	75.37	58.07	3.41	4.25
Trucking & Marketing	22.19	25.82	22.86	13.44	18.16	25.95	29.65
Fuel, Oil & Lube	26.32	28.17	29.65	33.21	33.73	32.91	33.98
Machinery Repairs	29.65	29.65	24.09	29.65	32.12	18.53	18.53
Building Repairs	2.47	2.47	2.47	2.47	2.47	1.24	1.24
Custom Work	7.34	7.34	7.34	7.34	7.34	0.00	7.34
Utilities & Misc.	24.71	24.71	19.77	24.71	24.71	16.06	16.06
Total	346.32	297.35	249.85	402.28	285.18	134.72	151.45

Source: AARD (2010-b)

4.4.3 Crop Residues

The harvesting of crops grown on the representative farms results in the "production" of residue, which is plant material (i.e., leaves, stalks, roots, etc.) left in the field after the grain is removed. In some cases, crop residue is considered a secondary output from crop production, and may be harvested and sold. In other instances, crop residue is left on the field. Management decisions regarding crop residues vary by producer and by crop.

In this study, residue management practices are determined based on typical moisture conditions for each representative farm, and on expert opinion regarding "normal" actions of producers. For the baseline scenario it is assumed that, where feasible, crop residue is removed from fields (i.e., harvested). Crops for which this is done include barley, durum wheat, oats and spring wheat.[19]

It is further assumed that producers in the southern areas of the province (i.e., Brown and Dark Brown soil zones) retain residue more frequently as compared to producers in the northern areas (i.e., Black and Dark Grey soil zones). This is due to the volume of residue produced as well as typical soil moisture conditions. In modelling whether residue is removed or retained it is assumed that in the Brown soil zone residue of the previously mentioned crops is removed one out of every five years. In the Dark Brown soil zone residue is removed once every four years. In the Black and Dark Grey soil zones residue is removed once every three years. The residue removed is staggered over time such that each crop with residue available for removal has an equal amount removed over time.

Crop residue production is modelled as a proportion of crop yield. Values are adapted from AARD (2008-c) and are provided in Table 5.26. Costs for baling and removing residue are charged at custom rates of $19.19 (SAF, 2008) per 544 kilogram bale of straw. Producers are assumed to sell all straw baled at $25 per bale (AARD, 2010-c).

Table 4.22 – Crop residue production, by crop and soil zone (kilogram of residue per kilogram of crop yield)

Crop / Soil zone	Brown	Dark Brown	Black/Dark Grey
Barley	0.729	0.833	1.042
Oats	1.030	1.177	1.471
Wheat (durum and spring)	1.166	1.416	1.666

Source: AARD (2008-c)

4.4.4 Crop and Hay Insurance

Crop and hay insurance are risk management tools used by many producers. Participation in these insurance programs assists in offsetting reduced revenue in years when yields are low. In 2008 crop insurance receipts totalled $344.6 million in Alberta, representing 3.2% of total farm cash receipts and 6.7% of crop related cash receipts (AARD, 2009-a). This amount is a significant portion of income for producers, particularly when unexpected weather events occur. Therefore crop and hay insurance are included in the farm simulation modelling and it is assumed that producers (i.e., the representative farms) participate in these programs. The structure of insurance used in the

---

[19] Other crop residues are assumed to be distributed over the soil during harvest, as the residue itself cannot be harvested.

models are production based and follow the structure of AFSC crop and hay insurance programs.

Insurance coverage and premium calculations are individualized to each farm as producers choose a percent of normal yield to be covered, with the options for coverage level being 50, 60, 70, or 80% of the individual normal yield (AFSC, 2011-a). The production based crop insurance provides a yield guarantee and also guarantees a price for yield losses. The program insures against natural perils including drought, excessive moisture, fire from lightning strikes, flood, frost, hail, insect infestations, snow, wind, wildlife invasions and other perils designated by AFSC (AFSC, 2011-a).

In the model there is flexibility for the producer to choose no insurance (0%) or 80% coverage, but once a level is chosen it is implemented for the entirety of the simulation period. For all baseline and BMP scenarios it is assumed producers choose an 80% coverage level; that is, if the simulated yield for a particular crop in a particular year is below 80% of the individual normal yield, an insurance payment is generated. This type of coverage uses spring insurance price (SIP), fall market price, risk area average yields, and actual yields to determine a payment to the producer when there is a shortfall and to determine the cost of crop insurance to the producer. Additional factors affecting crop insurance premiums and payouts are the variable price benefit (VPB) on shortfall, and whether or not the spring price endorsement (SPE) is purchased by the producer. Alberta is divided into risk areas for the purposes of crop insurance coverage and premium calculations. Risk areas examined in this project include 3, 8, 12, and 19 for the counties of Forty Mile, Starland, Camrose, and Smoky River, respectively. A discussion of the methods used for crop insurance calculations in the models is provided, followed by an example.

For each farm and each annual crop, the basic level of insurance coverage is equal to the insured yield multiplied by the SIP. The insured yield is equal to the risk area average yield multiplied by the coverage level (i.e., assumed to be 80% in the analysis). The insured yield depends on actual historical yields for the farm and “normal” yields in the crop insurance risk area. For simplicity purposes, the risk area average yield for each period is calculated as the average of the actual simulated farm yield for that period and the risk area average yield from the previous period. The risk area average is used alone for the first simulation period.

The spring insurance price (SIP) is a predicted fall market price and is based on historical, current and futures prices of crops (AFSC, 2010-a). The SIP for each crop will vary from year to year in reality. For simplicity, a constant SIP is used; specifically, the SIP for each crop is set at the 2010 value provided by AFSC. SIPs in this period are \$0.162, \$0.154, \$0.140, \$0.140, \$0.400 and \$0.165 per kilogram for spring wheat, durum wheat, barley, oats, canola and field peas, respectively.[20]

A crop insurance payment is generated if the actual simulated yield is below the insured yield; that is, if it is less than 80% of the risk area average yield (i.e., given the assumption of 80% coverage level chosen by the producer). The payment is equal to the difference between the insured yield level and actual yield, multiplied by the SIP. A variable price benefit (VPB) on the shortfall is also provided by AFSC. The VPB provides additional compensation to producers in the event that there is a yield shortfall (i.e., a crop insurance payment is generated) and the actual fall price of the insured crop is 10-50% (i.e., the benefit is capped at 50%) above the SIP (AFSC, 2010-a). The VPB is calculated by multiplying the yield shortfall by the difference between the fall price and

---

[20] A comparison of the SIP to the average simulated prices indicates that for some crops (i.e., barley, canola and oats) the two prices are similar. For durum and spring wheat, however, the prices are not as close. This represents a limitation of the modelling of crop insurance in this study.

the spring insurance price. The VPB is incorporated in the simulation analysis by using the difference between the simulated crop price and the SIP.

Producers can opt to purchase additional crop insurance protection, referred to as SPE. SPE provides price protection against price declines during the year; that is, if the fall price is 10-50% (i.e., the SPE payment is capped at 50%) lower than the SIP. If SPE is purchased and the fall crop price is sufficiently below the SIP, an SPE payment is generated. The payment is equal to the difference between the SIP and the actual fall price, multiplied by the actual yield or insured yield (whichever is greater). Producers are assumed to purchase SPE in this study, and so this is incorporated into the simulation calculations for the representative farm models.

To illustrate this with an example, suppose a producer chooses crop insurance level of 80% for 100 hectares of spring wheat with yields of 1,500 kilograms per hectare. The pre-determined risk area average yield is 2,000 kilograms per hectare for the same year. The SIP of spring wheat is \$0.162/kg, while the fall market price is \$0.200/kg. Production coverage for this producer is 160,000 kg (2000 kg/ha * 80% * 100 ha). The shortfall is calculated by the production coverage minus the producer's actual yield and in this case is 100,000 kilograms. Therefore the crop insurance payment to the producer is \$16,200 (\$0.162 * 100,000 kg). In addition to this, since the fall market price has increased by approximately 25% the producer receives a payment of the shortfall (100,000 kg) multiplied by the difference in the SIP and the fall market price, an additional \$3,800 in VPB. By participating in crop insurance the producer has gained additional income of \$20,000. If the fall market price had fallen 10-50% below the SIP then a payment from SPE would be calculated in place of the VPB.

Crop insurance premiums are based on the coverage level for the particular crop, the risk region in which the farm is located, and whether or not SPE is purchased. The premium is equal to the dollar value of the coverage level multiplied by a premium rate. For simplicity purposes, in this study the premium rate is assumed to be 10% for all crops and all representative farms.[21] Of the resulting premium, 40% is assumed to be paid by the producer and included as a cash outflow in the simulation model, as crop insurance premiums are subsidized by the provincial and federal governments. Provincial and federal governments each pay 25% of the total premiums and share 50% of the administration fees. In modelling crop insurance it is assumed that this is approximately 60% of the total, leaving 40% for producers to pay (AAFC, 2009).

Hay insurance is also based on actual production versus coverage level. When yield is below the chosen coverage level a claim is triggered (AFSC, 2010-c). Producers can insure dryland hay at 50, 60, 70, or 80% coverage levels and can also select different price options. However, if hay insurance is chosen producers must insure all land that they are using to produce hay. Insurance coverage is initially based on the normal expected yield in the risk area but is adjusted over time to reflect individual yield trends of the producer using a cumulative index based on the risk area average and actual yields (AFSC, 2010-c).

Risk area "normals" are calculated for each region to reflect the amount of hay producers can expect to grow in a normal year (AFSC, 2010-c). Risk area "normals" are estimated to be approximately 3,505, 4,250, and 3,825 kilograms per hectare for farms in the Dark Brown, Black, and Dark Grey soil zones. For this study the risk area "normals"

---

[21] In fact, the premium rates will vary by crop, risk region and year. For example, the 2011 AFSC premium rates for the crops included in this study and the relevant risk regions for the representative farms vary from 7% to 18% (AFSC, 2011-a).

are estimated in an ad hoc manner, based on the actual values that could be expected in each region without causing payments to occur too frequently or infrequently.[22]

For perennial crops AFSC uses an indexing system to stabilize coverage. The cumulative index is the ratio of the index yield divided by the risk area average yield. The index yield has three "levels" calculated to provide stability in insurance coverage. This allows the risk area "normals" to become individualized to the producer over time. Annual yields are capped and cushioned at 1.8 and 0.7 times, respectively, the risk area average times the producer's cumulative index in the previous period (AFSC, 2010-c). If the ratio of actual yields and the risk area average is less than 0.7, the index is cushioned at 70%, and if the ratio is greater than 1.8, the index is capped at 180%. When the ratio falls in between these ratios the index yield is simply calculated as the average of the actual yield and the risk area average yield. Production coverage for producers is then a function of the cumulative index, the risk area normal, and the coverage level.

Assumptions when modelling hay insurance are that hay is insured at the same level as crops, at 80%, and once this level is decided upon it remains constant for the duration of the simulation. Risk area normal yields are determined from the yield data, while risk area average yields and hay prices are determined within the model. It is assumed that when the producer chooses the 80% hay insurance level the price option is \$0.099/kg, which is consistent with the AFSC hay insurance program in 2010. These values are assumed to be constant through all years of the simulations for simplicity.

The production coverage is calculated the same way for hay as for crops, using the coverage level, acreage, and risk area average. When yield falls below the production coverage the producer claims the shortfall amount multiplied by the price option chosen. There is also VPB for hay insurance which provides compensation when the yield shortfall is below the insurance coverage and the price has increased during the growing season (AFSC, 2010-c) and is calculated in the same manner as it is for crop insurance.

4.4.5 AgriStability and AgriInvest

AgriStability and AgriInvest are public business risk management programs available to Canadian agricultural producers. Both are joint provincial-federal programs offered through the Growing Forward agricultural policy framework. AgriStability provides protection from larger declines in income while AgriInvest is intended to address smaller fluctuations in income. Both programs are designed to mitigate weather, disease, and market risk. All representative farms are assumed to participate in both AgriStability and AgriInvest.

The principle behind AgriStability is that government and producers share the responsibility for managing income risk. The reference measure of income used in AgriStability is referred to as the production margin (PM). The PM is calculated by subtracting allowable expenses from allowable income. Allowable income is revenue generated from the sale of agricultural commodities. Allowable expenses are those costs directly associated with agricultural production. For the purposes of this study the PM is calculated as the difference between revenue from crop sales and variable costs of crop production.[23]

In each year, the PM is compared to the reference margin (RM). The reference margin is calculated using an Olympic average of the previous five years' PMs, where the

---

[22] Risk area "normals" were determined as a simple average of yields from historic data, and adjusted to ensure crop insurance payments did not occur too frequently or not frequently enough, using a trial and error process in the simulation analysis.

[23] Details concerning what constitute allowable income and expenses are provided in the AgriStability Program Handbook (AFSC, 2011-a).

minimum and maximum values are excluded from the average. The reference margin is therefore actually a three year average of the production margin. If the PM is less than the RM, there is potential for an AgriStability payment to be triggered. If the deficit is less than 15% (i.e., the PM is at least 85% of the RM), there is no AgriStability payment generated. The principle here is that PMs that are 85-100% of the RM represent normal fluctuations in income. This range of PMs is referred to as Tier 1. Tier 1 deficits are assumed to be addressed by AgriInvest, which is discussed below.

If the PM is less than 85% of the RM, an AgriStability payment is generated. Tier 2 is the range of PMs that are between 70% and 85% of the RM. In Tier 2, AgriStability pays 70% of the difference between the PM and 85% of the RM. PMs that are between $0 and 70% of the RM are in Tier 3. In this tier, AgriStability pays 80% of the difference between the PM and 70% of the RM. Finally, negative PMs are in Tier 4. AgriStability pays 60% of the difference between the PM and $0 in this tier.[24] The maximum annual AgriStability payment cannot exceed $5,000,000 per farm in Alberta.

The payments associated with the various tiers are cumulative. For example, if a producer PM is in Tier 3, payments for Tiers 2 and 3 are generated. The AgriStability payment structure may be summarized as follows (Schaufele et al., 2010, p. 3):

$$\text{Payment} = \begin{cases} 0, \text{ if PM} \geq 85\% \text{ RM} \\ 70\% \, (85\% \text{ RM} - \text{PM}), \text{ if } 70\% \text{ RM} \leq \text{PM} < 85\% \text{ RM} \\ 80\% \, (70\% \text{ RM} - \text{PM}) + 70\% \, (15\% \text{ RM}), \text{ if } 0 \leq \text{PM} < 70\% \text{ RM} \\ 60\% \, (0\text{-PM}) + 80\% \, (70\% \text{ PM}) + 70\% \, (15\% \text{ RM}), \text{ if PM} < 0 \end{cases}$$

The following examples serve to illustrate the AgriStability payment calculations for the various tiers. Suppose a producer has a reference margin of $100,000. AgriStability payments for four alternative production margin scenarios are provided; production margins equal to $90,000, $75,000, $50,000 and -$10,000.

Example 1: Production Margin = $90,000. The producer is in Tier 1. There is no AgriStability payment.

Example 2: Production Margin = $75,000. The producer is in Tier 2. The resulting AgriStability payment is equal to $7,000; that is, 70% of the difference between $85,000 (85% of the reference margin) and $75,000 (the production margin).

Example 3: Production Margin = $50,000. The producer is in Tier 3. The AgriStability payment in this case is equal to $26,500. This includes a $16,000 Tier 3 payment, equal to 80% of the difference between $70,000 (i.e., 70% of the reference margin) and the $50,000 production margin. It also includes a $10,500 Tier 2 payment, equal to 70% of the difference between $85,000 and $70,000 (i.e., the ceiling and floor, respectively for Tier 2).

Example 4: Production Margin = -$10,000. The producer is in Tier 4. Assuming that the producer is eligible for Tier 4 coverage, the AgriStability payment is equal to $72,500. This includes a $6,000 Tier 4 payment, equal to 60% of the difference between $0 and the -$10,000 production margin. It also includes $56,000 Tier 3 payment (i.e., 80% of the difference between the ceiling and floor for Tier 3) and a $10,500 Tier 2 payment (i.e., 70% of the difference between the ceiling and floor for Tier 2).

Fees for participating in AgriStability are $0.0045 per $1 of reference margin, multiplied by 85%. There is a minimum fee of $45. The administrative cost share fee is an additional $55, making the minimum payment for any operation participating in

---

[24] AgriStability coverage for negative PMs is provided as long as the farm has not had negative margins in more than two of the previous five years (i.e., no more than one of the three years used in the Olympic average RM calculation)

AgriStability equal to $100. In the previous example producer fees would be $437.50 (i.e., [85% * $100,000 * $0.0045] + $55).

As noted above, the representative farms are also assumed to participate in AgriInvest. AgriInvest is essentially a savings program, where producers contribute to an account and their contributions are matched (to a pre-specified limit) by government contributions. Participation in AgriInvest is voluntary and is on at an individual level. AgriInvest accounts can be set up at any Canadian bank and producers manage their accounts individually. The purpose of the AgriInvest program is to provide agricultural producers with a program for managing smaller declines in income (i.e., within Tier 1).

Producers may contribute up to 1.5% of allowable net sales (ANS), where ANS is defined as sales of agricultural commodities minus purchase of agricultural commodities. ANS is capped at $1.5 million per producer for lifetime participation in the program for the purposes of AgriInvest. Producer contributions are matched dollar for dollar by government contributions. Given the ANS cap, the maximum annual matching government contribution is $22,500 (i.e., 1.5% of $1,500,000). Producers may withdraw funds from their AgriInvest account in any year.[25]

Given the flexibility in the AgriInvest program with respect to contribution and withdrawal decisions, some simplifying assumptions were necessary in modelling this program in the representative farm simulation analysis. AgriInvest contribution and withdrawal decisions were linked with AgriStability calculations. This was done to be consistent with the principle behind the AgriInvest program; that is, it is intended to "manage" small fluctuations in income that are not addressed by AgriStability. As a result, contributions and withdrawals were determined based on the production margin (PM) level.

In the simulation models, deposits are made to the producer's AgriInvest account in years when the PM is positive and greater than the RM.[26] For the representative farms it is assumed that when this scenario occurs, the producer deposits 1.5% of the PM into this account. The government deposits a matching amount equal to the producer's contribution, up to $22,500 per year. For example if the PM is $110,000 and the RM is $100,000 the producer would deposit $1,650 in the bank account and the government would match this amount, such that the total deposit to the account is $3,300. The producer deposit is treated as a cash outflow for the purposes of MNCF calculations.

Similarly, if a representative farm's PM in a particular year is less than the RM, and there are funds available in the AgriInvest account, a withdrawal is triggered. The AgriInvest withdrawal is equal to the difference between the PM and the RM, to a maximum of 15% of the RM (i.e., the deficit constituting Tier 1). The withdrawal is limited to the Tier 1 shortfall since it is assumed that AgriStability addresses any additional shortfall (i.e., in Tiers 2, 3 and/or 4). It is assumed that AgriInvest withdrawals only occur when the PM is less than the RM but greater than 85% of the RM. If the calculated withdrawal is greater than the current AgriStability account balance, the withdrawal is limited to the account balance. For example, if the PM and RM for a representative farm are $95,000 and $100,000, respectively, and there are sufficient funds in the AgriInvest account, the producer would withdraw $5,000 from the AgriInvest account to stabilize income. Alternatively, if the RM was $100,000 and the PM was $70,000, the AgriInvest account withdrawal (assuming sufficient funds being available in the account) would be $15,000; that is, the difference between the RM and the Tier 2 ceiling where AgriStability would begin to generate risk management support.

---

[25] Further details concerning AgriInvest are provided in the AgriInvest Program Handbook (AAFC, 2011).

[26] In reality an AgriInvest account would collect interest. However, this is not modelled.

4.5 Beneficial Management Practices

The objective of this study is to determine the direct economic costs and benefits associated with the adoption of on-farm BMPs. This portion of the chapter describes the rationale behind considering the selected practices as BMPs and how they are incorporated into the model farms. There are two main categories of BMPs modelled, rotational BMPs and non-rotational BMPs. All BMPs can be modelled individually or in combination with other BMPs, if applicable to the soil zone. Each BMP is described in terms of adjustments made in the farm models in terms of the incurred costs and associated benefits.

4.5.1 Crop Rotation Beneficial Management Practices

Rotational BMPs are adopted for the potential to improve the health of the soil through reduced erosion, reduced disease cycles, improved crop diversity, reduction of inputs, and an improved nitrogen carrying capacity of the soil. These effects are discussed in the following sections.

4.5.1.1 Conversion of Cropland to Forage

The first rotational BMP considered is the addition of alfalfa, a perennial legume forage, to the representative farm crop rotations. This change may be considered as a BMP because of the potential for reduced chemical fertilizer application in subsequent crops. This is due to the nitrogen fixing property of alfalfa, being a legume. The alfalfa hay BMP is modelled for the representative farms in the Dark Brown, Black and Dark Grey soil zones. Alfalfa hay is not considered for the Brown soil zone representative farm as alfalfa hay production in this location is not agronomically viable (Bergstrom, 2009).

Since alfalfa is a perennial crop, a decision is required concerning how long (i.e., number of years) to maintain the stand in the rotation before reverting back to annual crops. Alfalfa stand yields tend to initially increase with age before eventually decreasing as the stand ages. Based on information from previous studies (Koeckhoven, 2008; Leyshon et al., 1981) and for reasons related to convenience for modelling in the simulation analysis, three years of alfalfa hay are included in the BMP rotation. After the alfalfa stand is three years of age, yields begin to decline, as compared to the average alfalfa yield for a five year old alfalfa crop (Koeckhoven, 2008; Leyshon et al. 1981).

Results from the previous alfalfa studies in northern Alberta (Hoyt, 1990; Hoyt and Hennig, 1970) are used to determine the duration of the subsequent yield benefit from adopting three years of alfalfa hay into the representative farm rotations, accounting for differences in normal rainfall/soil zones. The assumption is made in the simulation analysis that the yield benefit is observed for the next three crop years following alfalfa hay. While there is potential to have yield benefits beyond three years (e.g., some studies observe yield benefits up to 15 subsequent years), three years is chosen as a reasonable, albeit conservative, estimate.

For all representative farms where the alfalfa hay BMP is modelled, the crops grown in rotation in the three years following alfalfa are spring wheat, canola, and barley in years one, two, and three, respectively. Annual crop yield increases attributable to alfalfa are assumed to be stochastic, and vary from year to year. As there is no guidance from the literature regarding the potential trend or distribution of the yield effect, it is modelled assuming a uniform distribution where a draw is taken using the minimum and maximum values shown in Table 4.23, and are adapted from Albertan alfalfa hay studies by Hoyt (1990) and Hoyt and Hennig (1970).

Table 4.23 – Yield increases (%) following alfalfa hay

Subsequent years (crop)		Northern Alberta	Southern Alberta
Year 1 (spring wheat)	Minimum	20%	10%
	Maximum	110%	80%
Year 2 (canola) & Year 3 (barley/durum wheat)	Minimum	14%	4%
	Maximum	104%	74%

The ability of legumes to fix atmospheric nitrogen and make it available for subsequent crops is modelled by yield increases in subsequent crops, but savings from reduced fertilizer savings is also considered. Yield increases and nitrogen cost savings are both modelled as there have been many studies citing the rotational benefits of including leguminous crops (Entz et al., 1995; Hoyt, 1990; Hoyt and Hennig, 1971; Lafond et al., 2007). Considering that many studies cite subsequent benefits from legume crops for up to 15 years, this study considers both a yield and nitrogen impact over only three years. The average contribution of nitrogen by alfalfa hay is 45 pounds per acre but can be as high as 107 pounds per acre under optimal growing conditions (MAFRI, 2010). A five year stand of alfalfa hay can produce considerable nitrogen benefit for up to the first seven subsequent crops (MAFRI, 2010). While there is evidence that nitrogen application for the first cereal crop following an alfalfa stand is not necessary (MAFRI, 2010), it is assumed that 25% of the normal nitrogen is applied to be realistic with the actions of producers (Hutton, 2010). In the second, third and fourth years following an alfalfa stand it is assumed that 50, 80, and 100% (Hutton, 2010) of the normal amount of nitrogen is applied. These nitrogen savings are quantified through reduced nitrogen fertilizer costs over different subsequent crops and soil zones. These cost savings range from $6.85/ha to $36.92/ha, as displayed in Table 4.24. Costs are calculated using *AgriProfit$* (AARD, 2010-b) nitrogen-phosphorus-potassium-sulphur (NPKS) blend ($/kg) fertilizer costs and determining the proportion that is nitrogen costs.

Table 4.24 – Nitrogen benefit from reduced fertilizer inputs following alfalfa hay in rotation measured as cost reduction ($/ha)

Subsequent Year / Crop	1 / Spring Wheat	2 / Canola	3 / Barley (Durum Wheat)
Dark Brown	$22.79/ha	$20.96/ha	$6.85/ha
Black	$30.57/ha	$28.27/ha	$8.15/ha
Dark Grey	$25.67/ha	$24.40/ha	$6.85/ha
N application (as % of normal)	25%	50%	80%

Additional costs of adopting a perennial forage stand include baling and removal of alfalfa hay. These costs are incurred at custom rates so as to not result in additional machinery being necessary. The cost of baling and removal for a 750 kilogram alfalfa hay bale is assumed to be $19.19 (SAF, 2008). Sale of alfalfa hay is on a per kilogram basis and the price is stochastic, as per the discussion earlier in this chapter.

4.5.1.2 Introduction of Field Peas

Similar to alfalfa hay, field peas are a legume and as such have the ability to fix nitrogen in the soil. Adding field peas to the crop rotations may therefore be considered a BMP because it allows for reduced use of chemical fertilizer. In terms of direct benefits for producers, incorporating field peas also allows for potential yield increases for subsequent crops. Adding field peas to existing crop rotations also increases diversity, which has been proven to improve crop yields within western Canada (Harapiak, 2007).

Field peas are considered a viable crop to adopt for all representative farms. Field peas are modelled to include direct benefits in terms of both a yield benefit to subsequent crops and reduced nitrogen inputs for crops following field peas. For the representative farms in the Dark Brown, Black and Dark Grey soil zones, the rotation is adjusted such that spring wheat follows field peas. For the farm in the Brown soil zone either spring wheat or barley may follow field peas. According to Harapiak (2007) there are differences in yield benefits following field peas that are related to rainfall levels; that is, greater rainfall contributes to greater yield effects. For the purposes of this study, crops following field peas in southern Alberta (i.e., Brown and Dark Brown soil zones) are modelled to have a yield benefit in the range of zero to ten percent while in northern Alberta (i.e., Black and Dark Grey soil zones) the yield benefit is in the range of 20 to 30% (Harapiak, 2007). This assumption is made due to overall lower historical precipitation in southern Alberta, as compared to northern Alberta.

As with the alfalfa BMP, the field pea yield benefit is modelled as being stochastic, as the impact will vary from year to year. Values are drawn from a uniform distribution with the minimum and maximum benefits shown in Table 4.25. A uniform distribution is chosen to draw yield benefits from as there is no indication in the literature concerning the nature of the distribution of the effects, or of trends within this range.

Table 4.25 – Yield increases (%) following field peas

Year 1	Northern Alberta	Southern Alberta
Minimum	20%	0%
Maximum	30%	10%

The nitrogen fertilizer benefit for the crop following field peas in the representative farm rotations is modelled as a reduced fertilizer cost for spring wheat or barley. The cost reduction is given in Table 4.26 and is based on nitrogen application following field peas being 33% of normal application (Harapiak, 2007). Costs are calculated using *AgriProfit$* (AARD, 2010-b) NPKS blend ($/kg) fertilizer costs, based on the proportion of fertilizer made up of nitrogen.

Table 4.26 – Nitrogen benefit from reduced fertilizer inputs following field peas in rotation measured as cost reduction ($/ha)

Soil zone	Spring Wheat	Barley
Brown	$17.01/ha	$20.35/ha
Dark Brown	$20.35/ha	N/A[a]
Black	$27.31/ha	N/A[a]
Dark Grey	$22.93/ha	N/A[a]

[a] N/A denotes not applicable for these regions as barley only follows field pea in rotation for the representative farm in the Brown soil zone.

4.5.1.3 Partial or Complete Replacement of Summerfallow with Legume Green Manures

Summerfallow is commonly used by producers in southern regions of Alberta to recapture soil moisture loss from continuous cropping (Zentner et al., 2004). However, as discussed in Chapter 2, there are potential negative environmental impacts from this practice, including increased soil erosion, reduced soil organic matter content, etc. One

BMP considered in this study is the partial or complete replacement of summerfallow in the rotation with a legume green manure crop. This shift in production practice has the effect of reducing the potentially negative effects of summerfallow. As well, the legume crop fixes nitrogen in the soil, reducing the need for chemical nitrogen application in the subsequent crop. Finally, the green manure crop adds organic matter when incorporated into the soil.

There are several options of crops that may be considered for use as green manure. These include annual crops, winter annual crops, perennial crops and legumes. Potential legume green manure crops include alfalfa, peas, lentils and many types of clover. For this study it is assumed that the legume green manure crop is red clover.

Legume green manures are adopted as a partial or complete replacement for summerfallow in the Brown and Dark Brown soil zones. In the Brown soil zone it is assumed that legume green manures only partially replace summerfallow as there is a high proportion of land allocated to this practice in the County of Forty Mile (Statistics Canada, 2006). It is assumed that legume green manures completely replace summerfallow in the Dark Brown soil zone as Statistics Canada (2006) data and expert opinion (Dunn, 2009) suggest this practice is used to a lesser extent in the County of Starland.

As with alfalfa and field peas, incorporating a legume green manure crop into the rotation has two potential effects; a yield effect and nitrogen benefit. The yield effect following legume green manures in rotation may be negative depending on moisture. As noted earlier, one reason for utilizing summerfallow is to allow soil moisture to build up by resting the land. If summerfallow is replaced by a green manure crop and it is a dry year there would be a lower yield for the crop in the following year due to reduced soil moisture content.

For the purposes of this study, a dry year occurs when the simulated yield of a legume green manure is less than the minimum yield from the municipal level data, minus one standard deviation. These numbers are estimated from the available data, as there was a lack of continuous data for legume green manure yields in these regions. In the event of a dry year the resulting yield effect for the subsequent crop is determined based on a draw from a uniform distribution; the minimum value is -16% and a maximum value is zero. The yield effect is measured stochastically to account for year to year differences. A uniform distribution is used as there is no information available regarding the appropriate distribution or of trends within the minimum and maximum yield decrease range. If legume green manure yield is in “normal” (i.e., if it is not a dry year) the yield effect for the subsequent crop is zero. The crop following legume green manures in rotation is always spring wheat for both representative farms on which this practice is adopted.

The nitrogen benefit that occurs following the legume green manure is similar to that discussed earlier for field peas and alfalfa; that is, nitrogen is fixed in the soil and is available for use by the subsequent crop. However, the nitrogen benefit associated with green manure is smaller than for the other two legumes considered in the BMPs previously discussed. Zentner et al. (2004) suggests that the nitrogen benefit to subsequent crops following legume green manures in rotation may not be noticeable until the second time in rotation. For modelling purposes in this study it is assumed that the first time legume green manures occurs in rotation the nitrogen application for spring wheat following the legume will be 97% of what it would be without legume green manures in rotation (i.e., following summerfallow). The second time legume green manures occur in the crop rotation the nitrogen application for the subsequent spring wheat crop is 90% of normal. Following the third (and any additional) occurrence of legume green manure in the rotation the nitrogen application rate for the subsequent spring wheat crop is 81% of normal. The dollar savings per hectare and percent savings for spring wheat are shown in Table 4.27.

Table 4.27 – Nitrogen savings ($/ha) and nitrogen application following legume green manures in rotation.

Number of times in rotation	1	2	3+
Brown	$0.76/ha	$2.54/ha	$4.82/ha
Dark Brown	$0.91/ha	$3.04/ha	$5.77/ha
N application (as % of normal)	97%	90%	81%

4.5.1.4 Introduction of Oats

Including oats in a crop rotation is considered a BMP as this crop has lower chemical input requirements (i.e., fertilizer and pesticide), as compared to other annual grains/oilseeds. This effect is modelled directly in terms of the costs of production; that is, the per hectare cost for oats is lower than for wheat, barley or canola. There are no other impacts in terms of the model. Production costs from *AgriProfit$* are used in the models. This BMP is modelled for the representative farms in the more northern soil zones, Black and Dark Grey. According to experts at Alberta Agriculture oats are not commonly grown in southern areas of Alberta due to a higher incidence of weedy species in the rotations during and after oat production (Bergstrom, 2010).

When oats are grown in the Black and Dark Grey soil zones the chemical input costs are $28.42 per hectare for each region. In the Black soil zone chemical costs for spring wheat, barley, canola, and field peas are $86.49, $43.24, $75.37, and $95.13 per hectare, respectively. In the Grey soil zone in the Peace region the chemical costs are the same for all crops except field peas where the cost is $58.07 per hectare due to the reduced nitrogen consideration for field peas. Chemical fertilizer costs for oats are significantly lower than for barley, canola, wheat, and field pea in these regions.

4.5.1.5 Resulting Beneficial Management Practice Crop Rotations[27]

Adoption of each of the rotational BMPs discussed in this section is modelled for the representative farms. Not all BMPs are modelled for all farms, for reasons outlined in the earlier discussion. For the Brown soil zone farm, field pea and legume green manure are both considered. For the Dark Brown representative farm, adoption of alfalfa hay, field peas, and legume green manure are all modelled as BMPs. For the two northern representative farms (i.e., Black and Dark Grey soil zones) alfalfa hay, field peas, and oats are modelled as rotational BMPs. Tables 4.28 to 4.30 show the possible rotations for each farm, starting with the base rotation (no BMPs). Each rotation is individually examined and compared to the base rotation. Crop name acronyms are the same as used earlier in this chapter, with the addition of “AH” for alfalfa hay, “FP” for field peas, “LGM” for legume green manures, and “O” for oats.

---

[27] Besides the basic crop rotational BMPs, adoption of “combination BMPs” (i.e., combinations of the individual BMPs) was also modeled for the representative farms. The results for these combination BMPs are not presented in this report but are available from the authors, on request.

Table 4.28 – Rotations for Brown soil zone farm

Rotation	Crop Rotation[a]
Base	SF – SW – C – DW – SF – B – C – SW
Add FP	SF – SW – C – DW – FP – B – C – SW
Add LGM	LGM – SW – C – DW – SF – B – C – SW

[a] B = barley; C = canola; DW = durum wheat; FP = field peas; LGM = legume green manure; SF = summerfallow; SW = spring wheat

Table 4.29 – Rotations for Dark Brown soil zone farm

Rotation	Crop Rotation[a]
Base	SW – C – B – SF
Add FP	SW – C – B – FP – SW – SF
Add LGM	SW – C – B – LGM
Add AH	AH – AH – AH – SW – C – B – SF

[a] AH = alfalfa hay; B = barley; C = canola; FP = field peas; LGM = legume green manure; SF = summerfallow; SW = spring wheat

Table 4.30 – Rotations for Black and Dark Grey soil zone farms

Rotation	Crop Rotation[a]
Base	SW – C – B – SW – C
Add FP	SW – C – B – FP – SW – C
Add O	SW – C – B – SW – C – O
Add AH	AH – AH – AH – SW – C – B – C – SW

[a] AH = alfalfa hay; B = barley; C = canola; FP = field peas; O = oats; SW = spring wheat

4.5.2 Non-Rotational Beneficial Management Practices

The purpose of non-rotational BMPs is similar to that of rotational BMPs; that is, to improve soil health, maintain productivity of the land, or provide protection of ecologically sensitive areas. Non-rotational BMPs considered in this project include shelterbelts, buffer strips, and residue management. There is also the additional option to include permanent cover in the buffer strip areas. When used appropriately these BMPs improve soil health by reducing wind and soil erosion. Buffer strips and permanent cover also provide protection for wetlands/riparian areas from runoff of agricultural chemicals from annual crop production (i.e., fertilizer and pesticides). This section provides a discussion of the specific methods and parameters used in modelling adoption of shelterbelts, buffer strips, and residue management as BMPs on the representative farms in terms of their direct effect on farm performance.

5.4.2.1 Shelterbelts

Shelterbelts are established on each representative farm based on the properties of the farm in terms of the potential need. As discussed earlier in Chapter 2, shelterbelts assist in reducing the potential for wind erosion. However, they also have a potential effect (both positive and negative) on crop yields in adjacent fields.

Shelterbelts may be established using a variety of species of trees. In modelling shelterbelt adoption in the current study it is decided to assume that a mix of Caragana and Green Ash trees are used for the shelterbelts. These types of trees are chosen as they are viable shelterbelt species throughout Alberta. The trees are assumed to be planted in a ratio of two Caragana trees for every one Green Ash, with spacing of 60 centimetres between trees (AARD, 2007-a). The average mature heights of Green Ash and Caragana are sixteen and five metres, respectively.

The protection resulting from shelterbelts is dependent on the number of shelterbelts per unit of area, and the height of the trees. Caragana typically grow faster than Green Ash, but eventually Green Ash is the taller of the two species. This is why the combination of these two species is often used for shelterbelts. For simplicity of modelling only the growth of Green Ash is calculated over time and the height of Green Ash trees is used to determine shelterbelt protection. The following growth equation, adapted from Geyer and Lynch (1990), is used to calculate the height (in metres) of the Green Ash trees:

$$\text{Height (m)} = 0.4 + (0.5 * \text{Age}) + (2.5 * (1 - e^{(-0.3 * \text{Age})})) \qquad (4.22)$$

where "Age" is the age of the trees, in years. In the simulation analysis the growth equation is adapted by assuming green ash tree height is "capped" at twenty metres as this is the average maximum height of Green Ash trees. Also it is assumed that shelterbelts do not have an effect on yields until the third year after they are planted. Since the trees are relatively small when they are first planted it would not be reasonable to assume significant protection from wind or competition between trees and crops for water and nutrients until the fourth year from BMP adoption.

Shelterbelts are most effective in dry soil regions where the risk of soil erosion is greater. For this reason representative dryland farm operations in the southern regions of Alberta (i.e., Brown and Dark Brown soil zones) will have more shelterbelts per quarter section as compared to farms in northern areas (i.e., Black and Dark Grey soil zones). In modelling the adoption of the shelterbelt BMP it is assumed that the farms representing the Brown, Dark Brown, Black, and Dark Grey soil zones plant five, four, three, and two shelterbelts per quarter section, respectively.

The shelterbelts are assumed to run the length of each field (i.e., 795 metres), and are twelve metres wide. This width is necessary for appropriate spacing between trees and crops, while allowing for tree growth. The specifications of shelterbelt adoption for each representative farm, including the acreage lost, are provided in Table 4.31. If shelterbelts are adopted, implementation is staggered equally over eight years. It is unlikely that producers would have the resources (i.e., time and money) to establish all shelterbelts in one time period. Eight years was chosen as an establishment time that would likely be feasible for most producers.

Table 4.31 – Shelterbelt specifications per region

Soil Zone	Number per quarter section	Number per farm	Total number of trees	Total lost acreage (ha)	Lost acreage as % of total
Brown	5	100	132,500	95.4	7.7%
Dark Brown	4	80	106,000	76.3	5.9%
Black	3	48	63,600	45.8	4.4%
Dark Grey	2	24	31,800	22.9	3.0%

Shelterbelt trees can be obtained at no cost from the Prairie Farm Rehabilitation Administration (PFRA), but there are planting and maintenance costs associated with this BMP. Site preparation and planting is assumed to cost \$0.70 per tree. Maintenance of trees is required starting in the year following planting until the sixth year after planting, with the cost being \$0.15 per tree per year. Cost estimates are adapted from a study in

Indiana, USA (Indiana Woodland Steward, 2010) which assumes machine planting at the rate of $250 to $300 per acre (i.e., $101 to $121 per hectare) with 500 trees planted per acre (i.e., 203 trees per hectare) and additional herbicide costs of approximately $50 per acre (i.e., $21 per hectare). Total establishment costs are $192,125, $153,700, $92,220, and $46,110 for the Brown, Dark Brown, Black, and Dark Grey representative farms, respectively.

Yield effects from shelterbelts occur in two areas of the field. The first area is directly adjacent to the shelterbelt and covers the area extending out to three times the height of the shelterbelt (0-3H). In this region there is a yield decrease due to competition of the crops with the shelterbelt trees for moisture and nutrients (AARD, 2004-b). The second area is from three to ten times the height of the shelterbelt (3-10H). In this area there is sufficient wind protection and increased moisture trapping for a yield increase (AARD, 2004-b). As a conservative measure yield effects from shelterbelts, both decreases and increases, are only considered on one side of the shelterbelt. This assumption is reasonable for yield increases as crops would typically only be sheltered in the direction of the prevailing wind. This assumption may be inconsistent for yield decreases directly adjacent to shelterbelts, however to obtain the full effect the resulting yield "cost" could simply be doubled. The yield changes used to model the effect of shelterbelts are based on information from multiple sources. Specifically, yield effects for barley, canola, wheat and hay are estimated from AARD (2004-b). Yield effects for oats are estimated from Kort (1988). Due to a lack of information for a yield effect of shelterbelts on field peas and legume green manures it is assumed that these effects are the same as those for barley. Table 4.32 shows the yield effect of shelterbelts per region and crop as a percent of normal (i.e. without shelterbelts) yields.

Table 4.32 – Yield effect (as % of normal) of shelterbelts for soil zones and regions adjacent to shelterbelts

Soil Zone	Height Category[a]	Barley	Canola	Field Peas	Hay	Legume Green Manures	Oats	Wheat
Brown	0-3H	61%	57%	61%	76%	61%	51%	62%
	3-10H	112%	112%	112%	116%	112%	104%	109%
Dark Brown	0-3H	62%	58%	62%	77%	62%	52%	63%
	3-10H	112%	113%	112%	117%	112%	104%	110%
Black	0-3H	61%	57%	61%	76%	61%	51%	62%
	3-10H	107%	108%	107%	112%	107%	102%	104%
Dark Grey	0-3H	62%	57%	62%	76%	62%	51%	62%
	3-10H	108%	109%	108%	112%	108%	103%	105%

[a] 0-3H is the area immediately adjacent to the trees extending out to a distance three times the height of the trees, while 3-10H is the area extending from three times the tree height out to ten times the tree height.

4.5.2.2 Buffer Strips

Creation of buffer strips is another BMP modelled in this study. As discussed in Chapter 2, buffer strips can serve as a potential filter in terms of reducing runoff of agricultural chemicals. Buffer strips may be implemented as area of land set aside from agricultural use. Alternatively, they may be implemented as permanent cover; that is, the area may be seeded to permanent forage which is used for hay production.

Buffer strips may be implemented anywhere on the representative farms. However, in this study they are used to provide a buffer around wetlands and associated riparian areas. Based on information from South Saskatchewan Regions (2009), it is assumed that four percent of land is wetland for the Brown and Dark Brown soil zone farms, while six percent of land is wetland for the Black and Dark Grey soil zone representative farms. All farm calculations take the area in wetland into consideration and land under production is adjusted accordingly.

The impact of the buffer strip BMP depends not only on the area of wetlands but also the configuration (i.e., shape). For ease of modelling, each quarter section is assumed to have one small circular wetland, of corresponding size, per 64.75 hectares. The impact of the BMP also depends on the buffer strip width. The buffer strips are assumed to be ten metres in width. This width is chosen as it is sufficient to provide riparian protection, and has been used in previous studies of BMPs in wetland areas (Koeckhoven, 2008). As well, in the scenario where the buffer strip is used for hay production, 10 metres is sufficiently wide to accommodate hay harvesting equipment. The total area of land lost due to the adoption of buffer strips for each of the farms is provided in Table 5.38.

Table 4.33 – Wetland characteristics and acreage lost due to wetland adoption

Soil zone	Number of wetlands per farm	Individual wetland radius (m)	Total buffer strip area per farm (ha)
Brown	20	90.8	12.04
Dark Brown	20	90.8	12.04
Black	16	111.2	11.68
Dark Grey	12	111.2	8.76

As with the other BMPs the decision to adopt buffer strips or adopt buffer strips and hay the area is made at the beginning of the simulation period (i.e., all land area is converted to buffer strips in year one of the simulation) and this decision is carried on for all forty years of the simulation. If the buffer strip is left idle, there is no implementation cost associated with the BMP, as it is assumed that the land is simply left alone. If the buffer strip is used for hay production (i.e., permanent cover) there is a onetime cost incorporated that is equivalent to seeding the area with hay (i.e., as per the costs provided in Tables 4.18 to 4.21). When the buffer strips are used for hay production, it is also assumed that the crop is custom baled. The cost incurred is $19.19 (SAF, 2008) for baling and removing a 635 kilogram grass hay bale. Costs are incurred at custom rates so the machinery complement does not need to be changed. It is estimated from the limited historical data from alfalfa hay and grass hay, that grass hay price is approximately 60% of the price of alfalfa hay which is determined stochastically. Therefore, it is assumed that grass hay is sold for 60% of the price of alfalfa hay.

4.5.2.3 Residue Management

As discussed earlier, in the baseline scenario post-harvest residue for some crops is removed from fields (i.e., harvested) in some years and “retained” on the field in other years. Residue management may actually be considered as a BMP. The residue management BMP is defined here as the practice of leaving residue on the fields in some years, rather than harvesting it. This practice provides a potential short term benefit of increased soil moisture content while in the long term it may improve soil organic matter (Korol, 2004). This could potentially lead to higher yields in dry years (Huanwen et al., 2004), as compared to no residue management.

For the purposes of the project only the crops barley, durum wheat, oats, and spring wheat are considered for residue management as these crops provide an amount and type of residue that can be harvested. The residue management BMP modelled in this analysis represents exactly the same practices that are assumed to be used in the baseline scenario in terms of the amount of residue removed. For the Brown soil zone, residue of the previously mentioned crops is removed one out of every five years. In the Dark Brown soil zone residue is removed once every four years. In the Black and Dark Grey soil zones residue is removed once every three years. As discussed earlier in this chapter, the differences between the different representative farms (i.e., soil zones) are due to the quantity of residue produced, and expected moisture conditions. The decision rules regarding the pattern of residue management for this BMP are static in the simulation analysis; that is, they do not change over time.

The long term effects of residue management on soil organic content are not modelled in this study. However, the short term effects on crop yield due to soil moisture are explicitly considered in the simulation analysis. The impact of residue management on subsequent crop yields is dependent on moisture conditions; that is, whether it is a "wet year" or a "dry year". A wet year (i.e., greater moisture) results in greater than average residue while in a dry year the opposite is the case. In a dry year, if crop residue is left on the field, there will be a positive effect on the yield of the subsequent crop due to improved soil moisture. However, leaving crop residue on the field in a wet year (i.e., when there is more soil moisture and a greater level of crop residue) can cause problems for the subsequent crop and actually result in reduced yield. Crop residues are correlated with crop yields; if crop yields are high, then residue yields are high. If large amounts of residue are retained on the soil surface there may be less opportunity for the soil surface to warm for germination, and there may also be poor seedling emergence from excessive surface residues (Lafond et al., 1992).

Crop residue production is modelled in the same way as for the baseline scenario (i.e., as a proportion of crop yield). For the purposes of modelling the yield effects associated with the residue management BMP, a wet year is one where the residue (in kg/ha) is greater than the mean residue production level[28] plus one standard deviation. A dry year is one where the residue is less than the mean residue amount minus one standard deviation. If residue is removed in a wet year, a predetermined action that is based on the pattern of residue management for the particular representative farm (discussed earlier), there is no effect on yield. However, if crop residue is retained in a wet year there is a negative effect on the yield for the subsequent crop. If residue is removed in a dry year the subsequent crop will have a reduced yield whereas if the producer retains the residue the subsequent crop will have an increased yield. In both the BMP and baseline scenarios there is potential for yield decreases to occur to the subsequent crops if residue is removed in a dry year. However, in the BMP scenario it is further assumed that subsequent crop yield increases can occur when residue is retained in dry years and that crop yield decreases can occur when residue is retained in wet years.

Yield effects (positive and negative) associated with residue management are assumed to be stochastic. The effects are modelled using draws from uniform distributions. Minimum and maximum values of residue effects are provided in Table 4.34. These values are adapted from studies by Lafond et al. (1992 and 2009). The crops affected by these yield effects are dependent on the specific crop rotations for the representative farms. Information indicating the crops following barley, durum wheat, oats, and spring wheat in rotation is provided earlier in this chapter.

---

[28] The mean value of residue production is the level associated with the average crop yield for the particular representative farm.

Table 4.34 – Minimum and maximum values of crop yield changes (as % of normal) from retaining or removing residue in dry and wet years

Yield effect from residue decision	Minimum	Maximum
Low residue (dry year), retain residue	0%	3%
Low residue (dry year), remove residue	-3%	0%
High residue (wet year), retain residue	-12%	0%
High residue (wet year), remove residue	0%	0%

The effect of the residue management BMP on farm performance is assessed by comparing the BMP simulation results with results for a revised baseline scenario. In particular, the baseline scenarios for the representative farms (i.e., with no BMP adoption) are re-simulated, assuming that residues for the relevant crops (i.e., barley, oats, durum and spring wheat) are removed (i.e., harvested) every year. This revised baseline simulation is required, as the original baseline scenarios included residue management practices that are identical to the residue management BMP, without the yield effects modelled for the BMP. The revised baseline allows for a more appropriate comparison, in order to determine the economic impact of the BMP. The negative yield effects associated with residue removal in dry years is modelled in the revised baseline analysis. Results from the residue management BMP are compared to both baseline scenarios.

4.6 Simulation and Cash Flows for Beneficial Management Practices Analysis

This section discusses how the cash flow simulation models are used for the economic analysis of BMP adoption. As discussed earlier in the chapter, there are four representative farm models developed and used in this study. These farm models are analyzed independently using Monte Carlo simulation. Each farm is initially simulated assuming a set of baseline crop rotations and production practices. Performance for the farms is then again simulated, assuming adoption of one or more rotational or non-rotational BMPs, as discussed earlier in this chapter.

An annual modified net cash flow is calculated and used in an NPV analysis to compare farm performance for the various BMP scenarios to the baseline scenario (i.e., no BMP adoption) for the farms. BMPs affect the cash flow structure of the farms. The acreage available for crop production changes with adoption of some of the BMPs (e.g., buffer strips, shelterbelts). Management of residue affects the input costs and yields of subsequent crops which affects the revenue of the farm. The rotational BMPs affect the pattern of crops grown and, in some cases, crop yields and input costs.

Adoption of BMPs is evaluated by comparing NPVs between scenarios for each of the representative farms. In each case, the NPV for the BMP scenario is compared with the BMP for the baseline scenario. If the difference between the two NPVs is positive, the BMP provides a net benefit to the producers, in that adoption results in improved cash flows and increased value or wealth. If the difference is negative, adoption of the BMP represents a net cost to the cropping operation, and would result in decreased value or wealth.

4.6.1 Discount Rate

The discount rate used for Monte Carlo simulation studies varies depending on the type of firm being analyzed. Typically, the discount rate incorporates the relative riskiness of the business. The Canadian Treasury Board uses a discount rate of 8%, calculated as a weighted average of the interest rate on domestic savings, the interest rate of a postponed investment, and the marginal cost of foreign borrowing (Treasury Board of Canada Secretariat, 2007). This rate was re-estimated, using the same criteria, from the 10% rate calculated in 1998.

Recent studies examining adoption of environmental practices by agricultural firms have used a discount rate of 10% (Cortus, 2005; Koeckhoven, 2008). The default discount rate for this study is also 10%.

4.6.2 Simulation Model Iterations

As discussed previously, Monte Carlo simulation is an iterative process that uses random draws from pre-specified distributions to model stochastic parameters. The result of this process is a distribution of results. When using Monte Carlo simulation a decision is required in terms of the number of iterations to use in the analysis. There is a tradeoff involved in making this decision. When more iterations are used, more confidence can be placed in the "accuracy" of the distribution of results; that is, a greater opportunity for the simulation results to accurately represent the outcome. However, when using *@RISK* as more iterations are added to each simulation the time for each simulation increases. Due to the many simulations that will be done on five models the number of iterations will be chosen so as to maximize modelling efficiency while still providing accurate results.

A t-test was performed comparing model results using 1,000 iterations with model results using 10,000 iterations. A paired t-test with the hypothesis that results from models simulated with 1,000 iterations and 10,000 iterations would be equal was not rejected ($p = 0.76$, $df = 4$). This is expected to hold across all other scenarios and 1,000 iterations will be used for all baseline and BMP analyses.

4.6.3 Net Present Value Calculations and Beneficial Management Practices Adoption Assessment

Net present value is calculated using cash flows associated with crop input costs, crop and forage revenues, machinery costs, and revenues and expenditures for AgriStability, AgriInvest and crop insurance programs. In the case of BMP scenarios, cash flows associated with adoption (e.g., revenues from hay production, costs of establishing shelterbelts, etc.) are also incorporated into the NPV calculations.

As noted earlier, a forty year time horizon is used for the simulation analysis. The forty years of cash flows are used to calculate an NPV in perpetuity ($NPV_{perpetuity}$). The use of a perpetuity NPV measure assumes there is no end to the cash flows; that is, they continue into perpetuity. This approach is used as some of the BMPs (e.g., crop rotations shelterbelts) require several years before the effects on farm performance are fully realized, and the impact of the BMPs continue beyond the end of the simulation time horizon. The calculation used for the NPV with perpetuity is given in equation 4.23:

$$NPV_{Perpetuity} = \sum_{t=0}^{40} \frac{C_t}{(1+r)^t} + \left(\frac{C_{40}}{r} * \frac{1}{(1+r)^{40}} \right) \tag{4.23}$$

where C_t is the net cash flow for year t ($t = 0$ to 40) and r is the discount rate. The first term in equation 4.23 is the summation of discounted cash flows over the 40 year time horizon. To this is added the perpetuity present value; that is, an estimate of the present value of cash flows beyond year 40. The cash flow in the year 40 is divided by the discount rate (r) to obtain a year 40 perpetuity present value, which is then discounted to a present value.

For further comparison of the results of BMP adoption the NPVs are converted to an annualized value per hectare. The annualized values are useful for comparison of scenarios for individual farms, as this calculation converts the NPVs to values that may be compared to estimate annual net benefits or costs per hectare for the various BMP scenarios. This computation also allows for a more direct comparison between representative farms for individual BMP scenarios.

The formula to annualize NPV with perpetuity is shown in equation 4.24:

$$A = NPV_{Perpetuity} * r \tag{4.24}$$

where A is the annualized NPV, $NPV_{Perpetuity}$ is the original NPV in perpetuity and r is the discount rate. Equation 4.24 is essentially the (rearranged) formula for a perpetual annuity; that is the present value of a constant stream of future returns that extends into perpetuity. In this case, the present value is the NPV from the simulation analysis, and the calculation provides the (constant) annual cash flow that would generate it.

The annualized present values are then used to calculate the annual change in farm performance/value resulting from a particular BMP scenario; that is, the difference between the annualized NPVs. This difference is then converted to a per hectare value. The specifics of this calculation depend on the type of BMP under consideration. In the case of rotational BMPs, the change in practice affects the whole farm since the overall crop rotation is adjusted. This is also true for the residue management BMP. For these scenarios, therefore, the annualized NPV difference is divided by total farm acreage to determine the annual net benefit or cost per hectare. For other non-rotational BMPs such as shelterbelts and buffer strips, the effect is to reduce the area available for regular annual crop production. For these BMP scenarios, the annualized NPV difference is divided by the farm acreage affected by the particular BMP to establish the net benefit or cost per hectare.

4.7 Chapter Summary

Stochastic, dynamic simulation models are used to examine the feasibility of the adoption of several rotational and non-rotational BMPs on four representative commercial crop farms in Alberta. Decisions regarding farm size, structure, and other characteristics are based on 2001 and 2006 Statistics Canada data, data from AARD and AFSC, and opinions from experts in these areas.

Stochastic variables in the model include crop and forage prices and crop and forage yields. The stochastic variables are based on historical price and yield data obtained from AARD and AFSC. Prices are assumed to be provincial in nature and are therefore common for all representative farms. However, yields are specific to each region. Several of the yield effects from BMP adoption also use stochastic draws from uniform distributions. The stochastic variables generate final yields and revenues for each operation.

The models are built to be flexible in the adoption of individual and combinations of BMPs. The BMPs considered include adding alfalfa hay, field peas, legume green manures, and oats to the rotation based on the feasibility of the soil zone, and adding shelterbelts, buffer strips, hay in the buffer strips, and management of residues on all representative farms. For each farm, NPV analysis is employed to compare the adoption of these BMPs to a baseline scenario.

Chapter 5: Results and Discussion

This chapter provides a discussion of the results from the model farm simulations that were presented in Chapter 4. The direct economic impact of BMP adoption is presented and explained along with sensitivity analysis for a subset of model variables. The value for each representative farm after adopting one or more BMPs, as proxied through an NPV calculation, is compared to a reference result for each farm.[29]

5.1 Baseline Scenario Results

Baseline scenarios are simulations modelled for the representative farms, assuming that none of the BMPs are adopted. Baseline results are determined using the base crop rotations that were presented and discussed in the previous chapter. The baseline results for each farm are used as the basis for comparison when one or more BMPs are adopted and also for comparison in sensitivity analysis.

Mean and standard deviation NPV[30] values for the reference farm simulations are shown in Table 5.1. The annualized mean values of the farms on a per hectare basis are also provided. The measure of NPV for the farms can be considered as a modified wealth measure for the operations but does not represent wealth in terms of equity or net worth. As discussed in the preceding chapter, this is due to the use of modified net cash flows (MNCFs) in the NPV calculations. MNCFs do not include all cash flows that would be relevant for equity calculations. The type of analysis in this study does not consider capital structure in terms of the method of financing farm assets as either debt or equity. However, higher mean NPV amounts do indicate greater wealth for the operation.

The annualized mean NPVs for the operations are approximately $65, $85, $274, and $311 per hectare for the farms located in the Brown, Dark Brown, Black, and Dark Grey soil zones, respectively. The highest wealth value per hectare is on the farm with the smallest acreage and furthest north in the province. Of the southern farms the farm in the Dark Brown soil zone has a higher wealth value per hectare due to higher crop yields in this region relative to those for dryland production in the Brown soil zone. Comparing the results of the farm in the Dark Brown soil zone with the farms in the Black and Dark Grey soil zones a large gap in value that is partially due to the amount of canola, a higher value crop, grown in the base rotations is present. In the Dark Brown soil zone canola is grown on one quarter of the land under production, while in the Black and Dark Grey soil zones it is grown on two fifths of the land[31].

When comparing the standard deviations of the NPVs for the representative farms it is also important to consider that a number of factors affect this variability measure. For example, economic theory suggests that variance of returns generally increases with greater levels of expected returns. As well, each farm may be considered as a “portfolio” of crop enterprises. As the number of enterprises in the portfolio increases, all else being equal, NPV variability would tend to be lower. The pattern of

---

[29] Summary results from the simulations are provided in tabular form in this chapter. Detailed simulation results are available from the authors.

[30] The NPVs presented and discussed in this chapter are “in perpetuity”; that is, they are calculated using an infinite time horizon. The calculation of NPV with perpetuity is provided in Chapter 4, section 4.6.3.

[31] It should be noted that the degree of intensity of canola production for the Black and Dark Grey farms (i.e., two of every five years) results in greater risk in terms of disease problems for this crop. However, this risk factor was not explicitly incorporated into the analysis due to lack of ability to quantify the impact on yield distributions.

NPV standard deviations in Table 5.1 is somewhat consistent with these considerations. For example, the Black soil zone farm has the greatest mean NPV and the second highest standard deviation while the Dark Brown farm has the second lowest mean NPV and standard deviation. The number of crop enterprises in the portfolio for each representative farm is likely not a major factor, as the farms either have three or four risky crop enterprises each, not including summerfallow.

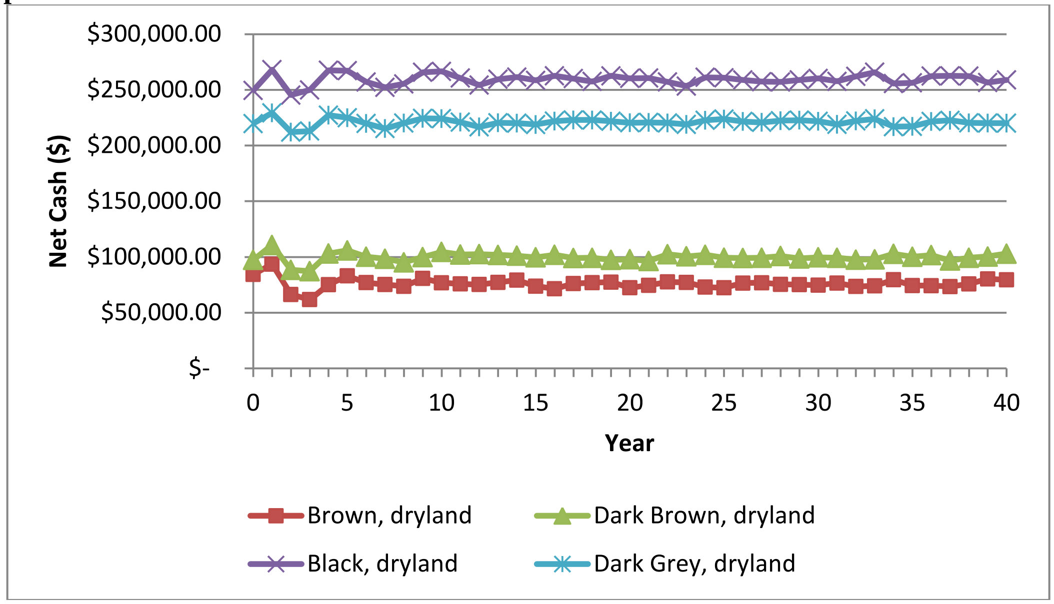
However, there are some significant deviations from the expected pattern. For example, the Brown soil zone farm has the highest standard deviation but also has the lowest mean NPV. Historical yields in this area have more variability as compared to other regions due to extreme differences in temperature and precipitation events. The naturally occurring variability in weather in this region is hypothesized to be the cause of the high variability calculated in the model. While it is not explicitly modelled, the soil in southern Alberta is more prone to erosion due to lower soil moisture levels and lower soil organic matter levels. Extrapolating from this, yields may vary more from year to year due to faster annual depletion of the soil under poor growing conditions, as compared to areas with higher levels of soil organic matter and soil moisture. The other significant exception to the expected pattern is the Dark Grey representative farm which has the second highest mean NPV but the smallest standard deviation. While there is no obvious explanation for this result, it may be the case that the opposite situation exists from the Brown soil zone farm; that is, crop production is less risky in this region.

Table 5.1 –Baseline results of the representative farms for the variable NPV

Soil zone	Mean NPV	Standard deviation NPV	Farm hectares	Annualized mean NPV per hectare
Brown	$845,707	$346,840	1,295	$65.31
Dark Brown	$1,094,775	$297,373	1,295	$84.54
Black	$2,841,695	$330,860	1,036	$274.29
Dark Grey	$2,419,362	$229,890	777	$311.37

Figure 5.1 shows the average annual cash flows of the simulation for the representative farms over the forty year time period. Over the forty years the average cash flows are approximately $76, $100, $259, and $221 thousand for the farms in the Brown, Dark Brown, Black, and Dark Grey soil zones, respectively. The overall trends between farms in average annual cash flow is consistent with the trends in perpetual wealth of the operations as discussed above. The average annual cash flows slightly decrease initially, in years two to four of the simulation. Further examination of the cash flows with static assumptions conclude that in these years average simulated crop prices of barley, durum wheat, and spring wheat are slightly lower than for other years, resulting in lower revenues. For example in year two of the simulation average spring wheat price is $0.19 per kilogram, while the 2008 and 31 year average prices were $0.32 and $0.22 per kilogram, respectively. In years three and four average simulated barley price was $0.13 per kilogram, while the 2008 and historic average prices were $0.21 and $0.15 per kilogram, respectively. All other expenses and revenues are relatively consistent. It is hypothesized that due to the nature of the price models using lagged variables and a 2008 starting price, the first several years of the simulation are more variable than subsequent years.

Figure 5.1 – Modified net cash flows for representative farms over the 40 year time period



5.1.1 Validation of Representative Farm Models

Simulation models are used in this study to predict the quantitative costs and benefits of BMP adoption. It is impossible to model all possible actions and events that can occur on cropping operations, but stochastic simulation analysis is employed to account for potential variability in outcomes. However, models are not useful for use in decision making unless they accurately represent and reproduce behaviours that occur in real systems (Macal, 2005). Many land use models use parameter sensitivity and error propagation, but do not consider full model validation (Kok et al., 2001). This is in part due to the objectives of the studies, to explore future scenarios that do not currently exist, and therefore do not have a benchmark for comparison (Kok et al., 2001). Verification and validation of models ensures some credibility is accounted for in modelling social systems (Macal, 2005), such as in agricultural production.

Verification ensures that models are programmed correctly and perform as intended (Macal, 2005). Verification for this study is done using price and yield model comparisons to historical data. Sensitivity analysis of input and BMP parameters, discussed later in this chapter, also ensure verification of model specifications. However, these tests do not ensure that the farm models are accurately and correctly reflective of real farms in the areas of interest. Verification improves the degree of statistical certainty, but Macal (2005) notes that no computational model will ever be guaranteed to be completely error free.

Ideally, validation of the representative farm models discussed in this project would be through comparison of the model farms to real farms in the respective areas, of the same size and crop characteristics. However, the real world system does not exist in this case, or in many cases of simulation analysis (Macal, 2005). Therefore, there are associated practical difficulties in validating models (Kok et al., 2001).

Koeckhoven (2008) uses simulation output to validate similar farm level models. It is suggested that the cash rental rate of land can be determined by half of the contribution margin (direct revenue minus direct expenses) to account for the possibility of renters to profit from agricultural activities on the land (Koeckhoven, 2008). Koeckhoven (2008) also suggests that the annualized cost is a good approximation of the contribution margin for crop production. Table 5.2 compares the annualized NPV per hectare and half the contribution margin, in year 40, per hectare, to land rental rates, by soil zone, in Alberta. Land rental rates were obtained for the year 2010 from AARD (2011-b). Comparing the contribution margin estimate to the Alberta land lease rates in 2010, the values are within the range for rental rates for the farms in the Brown and Dark Brown soil zones. However, the contribution margin values are higher than the rental rates for the farms in the Black and Dark Grey soil zones. A similar pattern is apparent when comparing the annualized NPV per hectare to the rental rates, with the exception of the farm in the Brown soil zone, where the annualized value is lower than the rental rate range.

Table 5.2 – Comparison of annualized NPV and half of the contribution margin in year 40 to land rental rates in Alberta, per hectare

Soil zone	Annualized NPV	Half of Year 40 Contribution Margin	Rental Rates (2010)[a]		
			Minimum	Maximum	Average
Brown	$65.31	$103.53	$81.51	$160.55	$124.07
Dark Brown	$84.54	$101.90	$81.51	$160.55	$124.07
Black	$274.29	$221.16	$46.31	$197.60	$124.19
Dark Grey	$311.37	$228.08	$34.58	$185.25	$124.71

[a] Rental rate values obtained from AARD (2011-b), Custom Rates Survey.

An alternative method to comparing annualized values and the contribution margin (net of the amount assumed to be profit) is to compare the total value of the operations (i.e., NPV with perpetuity) per hectare to farmland values. This type of comparison uses revealed preference theory to assume that there is a relationship between land property prices and the property characteristics (Swinton et al., 2007), in this case the ability of the land to support agricultural production. Farmland values, specifically for grain production, were obtained by Farm Credit Canada (FCC) from September 2009 to September 2011 (FCC, 2011). Table 5.3 provides the comparison of NPVs obtained from the simulation models and farmland values for crop land. Farmland values are reported by county or municipal district and were determined based on the representative counties for each corresponding representative soil zone, as defined in Chapter 3. Comparing the NPV results with farmland values it appears that the simulation values underestimate the value of land for farms in the Brown, Dark Brown, and Black soil zones. The NPV per hectare of the farm in the Dark Grey soil zone is within the range of farmland values in this soil zone. It should also be noted that the NPV per hectare for the farm in the Black soil zone is close to the range of farmland values in this region.

Table 5.3 – Comparison of NPV and farmland values, per hectare

Soil zone	NPV	Farmland Values (2010-11)[a]		
		Minimum	Maximum	Average
Brown	$653.06	$1,162	$5,513	$2,822
Dark Brown	$845.39	$2,116	$5,004	$3,574
Black	$2,742.95	$2,818	$6,472	$4,800
Dark Grey	$3,113.72	$2,108	$3,467	$2,642

[a] Farmland values obtained from FCC (2011).

While it is difficult to validate simulation models due to simplifying assumptions made that are not realistic, the combination of land rental rates and farmland values results in the models being consistent with at least one approach, and that these models are useful in predicting the costs and benefits of BMP adoption. It is assumed that the separate verification and sensitivity analysis, as presented later in this chapter, of BMP parameters retains the validation of the representative farm models.

5.2 Crop Rotation Beneficial Management Practices Results

This section presents and discusses results for the rotational BMPs. Alfalfa hay is added to rotations on farms in the Dark Brown, Black, and Dark Grey soil zones. Field peas are added to rotations on all farms. Legume green manures are added to rotations as a partial or complete replacement for summerfallow on farms in the Brown and Dark Brown soil zones. Oats are added in rotations on farms in the Black and Dark Grey soil zones.An explanation of each alternative rotation in terms of its role as a BMP is provided in Chapter 4.

As noted earlier, the BMPs are compared to the baseline scenario using the NPVs calculated from the simulation analysis. In the case of the rotational BMPs the annualized mean NPV per hectare from the baseline scenario (i.e., A_{Baseline} in Equation 5.1) is subtracted from the annualized mean NPV per hectare for the particular BMP (i.e., A_{BMP}). The difference represents the effect (positive or negative) of the BMP, expressed in annual terms per hectare of the farm. Positive (negative) values represent a positive (negative) impact of the BMP on farm wealth. The difference is then divided by the baseline annualized mean NPV per hectare to express the difference in percentage terms (Equation 5.1).

$$[(A_{BMP} - A_{Baseline})/A_{Baseline}] * 100\% \qquad (5.1)$$

5.2.1 Alfalfa Hay

When alfalfa hay is added to rotations there is a reduction in the percentage of other crops grown. Specifically, there are approximately 533, 365, and 274 hectares of land converted from crop production to forage production when a three year alfalfa hay stand is adopted in rotation for farms in the Dark Brown, Black, and Dark Grey soil zones, respectively. As discussed in the previous chapter, other effects of adopting three year stands of alfalfa include nitrogen fixing benefits in soil and improved yields in subsequent crops after the stand has been terminated.

The mean NPV of the farms increases when alfalfa hay is adopted in rotations due to beneficial assumptions made for subsequent crop yields and input costs. The average price of alfalfa hay is lower than the average price of all grain and oilseed crops considered in the analysis, but alfalfa hay produces relatively higher yields per hectare for all crops except for barley production in the Dark Grey soil zone. Also, per hectare direct expenses for alfalfa hay production is lower for all other crops considered in the baseline and alfalfa hay rotations. The net effect is that average cash inflow per year and per hectare for alfalfa hay is lower on all farms when compared to the crops being replaced (i.e., reduced in acreage) to adopt alfalfa hay in rotation, including barley, canola and wheat. The results in terms of increased mean NPV (i.e., from increased net cash for the entire simulation period) for the representative farms are therefore due to the yield and nitrogen benefits for crops following alfalfa hay in rotation.

Table 5.4 displays the mean and standard deviation values for the NPV variable and calculates the mean as an annual value per hectare of farm land. In the fifth column of this table the annual value of the operation with the BMP is compared with the annual value from the baseline scenario, column five in Table 5.1. The results show that the addition of alfalfa hay has the strongest effect on the farm situated in the Dark Brown soil zone with a difference in the mean value of the farm after adoption of approximately $63 per hectare per year. This is an increase of 75% as compared to the base rotation. Adding alfalfa hay to the farms in the Black and Dark Grey soil zones changes the value of the farms by approximately $48 and $32 per hectare per year, respectively. The percent change as compared to the base rotations on these farms are 17% and 10% for the Black and Dark Grey farms. In terms of differences between farms, a larger benefit from adding alfalfa hay is apparent for the farm located in the Dark Brown soil zone as compared to the other areas and is partly due to the way alfalfa hay fits in the rotations and replaces other crops and practices. In the Dark Brown soil zone alfalfa hay fits into the rotation as three years of alfalfa followed by the base rotation. Therefore, summerfallow occurs less frequently in the crop rotation, which improves the revenue generated by the farm, as this is a practice that does not generate revenue.

For all farms adding alfalfa hay increases the mean value of the operation. However the standard deviation of each operation is reduced when alfalfa hay is added to rotation. Standard deviation decreases by 26, 29, and 26% for the farms in the Dark Brown, Black, and Dark Grey soil zones. The lower standard deviation indicates that the range of outcomes is closer to the mean outcome after alfalfa is added to rotation, as compared to the base rotation. It appears that adding alfalfa hay somewhat reduces the uncertainty of production among producers in all relevant soil zones and production types. The reductions in standard deviation are also attributed to the standard error of alfalfa hay in the SUR model for price estimates in Chapter 4, which is the lowest of all crops in the model.

As discussed earlier for the baseline results, the cropping operations may be considered to have a portfolio of risky cropping enterprises. One factor affecting the variability of portfolio returns is the number of “assets” included in the portfolio. In particular, as the number of assets increases (all else being equal) the portfolio variance decreases. With this rotational BMP, an additional crop enterprise is added to the portfolio. Therefore, it might be expected that NPV variability would decrease. As well, portfolio variability is affected by the correlation between returns for the portfolio assets. In the case of alfalfa yields, there is an assumed positive correlation with other crop yields. In modelling alfalfa prices, however, as discussed in Chapter 4 the error term for the alfalfa price equation is not correlated (i.e., correlation equal to zero) with the error terms for the other crop price equations. This contributes to a lower correlation between alfalfa returns and other crop returns, which in turn would result in portfolio variance being reduced from the addition of the alfalfa enterprise.

It should be noted that while reduced risk is observed from the model results this may not occur in reality. In practice, hay production is dependent on many factors. Yields and price are affected by adverse weather during harvest of hay as rain at certain times may decrease the quality of hay and decrease the price, while lack of precipitation may also result in only one cut of hay, where the model always predicts two cuts of hay.

Table 5.4 – Results of NPV variable for alfalfa hay rotation on representative farms

Soil zone	Mean NPV	Standard deviation NPV	Annualized mean NPV per hectare	Annualized mean NPV difference per hectare (BMP – Baseline)	Percent difference annualized mean NPV per hectare (BMP – Baseline)
Dark Brown	$1,917,264	$221,454	$148.05	$63.51	75%
Black	$3,336,329	$236,190	$322.04	$47.74	17%
Dark Grey	$2,668,590	$170,301	$343.45	$32.08	10%

5.2.2 Field Peas

Similar to alfalfa hay, when field peas are added to the base rotation there is a decrease in the percentage of other crops grown due to land base constraints. Field pea production is assumed to use approximately 155, 207, 162, and 122 hectares of land on dryland farms in the Brown, Dark Brown, Black, and Dark Grey soil zones, respectively. Benefits of adopting field peas in crop rotations include reduced nitrogen fertilizer costs in the subsequent crop and a yield benefit for the subsequent crop.

Overall, when field peas are adopted into the rotations the value of the farms is increased. Table 5.5 displays, for each representative farm, NPV means and standard deviations, mean annualized NPV per hectare, and the percent difference in the annual value relative to the baseline scenarios. The addition of field peas increases the annual value of the farm in the Brown soil zone by $42 per hectare, a 65% difference from the base rotation. In the Dark Brown soil zone adding field peas increases the value of the farm by $28 per hectare per year, which is a 33% increase from the base rotation. In the Black soil zone the addition of field peas actually decreases the annual per hectare value of the farm by $2, which is a 1% difference as compared to the base rotation. However this is largely due to the reduction of acreage allotted to crops with higher production value such as canola. In the Dark Grey soil zone adding field peas to the crop rotation increases the annual wealth value of the farm by $5 per hectare which is a 2% increase as compared to the base rotation in this soil zone.

Similar to adding alfalfa hay to the rotation, adding field peas to rotations decreases the standard deviation of the NPV variable for all farms examined. However the effect is smaller here. Adding field peas to the rotation decreases the standard deviation by 1%, 7%, 10% and 6% for the farms in the Brown, Dark Brown, Black and Dark Grey soil zones. Adding field peas to the rotation slightly reduces the uncertainty of production. This effect is most noticeable on the farm in the Black soil zone for which adding field peas did not result in an increased value of production. Similar to the effect observed in alfalfa hay the decrease in standard deviation is likely due to increased diversification in the crop portfolio, resulting in decreased risk.

Table 5.5 – Results of NPV variable for field pea rotation on representative farms

Soil zone	Mean NPV	Standard deviation NPV	Annualized mean NPV per hectare	Annualized mean NPV difference per hectare (BMP – Baseline)	Percent difference annualized mean NPV per hectare (BMP – Baseline)
Brown	$1,394,374	$344,382	$107.67	$42.37	65%
Dark Brown	$1,459,713	$276,665	$112.72	$28.18	33%
Black	$2,823,872	$299,176	$272.57	-$1.72	-1%
Dark Grey	$2,457,592	$216,222	$316.29	$4.92	2%

5.2.3 Legume Green Manures

Legume green manures are added to rotations for the southern Alberta dryland farms as a complete or partial replacement for summerfallow. In the case of the Brown soil zone farm, prior to adopting this BMP there were approximately 310 hectares per year of land under summerfallow. The BMP results in this being reduced by half, to approximately 155 hectares. The other 155 hectares previously allocated to summerfallow practices are seeded to a legume green manure. For the Dark Brown soil zone farm, there were approximately 310 hectares of summerfallow in the base rotation. Adoption of this BMP results in all of this being seeded to legume green manures; that is, summerfallow is reduced to zero.

Having land under summerfallow has some costs, but there are typically higher costs associated with land seeded to legume green manures. The benefits of seeding land to legume green manures are outlined in the BMP discussion in Chapter 4. However, the simulation results indicate that the costs of adopting legume green manures into the rotations outweigh these benefits, given the assumptions of the models. The mean and standard deviation values for NPV, the mean annualized NPV values per hectare, and the percentage change in the mean annualized values for this BMP are shown in Table 5.6. The addition of legume green manures to the rotation results in average annualized values of approximately $60 and $74 per hectare for the farms in the Brown and Dark Brown soil zones, respectively. These represent reductions of 8% and 12%, respectively, compared to the base rotation. Changes to the standard deviation as a result of adding legume green manures are minimal and do not present any significant change in uncertainty as compared to the base rotation.

The benefits associated with this BMP are reduced nitrogen costs in subsequent years. It is assumed that the benefit to subsequent crops increases with the number of times legume green manures is present in rotation with benefits occurring from reduced input costs for nitrogen fertilizer. Conversely, the conversion from summerfallow to legume green manure results in a net increase in crop costs; that is, additional costs of seeding and ploughing legume green manures are greater than the costs associated with summerfallow being replaced. As well, legume green manures may deplete more soil moisture, as compared to summerfallow, and as such there is potential for a yield decrease in subsequent years. The simulation results indicate that the net effect of these changes is “negative” in terms of reduced cash flow and wealth. It should be noted that the model does not consider other long term benefits of legume green manures, such as improved soil organic matter content from reduction in summerfallow and increased residue returned to the soil. Incorporating these longer term effects of green manure would increase the potential for improvements in farm wealth as a consequence of adopting this type of BMP.

Table 5.6 – Results of NPV variable for legume green manures rotation on representative farms

Soil zone	Mean NPV	Standard deviation NPV	Annualized mean NPV per hectare	Annualized mean NPV difference per hectare (BMP – Baseline)	Percent difference annualized mean NPV per hectare (BMP – Baseline)
Brown	$778,252	$345,417	$60.10	-$5.21	-8%
Dark Brown	$962,575	$296,480	$74.33	-$10.21	-12%

5.2.4 Oats

Oats are added to rotations only in the northern (i.e., in the Black and Dark Grey soil zones) soil zones. When oats are adopted in rotations, 162 and 122 hectares per year of land are cropped as oats on the Black and Dark Grey soil zone farms, respectively. With the addition of oats, there is a proportionate reduction in the area for the other crops in rotation for the two farms; barley, canola, and spring wheat crops. Unlike the previously discussed BMPs which affect subsequent crops in terms of nitrogen requirements and/or yields, oats is considered a BMP simply due to the reduction in inputs, specifically chemical fertilizer and herbicide, necessary for this crop. As compared to spring wheat and barley, the fertilizer cost for oats is approximately $21 and $16 per hectare less in the Black and Dark Grey soil zones, respectively. Per hectare cost for chemical herbicide is approximately $28 for oats in the Black and Dark Grey soil zones, while it is approximately $86 and $43 per hectare for spring wheat and barley, respectively, in the same areas.[32]

Results for the representative farms that adopt oats into the rotation are shown in Table 5.7. Mean NPVs after adopting oats are approximately 2.5 and 2.4 million dollars with standard deviations of approximately 0.3 and 0.2 million dollars for the Black and Dark Grey soil zone farms, respectively. These represent reductions in both mean and standard deviation as compared to the baseline results. The annualized mean NPV of the farm in the Black soil zone after adopting oats is $246 per hectare. This represents a decrease of $29 per hectare per year, or a 10% reduction when compared to the base rotation. For the Dark Grey soil zone farm the annual mean NPV after adopting oats is approximately $305 per hectare, which is $6 per hectare per year lower, or a 2% reduction, when compared to the base rotation. The decreased mean NPV values are due to reduced net cash flows associated with oats relative to the crops being replaced in the rotation. In other words, lower revenues generated by including oats outweigh the input cost reductions associated with this crop. The decrease in variance is likely attributable to two factors. First, lower expected returns tend to be associated with lower variability. Secondly, there is increased diversification in the portfolio of crop enterprises.

---

[32] As noted in Chapter 4, oats should only be grown on fields where wild oats are not problematic as there are no herbicides available for control of wild oats when oats are grown.

Table 5.7 – Results of NPV variable for oats rotation on representative farms

Soil zone	Mean NPV	Standard deviation NPV	Annualized mean NPV per hectare	Annualized mean NPV difference per hectare (BMP – Baseline)	Percent difference annualized mean NPV per hectare (BMP – Baseline)
Black	$2,545,356	$309,612	$245.69	-$28.60	-10%
Dark Grey	$2,372,483	$217,208	$305.34	-$6.03	-2%

If the results for the two farms are compared, it appears that the impact of adopting oats is more significant (i.e., more negative) for the Black soil zone farm than for the Dark Grey soil zone farm. Part of this is due to the difference in costs associated with oats. Direct expenses from growing oats are approximately $241 and $201 per hectare on representative farms in the Black and Dark Grey soil zones, respectively, and this contributes at least in part to the differences in simulation results between the two farms.

Besides the differences in costs per hectare, however, much of the difference between the Black and Dark Grey soil zone farms is due to assumptions made about the oat yields; specifically, the detrending of yields. An explanation and justification for detrending procedures used for the yield data to account for changes in crop technology over time is provided in Chapter 4. As discussed there, the oat yield data for the representative municipal district in the Dark Grey soil zone had a significant trend and so the oat yield data were detrended prior to estimating the yield distribution for the simulation model. Conversely, there was no significant trend in the oat yield data for the Black soil zone and consequently no detrending procedure was used. One outcome from detrending the oat yield data for the Dark Grey soil zone was a higher average yield than for the original data series. In particular, the resulting average was significantly higher as compared to the overall average in the Black soil zone. From the original municipal level data mean oat yields were approximately 2,431 and 2,817 kilograms per hectare in the Black and Dark Grey soil zones, respectively. After detrending, the average for the Dark Grey soil zone was approximately 3,537 kilograms per hectare. This difference in average yield contributes significantly to the relative impact of adopting oats for the two farms. With an average yield similar to the original value for the Dark Grey soil zone farm (i.e., before correcting for the time trend), the impact on average modified net cash flows would be approximately $13,000. While this would still result in the net (negative) impact of adopting oats being smaller for the Dark Grey soil zone farm than for the Black soil zone farm, the difference between the farms would be much smaller.

5.3 Non-Rotational Beneficial Management Practice Results

This section presents and discusses results for the non-rotational BMPs that are considered for the representative farms. The BMPs include adoption of shelterbelts, buffer strips with or without hay, and residue management. All non-rotational BMPs are considered for the four representative farms. BMP results are compared to results for the reference farms where there are no BMPs implemented. Adoption of residue management is compared to the baseline scenarios in the same manner as for rotational BMPs, that is, an annualized value per hectare of land over the whole farm is used. For BMPs that consider a reduction in crop acreage, such as adoption of shelterbelts and buffer strips, comparisons with the baseline results will be on a per hectare of crop land lost. In particular, the NPVs for the baseline and BMP scenarios are both converted to an annual basis, $\mathrm{ANPV}_{\mathrm{Baseline}}$ and $\mathrm{ANPV}_{\mathrm{BMP}}$, respectively. The difference between these two values is then divided by the hectares of cropland lost due to implementation of the BMP. The resulting value is the annual impact of the BMP per hectare of affected cropland (Equation 5.2).

$$[(ANPV_{BMP} - ANPV_{Baseline})/Hectares\ lost] \qquad (5.2)$$

Results for combinations of non-rotational BMPs are also presented and discussed in this section.

5.3.1 Shelterbelts

Adopting shelterbelts as a BMP reduces total land area available for crop production. Hectares seeded to crops are reduced by 95.4, 76.3, 45.8, and 22.9 hectares for the farms situated in the Brown, Dark Brown, Black, and Dark Grey soil zones, respectively. Besides the effect in terms of reduced area for crop production, there are yield effects on land in proximity to the shelterbelts. As discussed in Chapter 4, there are yield benefits from adopting shelterbelts but these are limited to the area of land that is protected by the trees. Closer to the shelterbelts, however, there are yield decreases on land where crops are competing for soil moisture and nutrients with the shelterbelt tree species.

When shelterbelts are adopted on the representative farms the NPV decreases for the reference farms. This is consistent for all four farms. This result is largely due to the relatively high cost of adoption, including planting and maintenance costs, and the loss of cropland. The results of adopting shelterbelts on the mean and standard deviation of NPV of the farms are shown in Table 5.8 and compared as a total to the baseline results. Not surprisingly, the greatest total impact on NPV occurs for those farms with a greater area of land allocated to shelterbelts. The greatest overall cost occurs on the Brown soil zone farm, which has the greatest area of land converted due to the higher potential for soil erosion. Conversely, the lowest overall impact is for the Dark Grey soil zone farm. Since there is lower concern for soil erosion in this area, fewer shelterbelts are adopted, and less crop acreage is lost. A similar pattern is present for the other farms in that the relative overall reductions in NPV are consistent with the amount of cropland lost due to shelterbelt adoption. Standard deviations of the NPV values also decrease when shelterbelts are adopted. The decrease is relatively small and is due to the overall decrease in the mean NPV of the operations when shelterbelts are adopted.

However, when considering the cost per hectare of crop land lost the impact is greatest for farms with the lowest potential to see reductions in soil erosion. On the northern representative farms in the Black and Dark Grey soil zones the annualized cost of adopting shelterbelts is approximately $396 and $411 per hectare of cropland converted to shelterbelts, respectively. Conversely, for the representative farm in the Brown soil zone, the annualized cost is $195 per hectare of cropland allocated for shelterbelt adoption. In the Dark Brown soil zone the representative farm experiences an annualized cost of $181 per hectare converted for shelterbelts.

These differences per hectare affected by the shelterbelt BMP are due to two factors. Per hectare costs of establishing shelterbelts are the same for all representative farms, but this is not the case for the yield impacts. When shelterbelts are adopted all farms experience an annual yield loss (i.e., in kilograms per hectare) in the area of land directly adjacent to shelterbelts and a yield benefit on land that is sheltered by the trees, but that is not in direct competition for moisture and nutrients. Farms in the Brown and Dark Brown soil zones experience a slightly higher yield loss in the areas directly adjacent to the trees as compared to the farms in the Black and Dark Grey soil zones. However, the yield benefit in the sheltered area is greater on the farms in the Brown and Dark Brown soil zones, as compared to the farms in the Black and Dark Grey soil zones. The other factor influencing the difference in per hectare results for the representative farms is the difference in value of crop production lost due to reduced crop acreage between the farms; that is, the farms with the higher NPV per hectare for the baseline scenario tend to incur a greater per hectare cost for the shelterbelt BMP.

Table 5.8 – Results of NPV variable for representative farms adopting shelterbelts

Soil zone	Mean NPV	Standard deviation NPV	Difference in annualized NPV[a]	Annualized difference per hectare lost[b]
Brown	$659,880	$339,125	-$18,582.71	-$194.79
Dark Brown	$956,363	$292,528	-$13,841.24	-$181.41
Black	$2,660,446	$324,231	-$18,124.90	-$395.74
Dark Grey	$2,325,182	$227,062	-$9,418.00	-$411.27

[a] Calculated as the annualized NPV for the BMP scenario minus the annualized NPV for the baseline scenario. [b] Calculated as the difference in annualized NPV divided by the hectares of land lost with shelterbelt adoption.

5.3.2 Buffer Strips

Similar to shelterbelts, implementing buffer strips around existing wetlands also removes land from crop production. Therefore adoption of this BMP is also expected to decrease the overall NPVs for the representative farms. As discussed in the previous chapter, a certain amount of wetland is assumed to be present on the representative farms. In particular, 4%, 4%, 6%, and 6% of the farm area is wetland for the Brown, Dark Brown, Black, and Dark Grey soil zone farms, respectively. It is further assumed that there is approximately one circular wetland, of appropriate size based on the above percentages, for every 64 hectares of land.

Before buffer strips are adopted as a BMP the land around the wetland is assumed to be cropped. The buffer strip BMP involves establishing 10 metre wide strips around all wetlands. The resulting loss in land for crop production varies by farm; approximately 12.04, 12.04, 11.68, and 8.76 hectares of cropland are lost for the Brown, Dark Brown, Black, and Dark Grey representative farms, respectively.

Table 5.9 shows the mean and standard deviation of the NPV for the farms after adopting buffer strips, the difference in mean annualized NPV with buffer strips adopted as a BMP and the baseline results, and the difference in NPV per hectare lost from buffer strip adoption. Overall, adopting buffer strips has a small impact on the overall NPV for the operations. There is approximately a 1% decrease in mean NPV observed for all farms, as compared to the reference farms. There is also a small decrease (i.e., approximately 1%) in the standard deviation for the NPVs, which is also related to the decrease in cropland available for production.

On a per hectare basis, however, the cost of this BMP is more significant. The annualized decrease in mean NPV as a per hectare of land converted to buffer strips ranges from approximately $95 to almost $340. This annual cost per hectare of adoption of buffer strips is proportional to the loss in value from crop production in the cropland allocated to adopt buffer strips. The impact of buffer strip adoption is most costly for the farms in the Black and Dark Grey soil zones due to higher production that is assumed to be in the area previously. The annualized cost of adoption per hectare lost is lowest in the Brown soil zone and second lowest in the Dark Brown soil zone as yields are also lowest in these areas.

Table 5.9 – Results of NPV variable for representative farms adopting buffer strips without hay

Soil zone	Mean NPV	Standard deviation NPV	Difference in annualized NPV[a]	Annualized difference per hectare lost[b]
Brown	$834,301	$344,328	-$1,140.57	-$94.73
Dark Brown	$1,081,114	$295,249	-$1,366.10	-$113.46
Black	$2,806,884	$327,738	-$3,481.10	-$298.04
Dark Grey	$2,389,698	$227,806	-$2,966.40	-$338.63

[a] Calculated as the annualized NPV for the BMP scenario minus the annualized NPV for the baseline scenario. [b] Calculated as the difference in annualized NPV divided by the hectares of land lost with shelterbelt adoption.

The results from adopting buffer strips with hay grown in the buffer areas are shown in Table 5.10. Mean NPVs for the representative farms are still below the baseline scenario values but are greater as compared to when buffer strips are considered without hay (Table 5.9). The change relative to the original buffer strip scenario is due to the income generated from the direct sale of hay produced in the buffer strip area. The annual mean costs of adopting buffer strips with hay are approximately $20, $27, $222, and $277 per hectare for the farms in the Brown, Dark Brown, Black and Dark Grey soil zones, respectively. When the results are converted to an annualized cost per hectare of land lost from the buffer strips the cost is lower than when hay is not grown and sold. However, the trend is the same with it being most costly on farms in the Black and Dark Grey soil zones and least costly on the farm in the Brown soil zone. Selling hay from the buffer strips reduces the mean annual cost of adopting buffer strips by approximately $75, $86, $76, and $62 per hectare for the farms in the Brown, Dark Brown, Black, and Dark Grey soil zones, respectively.

Table 5.10 – Results of NPV variable for representative farms adopting buffer strips with hay

Soil zone	Mean NPV	Standard deviation NPV	Difference in annualized NPV[a]	Annualized difference per hectare lost[b]
Brown	$843,273	$344,247	-$243.37	-$20.21
Dark Brown	$1,091,522	$295,291	-$325.30	-$27.02
Black	$2,815,807	$327,866	-$2,588.80	-$221.64
Dark Grey	$2,395,069	$227,822	-$2,429.30	-$277.32

[a] Calculated as the annualized NPV for the BMP scenario minus the annualized NPV for the baseline scenario. [b] Calculated as the difference in annualized NPV divided by the hectares of land lost with shelterbelt adoption.

5.3.3 Residue Management

As discussed in Chapter 4, an alternative baseline scenario is modelled for the purposes of comparison with results for the residue management BMP. In particular, in this revised baseline scenario wheat (durum and spring) and barley residue is harvested and sold every year. If residues are removed in a dry year[33] then subsequent yields may decrease due to reduced ability to retain moisture. The subsequent yield decrease is drawn from a uniform distribution with a minimum value of -0.03 and a maximum value of zero (i.e., the maximum yield loss is 3%). When residues are removed the net benefit from selling the residue for $25 per 544 kilogram straw bale is approximately $5.80. Results from this alternative scenario are provided in Table 5.11. The revised baseline mean NPV values are higher than the original baseline due to the benefits from selling residues each year, which outweigh the potential cost (i.e., reduced yield in the subsequent year) of removing residue in dry years.

Table 5.11 – Baseline results of the representative farms for the variable NPV with residue removed annually for barley and wheat crops

Soil zone	Mean NPV	Standard Deviation NPV	Annualized Mean NPV per hectare	Annualized mean NPV difference per hectare[a]	Percent difference annualized mean NPV per hectare[b]
Brown	$1,008,116	$355,382	$77.85	$12.54	19%
Dark Brown	$1,297,274	$303,678	$100.18	$15.64	18%
Black	$3,110,800	$358,131	$300.27	$25.98	9%
Dark Grey	$2,630,588	$239,017	$338.56	$27.18	9%

[a] Calculated as the difference between annualized mean NPV per hectare minus the equivalent value for the original baseline scenario results (i.e., in Table 5.1). [b] Calculated as the percent difference relative to the original baseline scenario.

Adopting residue management as a BMP on the representative farms implies that producers remove and sell residue in some years, while retaining residue to conserve soil moisture in other years. The purpose of retaining residue is to try and preserve soil

---

[33] A dry year occurs when residue yield is less than the average residue yield minus one standard deviation.

moisture for use in the subsequent crop. This option applies for residues associated with barley, durum wheat, oats, and spring wheat. Residues for canola, and field peas are assumed to always be retained as these crop residues are not easily removed and sold, but rather easily spread over fields. As discussed in Chapter 4, when residue management is adopted as a BMP there is potential for yield benefits. Also, as discussed earlier decisions about removing residue vary by farm but are static for each farm. Residues for the previously mentioned crops are removed every fifth, fourth, third, and third year for representative farms in the Brown, Dark Brown, Black, and Dark Grey soil zones, respectively. The results for this BMP are compared to the revised baseline[34] results (discussed above) where residues for wheat and barley are assumed to be removed every year.

Results for the residue management BMP are provided in Table 5.11. When compared to the revised baseline scenario net decreases are observed on all representative farms for adoption of residue management as a BMP.[35] The cost of this BMP, on an annual basis per hectare of cropland, ranges from just over $11 to over $26. The greatest numerical decreases are observed for the Black and Dark Grey representative farms. This is due to the higher volume of residue produced on these farms. With adoption of this BMP, there is a greater loss of returns from retaining the residue (i.e., foregone opportunity for sale of straw). In general, the results for this BMP suggest that for all of the farms the cost of the foregone opportunity to harvest and market crop residue, combined with the potential for reduced yield in some years (i.e., due to retaining residue in wet years), outweighs any benefits associated with yield increases from retaining residue in dry years.

Table 5.12 – Results of NPV variable for representative farms adopting residue management, as compared to the revised baseline results

Soil zone	Mean NPV	Standard deviation NPV	Annualized mean NPV per hectare	Annualized mean NPV difference per hectare (BMP – Baseline)	Percent difference annualized mean NPV per hectare (BMP – Baseline)
Brown	$864,268	$343,732	$66.74	-$11.11	-14%
Dark Brown	$1,133,498	$296,407	$87.53	-$12.65	-13%
Black	$2,872,261	$318,774	$277.25	-$23.03	-8%
Dark Grey	$2,427,078	$224,770	$312.37	-$26.19	-8%

---

[34] In the original baseline scenario there is no financial gain or yield effect from crop residues. In the revised baseline crop residues are sold and yield decreases can occur in dry years when residue is removed. The BMP scenario adds additional yield effect in dry years when residue is retained (yield increase) and in wet years when residue is retained (yield decrease).

[35] When the residue management BMP is compared to the original baseline scenario net increases occur.

5.4 Beneficial Management Practices Adoption Sensitivity Analysis

Parameters used in the simulation analysis for BMP adoption are estimates based on information from a variety of sources including previous studies (including some from outside of Alberta) and expert opinion. In many cases there is a degree of uncertainty regarding the actual effects that might occur with adoption of the BMPs. These include the yield effects and nitrogen benefits associated with the crop rotation BMPs. To assess the importance of these assumptions to the overall results and conclusions for this study, sensitivity analysis is done on the yield effects as well as other relevant factors associated with the BMPs modelled in this study.

Sensitivity analysis is also conducted for parameters associated with the non-rotational BMPs. Shelterbelt yield estimates are tested using sensitivity analysis on both areas adjacent to the trees (i.e., the areas in which yields are negatively and positively affected, respectively), independently. Buffer strip sensitivity analysis is done by incrementally changing the width of the strip. Sensitivity analysis is also conducted with respect to the proportion of land assumed to be wetlands. Finally, the yield effects following residue management are tested in a similar manner as for the other yield effects, with minimum and maximum yield effects being changed incrementally.

The results from the various sensitivity analysis scenarios are not presented in this report, but are available from the authors on request. However, while the quantitative results for the BMPs changed with the different sensitivity analysis scenarios, none of the overall conclusions (reported later in this document) are affected by the range of parameter values considered in these scenarios.

5.5 Chapter Summary

Many rotational BMPs are beneficial for most farms while some non-rotational BMPs may be costly. Specifically, on farms in the Brown and Dark Brown soil zones the addition of alfalfa hay and/or field peas to rotations decreases the amount of land allocated to summerfallow practices and increases land allocated to crops. This improved the value of the operations, as expected. On other representative farms that considered adoption of alfalfa hay into rotation, in the Black and Dark Grey soil zones, increased NPVs due to the value of alfalfa hay as a crop and potential benefits to subsequent crops following alfalfa hay in rotation also occurred. While there are also potential benefits to crops following field peas in rotation, this crop alone did not improve the mean NPV of the farm in the Black soil and only marginally improved the NPV of the farm in the Dark Grey soil zone. When legume green manures were adopted alone as a partial or complete replacement for summerfallow in rotations on farms in the Brown and Dark Brown soil zones decreases in mean NPV of the operations were observed as there are more costs associated with including legume green manures in rotation, as compared to summerfallow practices. Oats were adopted as a rotational BMP on farms in the Black and Dark Grey soil zone as fewer inputs are required for this crop. However, due to lower crop price this BMP resulted in reduced mean NPV of the operations, largely due to reduction of land allocated to higher valued crops, such as canola.

While adoption of some rotational BMPs reduced the mean NPV of the operations with respect to the baseline results, they did not result in negative mean NPVs. Also, for other rotational BMPs there is potential for increased mean NPVs. These results are encouraging as producer adoption of many of the rotational BMPs examined in this study would require education and involvement of producers, rather than government provided incentives or disincentives; the former being a relatively cheaper policy option.

Adoption of the non-rotational BMPs (i.e., shelterbelts and buffer strips) were more costly for producers due to the allocation of previously cropped land for these practices. Shelterbelts removed significant portions of land from crop production. While shelterbelt adoption reduced the value of the operations as compared to the baseline results, all representative farms still experienced a positive mean NPV. Adoption of buffer strips also resulted in decreased mean NPVs for all representative farms. However, when producers enabled the option to harvest and sell forage from the buffer zones the cost of this BMP decreased. Residue management as a non-rotational BMP increased the mean NPV of the representative farms in all soil zones, relative to the original baseline scenario, but resulted in decreased mean NPVs for all farms relative to the revised baseline scenario where residue is removed every year.

Considering that many of the non-rotational BMPs examined came at a net cost for producers, government involvement in the form of positive incentives for adoption may be necessary. If it is the case that adoption is low for practices that are costly for producers, then it is likely that policy involvement such as incentive mechanisms may be necessary.

While not explicitly discussed in this chapter, there were ten sensitivity analyses performed in total. Some sensitivity analyses were done to expand and test some of the yield and input cost saving assumptions made for BMP adoptions.[36] Others were done to compare how other model assumptions including discount rate, starting crop price averages, and safety net participation affect the value of the operations for baseline and BMP results. For the most part sensitivity analysis of model assumptions did not change the relative outcome of the results. This conclusion offers greater confidence in the ability of the models to predict the effects of BMP adoption of representative farms in Alberta.

---

[36] As noted earlier, details regarding the sensitivity analyses and the associated results are available from the authors.

Chapter 6: Conclusions and Further Research

A summary of results from the simulation models is provided in this chapter. Following this, conclusions are made based on these results, regarding the feasibility of Beneficial Management Practices (BMP) adoption on representative Alberta crop farms. BMP results from this study are compared to other studies with adoption of similar management practices. This chapter also discusses implications of this research for crop production and policy in Alberta. The chapter concludes with a discussion of limitations and assumptions made in developing the models and potential areas of further research that may be of interest, based on the findings in this study.

6.1 Summary of Results

BMPs have been advocated as a means by which the level of ecological goods and services (EG&S) supplied by agriculture may be increased. However, the societal optimum level of EG&S from agriculture may not equal the amount willing to be supplied by producers. Policy intervention may be necessary to ensure a balance between society and agricultural producers with respect to EG&S production from agricultural practices. Policy decisions might focus on encouraging adoption of BMPs, through extension or incentive policies, to reach the optimum supply of EG&S.

The objective of this study was to quantify and evaluate the economic impact of BMPs for representative Alberta crop farms. To accomplish this, an analysis of the economic costs and benefits associated with BMP adoption on representative Alberta crop farms was undertaken. In particular, this study was performed to determine the direct costs and benefits for Alberta crop farms when BMPs are adopted. The BMPs of interest included adoption of shelterbelts, buffer strips around wetlands, crop residue management, and the introduction of alfalfa hay, field peas, legume green manures as a replacement for summerfallow, and oats in crop rotations. Cost and benefit estimates of adoption of these BMPs were obtained by modelling four farms that are representative of commercial cropping agriculture in Alberta. Farms varied by size and location, but were developed to represent areas where cropping agriculture is significant.

Municipal level crop yields and crop price data from AARD, AFSC, and CWB were used in a Monte Carlo simulation analysis. For baseline and BMP scenarios NPVs with perpetuity were calculated. The impact of risk in agriculture was incorporated in the models using stochastic variables for crop prices and yields. Further to this, stochastic BMP parameters were incorporated to model the effect of shelterbelt, residue management, alfalfa hay, field peas, and legume green manure adoption. Economic and cropping relationships were modelled for the representative farms and the outcome of BMP adoption was assessed through comparisons to the baseline scenarios. All BMP scenarios were compared to the baseline where BMPs were not adopted to determine the potential costs or benefits of BMP adoption for the representative farms. This chapter presents the main findings of the analysis and the implications for producer and policy decisions, model limitations, and further research that could be extrapolated from this study.

6.2 Economic Feasibility of Beneficial Management Practices Adoption

Four farms were modelled to simulate representative regions and cropping operations in Alberta. Farms were located to provide coverage of the major crop producing regions in Alberta; specifically, farms were located in the Brown, Dark Brown, Black, and Dark Grey soil zones. Dryland production was considered in all soil zones. Farms were further defined by crop rotation. Baseline results were obtained for each farm and the base rotation and further BMP results were compared to the baseline scenarios.

There were four main crop rotation BMPs considered for the five representative farms. Crops considered BMPs for this study include alfalfa hay, field peas, legume green manure, and oats. Adding alfalfa hay to the crop rotation may be considered as a BMP because it is a leguminous perennial crop that has potential to increase nitrogen stores in the soil. This may lead to potential yield increases following alfalfa hay from increased nitrogen and a break in annual crop disease cycles. Reduced costs from fewer nitrogen fertilizer inputs following the alfalfa hay stand may also occur. Alfalfa hay was adopted on farms located in the Dark Brown, Black, and Dark Grey soil zones. The adoption of this rotational BMP proved economically beneficial in all cases. Mean annual benefits were approximately $64, $48, and $32 per hectare for farms in the Dark Brown, Black, and Dark Grey soil zones, respectively. Benefits from this BMP were attributable to stochastic yield benefits for crops following alfalfa stands, for up to three years. Other benefits contributing to the positive effect of including alfalfa hay in rotation were reduced nitrogen fertilizer costs for crops following alfalfa hay.

Including field peas in the crop rotations may be considered a BMP as this is also a leguminous crop where there is potential for nitrogen and yield benefits for crops following field peas. Fewer inputs are required following field peas and field peas in rotation have potential to break disease cycles in other annual crops. Field peas were adopted as a rotational BMP on all representative farms. The adoption of this BMP also proved relatively beneficial and feasible for producers with mean annual benefits being approximately $42, $28, -$2, and $5 per hectare for farms in the Brown, Dark Brown, Black, and Dark Grey soil zones, respectively. Similar to alfalfa hay the benefit of including field peas in crop rotations was due to potential yield benefits and nitrogen fertilizer savings for the crop following field pea in rotation. Larger benefits from adoption of field peas were observed for representative farms in the southern areas (i.e., Brown and Dark Brown soil zone farms) of the province. This was due to partial replacement of land that was previously under summerfallow practice with field pea. Conversely, the benefits were relatively smaller for farms in the northern soil zones (and negative for the Black soil zone farm) as the adoption of field pea in rotation removes some of the land that was previously used for higher valued crops such as canola.

Incorporating legume green manures into crop rotations may also be considered a BMP as there are similar benefits to alfalfa hay and field peas from this being a leguminous crop. Also, in this study legume green manures were a partial replacement for summerfallow practices. Summerfallow has potential to increase the rate of soil erosion. Reducing this practice by replacing it with an annual crop that is ploughed down, increases soil aggregates and may improve soil quality in the long term. Legume green manures were adopted as a partial or complete replacement for summerfallow on the Brown and Dark Brown soil zone representative farms. Adoption of this BMP resulted in a net cost of approximately $5 and $10 per hectare, respectively, for the Brown and Dark Brown soil zone farms. Similar to the alfalfa hay and field pea BMPs, associated with this BMP were nitrogen fertilizer savings for the crop following legume green manures in rotation. However, these savings were outweighed by the fact that growing the green manure crop was more costly (i.e., more input costs) as compared to summerfallow, with no marketable crop being produced. Also there was a potential negative yield effect for the crop following legume green manures in rotation as this crop may compete with future crops for reserved soil moisture, as compared to summerfallow practices.

Oats were adopted as a BMP on farms located in the northern soil zones, Black and Dark Grey. The adoption of oats in rotation was considered a BMP due to reduced inputs during the production year. Adoption of oats in the crop rotations resulted in mean annual net costs of approximately $29 and $6 per hectare, respectively, for the Black and Dark Grey soil zone representative farms. This result occurs because adoption of oats in rotation removed some of the land that was previously cropped as higher valued crops such as canola. The difference in results between the two representative farms was due to a combination of lower input costs for oats in the Dark Grey soil zone as compared to the Black soil zone and higher modelled oat yields for the Dark Grey soil zone.[37]

Three non-rotational BMPs, adopted by all representative farms, were also modelled in this study. These included shelterbelts, buffer strips around wetlands, and residue management. Buffer strips were examined in two different ways; with the land taken out of annual crop production being left idle or being used for hay production.

Shelterbelt adoption was considered a BMP for this study as there is potential for reduced soil erosion in areas sheltered by the tree species. Reduced soil erosion may improve soil quality and decrease water runoff that may affect water quality in the long term. Adoption of shelterbelts was costly for producers. Land that was previously cropped was "lost" to shelterbelts. That opportunity cost combined with the cost of planting and maintaining the trees until they are mature enough to survive unattended resulted in a net annual cost being associated with this BMP. There were also yield effects for crops in the areas adjacent to the shelterbelts (both positive and negative, depending on distance from the trees). However, these effects were generally outweighed by the other costs noted above. Mean annual costs were approximately $195, $181, $396, and $411 per hectare lost due to shelterbelt adoption on farms representative of the Brown, Dark Brown, Black, and Dark Grey soil zones, respectively.

Buffer strips around wetlands were considered BMPs for this study as water quality is improved by this practice. Buffer strips reduce the amount of soil particles that enter aquatic systems, which improves water quality and may affect aquatic species present in the ecosystem. Adoption of the buffer strip BMP also resulted in a net cost for all representative farms. Adoption costs consisted of the opportunity cost associated with loss of land that was previously being cropped. These costs varied by farm. The mean annual costs for the BMP were approximately $95, $113, $298, and $338 per hectare lost from buffer strip adoption for the farms representative of the Brown, Dark Brown, Black, and Dark Grey soil zones, respectively. The version of this BMP in which hay was produced on the buffer strip area resulted in lower net costs for the representative farms. This was due to the fact that in this scenario the buffer strip area was generating returns for the farm. When the option to grow and sell hay for this BMP was employed the cost of the BMP was reduced by approximately $75, $86, $76, and $61 per hectare lost from buffer strip adoption on representative farms in the Brown, Dark Brown, Black, and Dark Grey soil zones, respectively. Even with this adjustment in the BMP, however, there was still a net cost to the farms as the returns from hay production were lower than the foregone returns from annual crop production.

The adoption of residue management was also considered as a BMP for this study. Active residue management has potential to reduce water and soil erosion, particularly on dry soils. Retention of residues in dry years may improve yields as soil moisture is less likely to be evaporated and more organic matter on the surface provides nutrients for crops. However, residue management also entails the removal of residues when they are present in excess. Too much residue may lead to cool spring soils and poor

---

[37] The assumptions made in the analysis that led to the higher modelled yields for the Dark Gray soil zone farm are discussed in Chapter 4.

seedling emergence, and thus poor yields. As with the other non-rotation BMPs examined in this study, adoption of residue management also resulted in a net cost to the representative farm operations. While there were potential yield benefits assumed for subsequent crops if crop residue was retained in dry years, there were also potential yield decreases associated with this practice in wet years. As well, the residue (i.e., straw) was assumed to be marketable and so retaining it represents a foregone opportunity for additional returns. The mean annual costs associated with this BMP were approximately $11, $13, $23, and $26 per hectare on farms representative of the Brown, Dark Brown, Black, and Dark Grey soil zones, respectively.[38]

6.2.1 Comparison of Selected Results to Other Studies

This section compares BMP results from this study, specifically the adoption of alfalfa hay, field peas, annual cover crops, shelterbelts, and buffer strips, to results from other sources. However, it should be noted that it is difficult to directly compare the economic impacts of BMPs across studies because most studies do not use the same type of analysis or there are differences in the quantification of net benefits from BMPs.

A study of production returns from alfalfa hay under irrigated production was conducted by the University of California Extension (2007) using a hypothetical farm representative of the Butte Valley region of California. Production returns, net of total costs, from alfalfa hay under irrigated production were approximately $160 per hectare (University of California Extension, 2007). This estimate included operating and investment costs, some of which are not included in the current study, where the annual benefit of including alfalfa hay in rotation, as compared to the base rotation ranged from approximately $32 to $64 per hectare. Specifically, the difference was $32 per hectare under irrigated production. While the base and BMP rotations in the current study differ from the California study and cannot be directly compared due to different proportions of crops grown, the results are consistent in terms of finding positive net benefits associated with adopting alfalfa production.

Harapiak (2007) estimated that the fertilizer benefit of growing field peas would increase economic returns by approximately $84 per hectare, and that field peas provided residual benefit to crops in the range of $74 to $124 per hectare. An approximate estimate from the economic benefit from including field peas in rotation is $183 per hectare (Harapiak, 2007). As previously mentioned, it is difficult to determine the exact benefit of a crop in rotation in the current study since the rotations are altered when the BMP crop is adopted. However, on the representative farm in the Brown soil zone (dryland) field peas directly replaced one year of summerfallow in rotation. The average direct expense for field peas was approximately $257 per hectare. However, there are revenue benefits from replacing summerfallow with field peas. Revenue from field pea was estimated to be approximately $406 per hectare (based on 1900 kg/ha yield, multiplied by $0.21/kg). The approximate, revenue net of direct expenses, benefit of including field peas was $149 per hectare, which would be lower, but still comparable to the estimated benefit by Harapiak (2007).

The University of California Extension (2003) also conducted a study of the production returns from growing an annual cover crop. In this study it was assumed that there is no loss in revenue and the type of cover crop was an oat cereal crop, as compared to the legume crop used in the current study. It was found that cover crops resulted in a short term benefit of approximately $69 per hectare per year, but had a total cost of

---

[38] For reasons provided in Chapter 4, the results for this BMP were compared to a revised baseline scenario.

approximately $363 per hectare per year (University of California Extension, 2003). The net change in income was estimated to be approximately -$294 per hectare. In the current study the representative farm in the Brown soil zone directly replaces one year of summerfallow with a legume cover crop. The total direct expenses were found to be approximately $108 per hectare. This is likely not significantly different from the expenses associated with summerfallow, but there were also yield effects (i.e., negative subsequent yields in dry years) from including a cover crop in rotation. In the California study it was assumed that the land was simply not used (i.e., no summerfallow expenses) prior to growing a cover crop, and the cover crop was irrigated (University of California Extension, 2003). Both studies concluded that there are net costs associated with cover crops. The results would be more comparable without the additional costs of irrigation in the California study and with the potential yield decrease effect in terms of economic cost in the current study.

Kort (1988) conducted a review of literature on the economic value of shelterbelts. From multiple sources it was generally found that shelterbelts resulted in increased net economic returns. Several studies examined by Kort (1988) found that shelterbelts paid for themselves in improved yields after 15 to 40 years. A study of Canadian shelterbelts by Nicholaichuk (1980) estimated a net economic return of $3.40 per hectare per year. However, McMartin et al. (1974) conducted a study in North Dakota where yields were collected in fields with existing shelterbelts and found net economic returns to be -$6 per hectare per year. Economic returns from shelterbelts vary geographically and with the reliability of yield estimates from shelterbelt studies. The current study bases yield effects from shelterbelt studies in Alberta. The results are that shelterbelt adoption is costly for producers and ranges from $180 to $411 per hectare per year of crop land converted. The assumptions made for the current study were reasonable in terms of the literature used, and were even thought to be conservative in the estimates. Many past studies concluded that shelterbelts are economically beneficial, however the type of analysis done to confirm these findings differ from that of the current study.

Koeckhoven (2008) used both simulation and NPV analysis to determine the effect of conversion of crop land to permanent forage in riparian areas. This particular BMP is comparable to the buffer strip BMP in the current study. Koeckhoven (2008) estimated the annualized reduction in NPV to be approximately $444 per hectare of crop land converted. This estimate considers NPV with perpetuity and complete protection of the land. The current study estimated the annualized reduction in NPV to range from approximately $95 to $339 per hectare of crop land converted to permanent forage in buffer zones. It should be noted that of the total land converted in Koeckhoven (2008), 155 hectares, approximately 85 hectares is converted to permanent cover and 70 hectares is returned to riparian habitat. In addition, Koeckhoven (2008) includes fencing costs to exclude cattle from the areas. While direct comparisons between the two studies cannot be made, in general, it was concluded from both studies that it is costly for producers to convert crop land to permanent forage.

6.3 Implications for Crop Production and Policy in Alberta

The overall conclusion of this study was that cropping-related BMPs have limited potential for providing direct net benefits to crop producers in Alberta. BMPs that involved removal of land from production (e.g., shelterbelts, buffer strips) were costly for producers. As well, BMPs that changed crop rotations in ways that do not involve adding marketable crops (e.g., green manure) or that did not provide yield benefits or significant cost savings for subsequent crops (e.g., oats), also represented a net cost to producers. The opportunities for direct net benefits arose from adoption of BMPs that involved incorporating marketable crops into rotations that also provided potential nitrogen and/or yield benefits to subsequent crops.

Economic theory suggests that producers, as risk-neutral and price taking firms, minimize costs or maximize profits (Love, 1999). The results and conclusions from this study suggest, then, that the potential for uptake of relevant BMPs by Albertan crop producers is limited. While some or many producers may also incorporate environmental quality considerations in decision making, it is entirely possible that policy intervention will be necessary to encourage Albertan crop producers to adopt BMPs so that a socially optimal level of EG&S production from agriculture is achieved.

As discussed in Chapter 1, the Pannell (2008) environmental policy decision making framework (see Figure 1.1) may be used to assist in guiding decisions regarding policy instruments. What are required to utilize this framework are estimates of public and private net benefits associated with specific land use or production practice changes. The analysis in this study has generated estimates of private (i.e., direct producer) net benefits associated with a specific set of cropping BMPs. If it is assumed that the net public benefits associated with these BMPs (i.e., the societal value of increased EG&S production) are positive, Pannell's policy framework may be used to identify appropriate potential policy instruments.

For those BMPs modelled in this study that resulted in positive net private benefits for the representative cropping operations (i.e., alfalfa and field pea rotational BMPs), Pannell's framework would suggest that extension is the appropriate policy instrument. In other words, information and education should be sufficient to encourage adoption of these production practices.

For the other BMPs examined in this study, the net private benefits are negative; that is, adoption of these BMPs results in a net cost to producers. Based on these results, to improve adoption of shelterbelt and buffer strip BMPs it is likely that positive incentives or technological innovation would be appropriate policy mechanisms. Positive incentives may include direct subsidies or payments to encourage adoption. Conversely, technological innovation as a policy response would depend on the nature of the BMP. Technological innovations could include improved yields for hay or oats, for example, which would help offset the opportunity costs of taking land out of production from other crops. According to Pannell's policy framework, the appropriate choice of policy in this case depends on the relative magnitude of the net public benefits versus the net private costs (i.e., magnitude of the negative benefits). Further research would be required to establish estimates of the value of these public benefits.

Increasing adoption of BMPs results in the provision of EG&S, such as improvements in soil, water, and air quality, that is closer to the societal optimum. For environmental conservation to occur, changes in land practices at the private land owner level are necessary. However, supplying EG&S through BMP adoption is not valued by markets, and as such there is no private incentive for producers/land owners to provide these services. It is also known that there are costs associated with adoption of BMPs to supply EG&S, such as time and/or money. This study aimed to quantify the benefits and costs of BMP adoption. These estimates represent one piece of information that can be used to determine appropriate policy mechanisms to encourage adoption of BMPs.

6.4 Limitations and Assumptions of the Models

It should be noted that the results of this study are specific to the regions of interest, namely four soil zones in Alberta. The models are comprehensive for these regions, but results may not be applicable in other situations. There are limitations associated with the restrictions of defining a finite set of representative farms, when it is generally accepted that cropping agriculture in Alberta is, in reality, heterogeneous. Assumptions were made to specify each farm to the region, including common crops grown and yield of the crops. Results are representative of commercial cropping operations in Alberta, per major cropping soil zone. It should also be noted that assumptions were made to broaden the applicability of the farms to soil zones, rather than smaller, specific agricultural regions in Alberta. In developing representative farm models many assumptions were made, including the percent of wetland in each region, farm size, and crop rotations.

Assumptions made in defining a set of representative farms for this study result in relationships between the magnitude of the net benefit from BMP adoption and assumed farm characteristics. The results of the net benefit of BMP adoption may vary significantly across crop farms in Alberta, but this is not modelled with the use of representative farms with predetermined characteristics. Specifically, it was assumed that each farm had a set percentage of wetland that was realistic for the region of interest with set shape and distribution of wetlands across the farms for simplicity in modelling. In reality, farm profitability would vary if the size or shape of wetlands varied. In addition to this, societal benefit from wetland BMP adoption would vary based on the size of wetland. Assumptions regarding crop rotations for the regions of interest were also made. Crops in rotation were determined using Statistics Canada data, but assumptions to narrow the number of crops grown were made. Certain crops, such as flax and malt barley, were not present in any of the rotations, even though they may be considered on commercial operations in the representative soil zones in reality. Also, once the base or BMP crop rotations were assumed these rotations remained the same throughout the entire simulation. This assumption, of no reversibility in decisions was true for all BMPs considered. Once adoption occurred, the BMP was modelled for the entirety of the simulation period.

While using yield distributions somewhat accounts for risks in agriculture, including crop disease, the probability of crop disease as associated with the assumed crop rotation, was not explored. For example, in the Black and Dark Grey soil zones canola occurs relatively frequently in rotation. In reality producers may break from this rotation if clubroot, a common disease from frequent canola in rotation, occurs. In addition, there are crop diseases associated with pulse crops that were not explored in this study. Yield effects from retaining versus removing or reducing the amount of land under summerfallow practice on representative farms in the Brown and Dark Brown soil zones were also not explored. Considering the popularity of this practice in some areas of Alberta there are likely more involved subsequent yield effects and decisions regarding this practice. It is possible that the decision to allocate land to summerfallow practice is more complicated and may depend on time available for seeding in the spring. In general, yield effects from diseases and cropping practices are highly probable and this study assumes that the effect is modelled in part by the yield distribution. In reality additional disease or cropping practice distributions would better account for these effects.

Many assumptions were made regarding residue management as a BMP. Initially it was assumed that residue was removed at static annual intervals, but no yield impacts were considered in the results. Another baseline scenario was developed where residue was removed each year at custom rates, and sold. Yield decreases were a possibility in dry years for this scenario. In the BMP scenario residue was removed at the same frequency as the initial baseline scenario, but yield increases and decreases were a possibility, as well as the added costs and benefits of baling and sale of the residue. There were challenges in accurately modelling this BMP, and as such assumptions were made in an attempt to quantify the benefits and costs of adoption and compare these to two baseline scenarios.

6.5 Further Research

This study included four major soil zones that are representative of cropping agriculture in Alberta. It would be interesting to expand this study to look at an extended set of representative farms in Alberta where alternative baseline crop rotations and farms of different sizes are examined. These types of expansions to the current study may provide insight to the impact of different farm size on the potential for economies of scale in BMP adoption. Comparisons of different base rotations would also provide further insight on the net benefit of BMP adoption.

This research used dynamic simulation methods and cash flow analysis to determine the net effect of BMP adoption. Future studies could improve upon the predictability of producer decisions by including an optimization portion to the analysis. As previously stated, producers act in a rational manner, where costs are minimized or profits are maximized. Optimization of variables could improve upon some of the assumptions that were made in the models by ensuring some decision variables are optimized for crop production. For example, in this study it was assumed that both baseline and BMP crop rotations are fixed over time. That is, once a crop rotation is decided upon it continues for the entire simulation. Further studies could expand on this assumption by using a long term rotation that is similar to the application in the current study, but allow annual deviations based on market signals that may include yield predictions that are drawn from climate and weather, or price predictions. Another potentially interesting application for BMP adoption decisions, including crop rotations would be to incorporate endogenous producer decisions. Similar decisions were used in the study by Cortus (2005) for drainage decisions, where producer decisions were based on factors within the model. Similar to deviations from crop rotation decisions, BMP adoption decisions may occur due to policy mechanisms or market signals. Endogenous decisions may be particularly interesting for the residue management BMP as a decision rule could be built to determine when residue is removed or retained, based on yield or market signals within the models.

The focus of this study was to quantify the private benefits and costs of BMP adoption, that is, the benefits and costs incurred by producers. In making policy decisions it would be useful to determine the quantitative public or societal net benefits from agricultural BMP adoption. BMPs to improve the provisioning of EG&S have potential external benefits for other agricultural producers, recreational users, wildlife species in the surrounding areas, and nearby municipalities. Estimates of net benefits for these users, especially as it applies to soil and water quality would be a useful extension of this project to determine optimal policy programs (i.e., incentive, extension, or technology based) for increasing BMP adoption. Further research of the willingness to pay or willingness to accept for producers and society for the provisioning of EG&S through BMPs and the evaluation of non-market goods would also aid in the development of efficient policy design.

References

Adderley, D.R., J.J. Schoenau, R.A. Holm, and P. Qian. 2006. Nutrient Availability and Yield of Wheat Following Field Peas and Lentil in Saskatchewan, Canada. *Journal of Plant Nutrition* 29: 25-34.

Agriculture and Agri-Food Canada (AAFC). 2000. Agricultural Best Management Practices: Agriculture and Water Quality. Government of Canada, Ottawa, Ontario, Canada.

Agriculture and Agri-Food Canada (AAFC). 2001. Agriculture in Harmony with Nature, Strategic Direction 2: Promoting Environmental and Resource Stewardship. Minister of Public Works and Government Services, Government of Canada, Ottawa, Ontario, Canada.

Agriculture and Agri-Food Canada (AAFC). 2005. Quantitative Analysis of the Impact of Agricultural Strategies on Environmental Indicators. Research and Analysis Directorate, Strategic Policy Branch, Agriculture and Agri-Food Canada.

Agriculture and Agri-Food Canada (AAFC). 2006. National Farm Stewardship Program: 2007/08 National BMP List. Presented at 2006 Crop Nutrients Council Symposium, Ottawa.

Agriculture and Agri-Food Canada (AAFC). 2007-a. Farm Environmental Management Survey (FEMS). Statistics Canada. http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5044&lang=en&db=imdb&adm=8&dis=2 (Last Accessed 21 April 2010).

Agriculture and Agri-Food Canada (AAFC). 2007-b. Planning Field Shelterbelts. http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1192556664605&lang=eng (Last Accessed 30 June 2010).

Agriculture and Agri-Food Canada (AAFC). 2007-c. Growing Forward Agricultural Policy Framework. http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1200339470715&lang=eng (Last Accessed 17 May 2011).

Agriculture and Agri-Food Canada (AAFC). 2007-d. National Farm Stewardship Program Overview. http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1181580519716&lang=eng (Last Accessed 24 May 2011).

Agriculture and Agri-Food Canada (AAFC). 2009. Background to Crop Insurance and Review of Environmental Assessments. http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1179245881894 (Last Accessed 22 June 2011).

Agriculture and Agri-Food Canada (AAFC). 2010-a. Agri-Environment Services Branch. http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1187362338955&lang=eng (Last Accessed 10 January 2011).

Agriculture and Agri-Food Canada (AAFC). 2010-b. National Environmental Farm Planning Initiative. http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1181579114202&lang=eng (Last Accessed 24 May 2011).

Agriculture and Agri-Food Canada (AAFC). 2011. AgriInvest Program Handbook. http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1298469566413&lang=eng (Last Accessed 13 June 2011).

Agriculture Financial Services Corporation (AFSC). 2009. Municipal crop yields. Obtained from personal communication with Rob Cruickshank, November 2009.

Agriculture Financial Services Corporation (AFSC). 2010-a. 2010 Spring Insurance Prices (Crops Eligible for VPB & SPE). Canada-Alberta Production Insurance. http://www.afsc.ca/doc.aspx?id=3454 (Last Accessed 21 December 2010).

Agriculture Financial Services Corporation (AFSC). 2010-b. Canada-Alberta Agri-Insurance Products for 2010 Annual Crops. http://www.afsc.ca/Default.aspx?cid=10&lang=1 (Last Accessed 13 June 2011).

Agriculture Financial Services Corporation (AFSC). 2010-c. Protection for Perennial Crops. http://www.afsc.ca/Default.aspx?cid=984&lang=1 (Last Accessed 13 June 2011).

Agriculture Financial Services Corporation (AFSC). 2011-a. AgriStability Program Handbook. http://www.afsc.ca/Default.aspx?cid=745&lang=1 (Last Accessed 13 June 2011).

Agriculture Financial Services Corporation (AFSC). 2011-b. Crop Insurance Calculators. http://www.afsc.ca/Default.aspx?cid=1-1211&pre=view (Last Accessed 22 June 2011).

Alberta Agriculture and Rural Development (AARD). 1999-a. A Profile of Alberta Farm Operators and Their Farms 1996 (Part 1) – Population. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd1422 (Last Accessed 13 August 2009).

Alberta Agriculture and Rural Development (AARD). 1999-b. Direct Seeding: Residue Management for Successful Direct Seeding. *Agdex* 570-4.

Alberta Agriculture and Rural Development (AARD). 2000. Soil Organic Matter. AGRI-FACTS. *Agdex* 536-1.

Alberta Agriculture and Rural Development (AARD). 2004-a. Beneficial Management Practices: Environmental Manual for Crop Producers in Alberta. Alberta Agriculture and Rural Development, Edmonton, Alberta, Canada.

Alberta Agriculture and Rural Development (AARD). 2004-b. Effect of Field Shelterbelts on Crop Yields in Alberta. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag3328 (Last Accessed 05 January 2010).

Alberta Agriculture and Rural Development (AARD). 2005-a. Agricultural Land Resource Atlas of Alberta – Soil Groups of Alberta. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10307 (Last Accessed 07 January 2010).

Alberta Agriculture and Rural Development (AARD). 2005-b. Municipal Districts and Counties of Alberta.

http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10301 (Last Accessed 07 January 2010).

Alberta Agriculture and Rural Development (AARD). 2007-a. Field Shelterbelts for Soil Conservation. *Agdex* 277/20-3.

Alberta Agriculture and Rural Development (AARD). 2007-b. Final Yield Matrices. Obtained through personal communication with Dale Kaliel, Senior Production Economist, Edmonton, Alberta, March 2010.

Alberta Agriculture and Rural Development (AARD). 2008-a. Alberta 2008 Farm Cash Receipts. Alberta Agriculture Statistics Yearbook, Government of Alberta, Edmonton, Alberta, Canada.

Alberta Agriculture and Rural Development (AARD). 2008-b. Direct Seeding: Crop Rotations in Direct Seeding. *Agdex* 519-28.

Alberta Agriculture and Rural Development (AARD). 2008-c. Direct Seeding: Estimating the Value of Crop Residues. *Agdex* 519-25.

Alberta Agriculture and Rural Development (AARD). 2008-d. Machinery Cost Calculator. http://www1.agric.gov.ab.ca/$department/newslett.nsf/all/agnw18086 (Last Accessed 01 September 2009)

Alberta Agriculture and Rural Development (AARD). 2008-e. Pea-Wheat Rotation in Southern Alberta. *Agdex* 100/515-1.

Alberta Agriculture and Rural Development (AARD). 2009-a. Agri-food Statistics Update. Issue No. FC09-3.

Alberta Agriculture and Rural Development (AARD) 2009-b. Agroclimatic Atlas of Alberta: Soils and Ecoregions in Alberta. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6303 (Last Accessed 20 May 2011).

Alberta Agriculture and Rural Development (AARD) 2009-c. Alberta 2009 Specialty Crop Report. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd12862 (Last Accessed 08 July 2011).

Alberta Agriculture and Rural Development (AARD). 2010-a. Agricultural Operation Practices Act. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/acts5986 (Last Accessed 18 May 2011).

Alberta Agriculture and Rural Development (AARD). 2010-b. AgriProfit$ Cropping Alternatives. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ10238 (Last Accessed 05 July 2010).

Alberta Agriculture and Rural Development (AARD). 2010-c. Hay, Straw and Pasture Listings: Straw for sale listings. http://www.agric.gov.ab.ca/app68/hay?cat=For%20Sale&cat1=Straw (Last Accessed 10 October 2010).

Alberta Agriculture and Rural Development (AARD). 2010-d. Stewardship Plans. http://www.growingforward.alberta.ca/ProgramAreas/EnhancedEnvironment/StewardshipPlans/IntegratedCropManagement/ (Last Accessed 17 May 2011).

Alberta Agriculture and Rural Development (AARD). 2010-e. Water Management. http://www.growingforward.alberta.ca/ProgramAreas/EnhancedEnvironment/WaterManagement/WaterManagementDetail/index.htm (Last Accessed 17 May 2011).

Alberta Agriculture and Rural Development (AARD) 2011-a. 2010 Environmentally Sustainable Agriculture Tracking Survey Report. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/aesa6467 (Last Accessed 22 November 2011).

Alberta Agriculture and Rural Development (AARD). 2011-b. Custom Rates 2011 – Land Leasing. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/inf13393 (Last Accessed 29 October 2011).

Alberta Environmental Farm Plan (AEFP). 2011. Alberta Environmental Farm Plan Program. http://www.albertaefp.com/program/progWhy.html (Last Accessed 21 April 2011).

April, J., F. Glover, J.P. Kelly, and M. Laguna. 2003. Practical Introduction to Simulation Optimization. Proceedings of the 2003 Winter Simulation Conference.

Bechini, L. and C.O. Stöckle. Integration of a Cropping Systems Simulation Model and a Relational Database for Simple Farm-Scale Analyses. *Agronomy Journal* 99: 1226-1237.

Belcher, K., M.M. Boehm, and R.P. Zentner. 2003. The economic value of soil quality under alternative management in the Canadian Prairies. *Canadian Journal of Agricultural Economics*, 51: 175–196.

Bergstrom, K. 2009. Personal Communication with Karla Bergstrom, Production Crops Economist, Alberta Agriculture and Rural Development. Ongoing from July 2009.

Bergstom, K. 2010. AgriProfit$ 2010 Cropping Alternatives Methodology. Alberta Agriculture and Rural Development, Economics Branch. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ10238 (Last Accessed 21 July 2010).

Blanco, H., and R. Lal. 2008. Principles of Soil Conservation and Management. Chapter 9: Buffer strips. Springer, Heidelberg, Germany, p. 620.

Boxall, P., M. Weber, O. Perger, M. Cutlac, and A. Samarawickrema. 2008. Preliminary Results from the Farm Behaviour Component of the Integrated Economic-Hydrologic Model for the Watershed Evaluation of Beneficial Management Practices Program. *Draft Progress Report*.

Brethour, C., B. Sparling, B. Cortus, M. Klimas, T. Moore, and J. Sadler. 2007. An Economic Evaluation of Beneficial Management Practices for Crop Nutrients in Canadian Agriculture. George Morris Centre, Prepared for Crop Nutrients Council.

Carson, J.S. 2003. Introduction to Modelling and Simulation. Proceedings of the 2003 Winter Simulation Conference.

Centner, T. J., J. E. Houston, A. G. Keeler, and C. Fuchs. 1999. The adoption of best management practices to reduce agricultural water contamination. *Limnologica - Ecology and Management of Inland Waters* 29: 366-73.

Coiner, C., J.J. Wu, and S. Polasky. 2001. Economic and environmental implications of alternative landscape designs in the Walnut Creek Watershed of Iowa. *Ecological Economics* 38: 119-39.

Copeland, T. and J.F. Weston. 1988. *Financial Theory and Corporate Policy* – 3rd ed., Addison Wesley Publishing,

Cortus, B.G. 2005. The Economics of Wetland Drainage: A Case Study in Canada's Prairie Pothole Region. Unpublished Master of Science Thesis, University of Alberta.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. O'Neill, J. Paruelo, R. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260.

Crop Nutrients Council. 2004. Beneficial Management Practices. Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada.

Dale, V.H. and S. Polasky. 2007. Measures of the effects of agricultural practices on ecosystem services. *Ecological Economics* 64: 286-296.

Daily, G.C. 1997. Nature's services: societal dependence on natural ecosystems. Island Press, Washington, D.C., p. 392.

Dunn, Rob. 2009. Personal Communication with Rob Dunn, Land Management Specialist, Alberta Agriculture and Rural Development, Lethbridge, Alberta, ongoing from September 2009.

Eastern Canada Soil and Water Conservation Center (ECSWCC). 2004. Best Management Practices: Oats. http://www.ccse-swcc.nb.ca/bmp/bmp3.cfm?id=1&titre=9&fiche=9 (Last Accessed 29 April 2011).

Edwards, W. 2009. Farm Machinery Selection. *Ag Decision Maker*, Iowa State University.

Entz M. H., P.D. Ominski, R. Mohr, A. Schoofs, D. Forster, W.J. Bullied, S. Shirtliffe, and K.C. Bamford. 1995. Forages Improve Efficiency of Prairie Cropping Systems. Department of Plant Science, University of Manitoba. http://www.umanitoba.ca/afs/plant_science/extension/agrif95.html (Last Accessed 26 April 2011).

Evans, J., G.E. O'Connor, G.L. Turner, D.R. Coventry, N. Fettel, J. Mahoney, E.L. Armstrong, and D.N.Walsgott. 1989. N_2 fixation and its value to soil N increase in lupin, field pea and other legumes in south-eastern Australia. *Australian Journal of Agricultural Research* 40: 791–805.

Evans, J.R. and D.L. Olson. 2002. *Introduction to Simulation and Risk Analysis*. 2nd Ed., Prentice Hall, Upper Saddle River, New Jersey, USA.

Farber, S.C., R. Costanza, and M.A. Wilson. 2002. Economic and ecological concepts for valuing ecosystem services. *Ecological Economics* 41: 375-392.

Farm Credit Canada. 2011. Farmland Values Online. http://www.fcc-fac.ca/en/onlineservices/flv_online_service_e.asp (Last Accessed 29 October 2011).

Fu, G., S. Chen, and D.K. McCool. 2006. Modeling the impacts of no-till practice on soil erosion and sediment yield with RUSLE, SEDD, and ArcView GIS. *Soil and Tillage Research* 85: 38-49.

Gebremedhin, B. and G. Schwab. 1998. The economic importance of crop rotation systems: evidence from the literature. Staff Paper 98-13, Department of Agricultural Economics, Michigan State University.

Geyer W.A. and A.D. Lynch. 1990. Green Ash Growth Curves. *Transactions of the Kansas Academy of Science* 93 (1/2): 12-16.

Gray, R.S., J.S. Taylor, and W.J. Brown. 1996. Economic factors contributing to the adoption of reduced tillage technologies in central Saskatchewan. *Canadian Journal of Plant Science* 76: 661-668.

Government of Alberta. 2002. Soil Group Map of Alberta. http://www1.agric.gov.ab.ca/soils/soils.nsf/soilgroupmap?readform (Last Accessed 07 January 2010).

Hamel, C., A. Freire Cruz, B. McConkey, D. Layzell, D. Mavragani, F. Selles, J. Clapperton, J. Germida, K. Hanson, M. St-Arnaud, S. Horii, S. Bouzid, T. Ishii, T. Fraser, V. Vujanovic, W. Ellouze, Y. Cen, Y. Gan. 2007. Impact of Pulse Crops on Soil Biological Quality. Report Prepared for Alberta Pulse Growers in cooperation with Agriculture and Agri-Food Canada, University of Saskatchewan, Université de Tunis El-Manar, Université de Montréal, Queens University, and Graduate School of Kyoto Prefectural University.

Harapiak, J. 2007. Giving field peas an extended crop production credit. *Top Crop Manager*. http://www.topcropmanager.com/content/view/915/132/ (Last Accessed 06 January 2011).

Hilliard, C., N. Scott, L. Armando, and S. Reedyk. 2002. Agricultural Best Management Practices for the Canadian Prairies: a review of literature. Canada-Saskatchewan Agri-Food Innovation Fund.

Holford, I.C.R. 1980. Effects of duration of grazed lucerne on long-term yields and nitrogen uptake of subsequent wheat. *Australian Journal of Agricultural Research* 31: 239-250.

Houston, J.E. and H. Sun. 1999. Cost share incentives and best management practices in a pilot water quality program. *Journal of Agricultural and Resource Economics* 24: 239-252.

Hoyt, P.B. 1990. Residual effects of alfalfa and bromegrass cropping on yields of wheat grown for 15 subsequent years. *Canadian Journal of Soil Science* 70: 109-113.

Hoyt, P.B. and A.M.F. Hennig. 1971. Effect of alfalfa and grasses on yield of subsequent wheat crops and some chemical properties of a grey wooded soil. *Canadian Journal of Soil Science* 51: 177-183.

Hoyt, P.B. and R.H. Leitch. 1983. Effects of forage legume species on soil moisture, nitrogen, and yield of succeeding barley crops. *Canadian Journal of Soil Science*: 63: 125-136.

Huanwen, G., Liansheng, C., Xisen, J., Hongqi, L., 2004. Continuous experiment of no tillage system for 12 years in north of China. Proceedings of the 2004 CIGR International Conference. China Agricultural Science and Technology Press, Beijing, 560 p.

Hull, J.C. 2003. *Options, futures & other derivatives*. *5th Ed*. Prentice Hall: Upper Saddle River, NJ.

Hutton, G. 2010. Personal Communication with Gordon Hutton, Development Officer – Feed Grains, Crop Business Development Branch, Alberta Agriculture and Rural Development. May 2010.

Indiana Woodland Steward. 2010. Tree Planting Costs. http://www.fnr.purdue.edu/inwood/tree%20planting%20costs.htm (Last Accessed 05 January 2011).

Johnston, A.M., H.R. Kutcher, and K.L. Bailey. 2005. Impact of crop sequence decisions in the Saskatchewan parkland. *Canadian Journal of Plant Science* 85: 95-102.

Just, R.E. and Q. Weninger. 1999. Are Crop Yields Normally Distributed? *American Journal of Agricultural Economics* 81 (2): 287-304.

Kansas Rural Center. 1998. Alfalfa. *Sustainable Agriculture Management Guides* MG1B.1.

Khakbazan, M., R. Mohr, K. Volkmar, D. Tomasiewicz, C. Hamilton, A. Moulin, and K. Belcher. 2009. Modeling economic and agro-environmental dynamics of potato production systems. *Journal of Bioeconomics* 11: 65-93.

Kilian, L. 2001. Impulse Response Analysis in Vector Autoregressions with Unknown Lag Order. *Journal of Forecasting* 20: 161-179.

Koeckhoven, S.W.J. 2008. Economics of Agricultural Best Management Practices in the Lower Little Bow Watershed. Unpublished Master of Science Thesis, University of Alberta.

Kock, H. 1990. Shelterbelt agriculture uses trees to protect soil and water resources. University of Guelph Arboretum. http://eap.mcgill.ca/MagRack/SF/Summer%2090%20M.htm (Last Accessed 30 June 2010).

Kok, K., A. Farrow, A. Veldkamp, and P.H. Verburg. 2001. A method and application of multi-scale validation in spatial land use models. *Agriculture, Ecosystems and Environment* 85: 223-238.

Korol, M. 2004. Fertilizer and Pesticide Management in Canada. Results of the 2001 Farm Environmental Management Survey (FEMS). Agriculture and Agri-Food Canada and Statistics Canada.

Kort, J. 1988. Benefits of windbreaks to field and forage crops. *Agriculture, Ecosystems and Environment* 22: 165-190.

Kroeger, T. and F. Casey. 2007. An assessment of market-based approaches to providing ecosystem services on agricultural lands. *Ecological Economics* 64: 321-332.

Krupinsky, J.M., S.D. Merrill, D.L. Tanaka, M.A. Liebig, M.T. Lares, and J.D. Hanson. 2007. Crop residue coverage of soil influenced by crop sequence in a no-till system. *Agronomy Journal* 99: 921-930.

Kulshreshtha, S. and J. Kort. 2009. External economic benefits and social goods from prairie shelterbelts. *Agroforestry Systems* 75: 39-47.

Lafond, G.P., H. Loeppky, and D.A. Derksen. 1992. The effects of tillage systems and crop rotations on soil water conservation, seedling establishment and crop yield. *Canadian Journal of Plant Science* 72: 103-115.

Lafond, G.P., W.E. May, E.N. Johnson, and S.A. Brandt. 2007. Frequency of Field Pea in Rotation: the Issues and Opportunities. Presented at the Saskatchewan Soil Conservation Association Annual Meeting, Jan. 2007. Saskatoon, Saskatchewan. http://www.ssca.ca/conference/conference2007/Lafond.pdf (Last Accessed 17 May 2010).

Lafond, G.P., B.G. McConkey, and M. Stumborg. 2009. Conservation tillage models for small-scale farming: Linking the Canadian experience to the small farms of Inner Mongolia Autonomous Region in China. *Soil and Tillage Research* 104: 150-155.

Lankoski, J., M. Ollikainen, and P. Uusitalo. 2006. No-till technology: benefits to farmers and the environment? Theoretical analysis and application to Finnish agriculture. *European Review of Agricultural Economics* 33: 193-221.

Leyshon, A.J., M.R. Kilcher, and J.D. McElgunn. 1981. Seeding rates and row spacings for three forage crops grown alone or in alternate grass-alfalfa rows in southwestern Saskatchewan. *Canadian Journal of Plant Science* 61: 711-717.

Love, H.A. 1999. Conflicts between Theory and Practice in Production Economics. *American Journal of Agricultural Economics* 81 (3): 696-702.

Macal, C.M. 2005. Model Verification and Validation. Workshop on: Threat Anticipation: Social Science Methods and Models. April 7-9, Chicago, Illinois.

Malhi, S.S., R. Lemke, Z.H. Wang, B.S. Chhabra. 2006. Tillage, nitrogen and crop residue effects on crop yield, nitrogen uptake, soil quality and greenhouse gas emissions. *Soil and Tillage Research* 90: 171-183.

Manitoba Agriculture, Food, and Rural Initiatives (MAFRI), 2010. The Benefits of Including Forages in Your Crop Rotation. http://www.gov.mb.ca/agriculture/crops/forages/bjb00s43.html (Last Accessed 04 April 2011).

Marra, M.C. and J.W. Schurle. 1994. Kansas Wheat Yield Risk Measures and Aggregation: A Meta-Analysis Approach. *Journal of Agricultural and Resource Economics* 19: 60-77.

Matekole, A., and J. Westra. 2009. Economic Analysis of Tillage and Nutrient Best Management Practices in the Ouachita River Basin, Louisiana. Agriculture and Applied Economics Association 2009 Annual Meeting.

Matekole, A., J. Westra, and T. Appelboom. 2009. Best Managment Practices: How Economical is it in Southern Agricultural Systems? Southern Agricultural Economics Association Annual Meeting.

McMartin, W., A.B. Frank, and R.H. Heintz. 1974. Economics of shelterbelt influence on wheat yields in North Dakota. *Journal of Soil and Water Conservation* 29: 87-91.

McRae, T., C.A.S. Smith, and L.J. Gregorich (Editors). 2000. Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project. Research Branch, Policy Branch, Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada.

Michigan State University Extension (MSUE). 2009. Estimating Annual Irrigation Operation Costs: 160 Acre Centre Pivot Example. www.msue.msu.edu/.../IRRCOST.160%20pivot%209-07.doc/ (Last Accessed 28 October 2009).

Moss, C.B. and J.S. Shonkwiler. 1993. Estimating Yield Distributions with a Stochastic Trend and Nonnormal Errors. *American Journal of Agricultural Economics* 75 (4): 1056-1062.

Munoz-Carpena, R., A. Ritter, D.D. Bosch, B. Schaffer, and T.L. Potter. 2008. Summer cover crop impacts on soil percolation and nitrogen leaching from a winter corn field. *Agricultural Water Management* 95: 633-644.

Nendel, C. 2009. Evaluation of best management practices for N fertilisation in regional field vegetable production with a small scale simulation model. *European Journal of Agronomy* 30: 110-118.

Nicholaichuk, W. 1980. Snow management to provide additional water for agriculture. Proceedings Prairie Production Symposium, 29-31, October 1980, Saskatoon, Saskatchewan, p. 1-9.

Palisade Corporation. 2007. *Guide to Using @RISK, Version 5.0*. Ithaca, New York: Palisade Corporation.

Pannell, D.J. 2008. Public Benefits, Private Benefits, and Policy Mechanism Choice for Land-Use Change for Environmental Benefits. *Land Economics* 84 (2): 225-240.

Papworth, L. 2010. Personal Communication with Lawrence Papworth, Lead, Energy and Climate Change Section, Alberta Agriculture and Rural Development, Lethbridge, Alberta, February 2010.

Powell, G. 2000. Selection and Matching of Tractors and Implements. Department of Employment, Economic Development and Innovation, Queensland Government, Australia. http://www2.dpi.qld.gov.au/fieldcrops/3492.html (Last Accessed 02 July 2010).

Power, J.F., W.W. Wilhelm, and J.W. Doran. 1986. Crop residue effects on soil environment and dryland maize and soya bean production. *Soil and Tillage Research* 8: 101-111.

Putnam, D., M. Russelle, S. Orloff, J. Kuhn, L. Fitzhugh, L. Godfrey, A. Kiess, and R. Long. 2001. Alfalfa, Wildlife and the Environment: The Importance and Benefits of Alfalfa in the 21st Century. California Alfalfa and Forage Association.

Rae, G. 2007. Market-Based Instruments for Ecological Goods and Services: Learning from the Australian Experience. Canada West Foundation.

Ross, S.A., R.W. Westerfield, J.F. Jaffe and G.S. Roberts. 2003. *Corporate Finance* - 3rd Canadian ed., McGraw-Hill Ryerson: Toronto, Ontario.

Ross, S.M., J.R. King, R.C. Izaurralde, and J.T. O'Donovan. 2009. The green manure value of seven clover species grown as annual crops on low and high fertility temperate soils. *Canadian Journal of Plant Science* 89: 465-476.

Rotz, C.A., H.A. Muhtar, and J.R. Black. 1983. A Multiple Crop Machinery Selection Algorithm. *Transactions of the ASAE* 26 (2): 1644-1649.

Ruhl, J.B. 2008. Farm and Ecosystem Services. *Choices* 23: 32-36.

Saskatchewan Agriculture and Food (SAF). 2008. Farm Machinery Custom and Rental Rate Guide 2008-09. Saskatchewan Ministry of Agriculture, Regina, Saskatchewan, Canada.

Saskatchewan Pulse Growers. 2000. Pulse Production Manual, 2nd Edition. Saskatchewan Pulse Growers, Saskatoon, Saskatchewan, Canada.

Schaufele, B, J.R. Unterschultz, and T. Nilsson. 2010. AgriStability with Catastrophic Price Risk for Cow-Calf Producers. *Canadian Journal of Agricultural Economics* 58: 361-380.

SHAZAM User Manual. 2008. Shazam Guide. http://shazam.econ.ubc.ca/intro/ (Last Accessed 01 October 2009).

Sidhu, B.S. and V. Beri. 1988. Effect of Crop Residue Management on the Yields of Different Crops and on Soil Properties. *Biological Wastes* 27: 15-27.

Singh, B. and S.S. Malhi. 2006. Response of soil physical properties to tillage and residue management on two soils in a cool temperate environment. *Soil and Tillage Research* 85: 143-153.

Singh, B., D.S. Chanasyk, W.B. McGill, and M.P.K. Nyborg. 1994. Residue and tillage management effects on soil properties of a typic cryoboroll under continuous barley. *Soil and Tillage Research* 32: 117-133.

Soon, Y.K., K.N. Harker, and G.W. Clayton. 2004. Plant Competition Effects on the Nitrogen Economy of Field Pea and the Subsequent Crop. *Soil Science Society of America Journal* 68: 552-557.

South Saskatchewan Regions – Wetlands. 2009. Facts at Your Fingertips. Alberta Government.

Sparling, B. and C. Brethour. 2007. An Economic Evaluation of Beneficial Management Practices for Crop Nutrients in Canadian Agriculture. Canadian Agricultural Economics Society Selected Paper.

Statistics Canada. 2006. 2006 Census of Agriculture. Statistics Canada, Ottawa, Ontario.

Statistics Canada. 2001. 2001 Census of Agriculture. Statistics Canada, Ottawa, Ontario.

Statistics Canada. 2009. CANSIM Historical crop acreage in Alberta (yearly). Government of Canada, Ottawa, Ontario.

Stevenson F.C. and C. van Kessel. 1996. The nitrogen and non-nitrogen rotation benefits of pea to succeeding crops. *Canadian Journal of Plant Science* 76: 735-745.

Sullivan, P. 2003. Overview of cover crops and green manures. Appropriate Technology Transfer for Rural Areas (ATTRA), USDA Rural-Business Cooperative Service.

Swinton, S.M. 2008. Reimagining Farms as Managed Ecosystems. *Choices* 23: 28-31.

Swinton, S.M., F. Lupi, G.P. Robertson, S.K. Hamilton. 2007. Ecosystem services and agriculture: Cultivating agricultural ecosystems for diverse benefits. *Ecological Economics* 64: 245-252.

Tapia-Vargas, M., M. Tiscareno-Lopez, J.J. Stone, J.L. Oropeza-Mota, and M. Velazquez-Valle. 2001. Tillage system effects on runoff and sediment yield in hillslope agriculture. *Field Crops Research* 69: 173-82.

Taylor, M.L, R.M. Adams, and S.F. Miller. 1992. Farm level response to agricultural effluent control strategies: the case of the Willamette Valley. *Journal of Agricultural and Resource Economics* 17: 173-185.

Tilman, D., K.G. Cassman, P.A. Matson, R. Naylor, and S. Polasky. 2002. Agricultural sustainability and intensive production practices. *Nature* 418: 671-677.

Toma and Bouma Management Consultants. 2007. Alberta Crop Environmental Strategy. Prepared for: Alberta Barley Commission, Alberta Canola Producers Commission, and Alberta Pulse Growers.

Treasury Board of Canada Secretariat. 2007. Canadian Cost-Benefit Analysis Guide: Regulatory Proposals. Government of Canada, Ottawa, Ontario, Canada.

United States Department of Agriculture (USDA) Agricultural Research Service (ARS). 2008. Crop Sequence Calculator: A Revised Computer Program to Assist Producers. http://www.ars.usda.gov/Services/docs.htm?docid=10791. Accessed August 2009.

University of California Extension. 2003. Central Coast Conservation Practices: Estimated Costs and Potential Benefits for an Annually Planted Cover Crop. http://coststudies.ucdavis.edu/conservation_practices/ (Last Accessed 01 October 2011).

University of California Extension. 2007. Sample Costs to Establish and Produce Alfalfa Hay. http://coststudies.ucdavis.edu/files/AlfalfaSV08.pdf (Last Accessed 01 October 2011).

Unterschultz, J.R. and G. Mumey. 1996. Reducing Investment Risk in Tractors and Combines with Improved Terminal Asset Value Forecasts. *Canadian Journal of Agricultural Economics* 44:295-309.

Vanderwel, D. S. and Jedrych, A. T. 1997. A Method for Developing Best Management Practices for Riparian Areas Using WEPP. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag3376/$file/csq10.pdf?OpenElement (Last Accessed 14 May 2009).

Vlahos, K. 1997. Taking the risk out of uncertainty. In The Complete MBA Companion, edited by Tim Dickson and Geoege Bickerstaffe, 142-147. Lanham: Pitman Publishing.

Western Australia Agriculture and Food (WAAF). 2007. Oat Crop Establishment. Department of Agriculture and Food, Government of Western Australia.

Wilde, M. 2011. Sowing their oats: beneficial small grains see rebound among Iowa growers. *Ceder Valley Business.* http://wcfcourier.com/business/local/article_41689942-57af-11e0-a188-001cc4c03286.html (Last Accessed 29 April 2011).

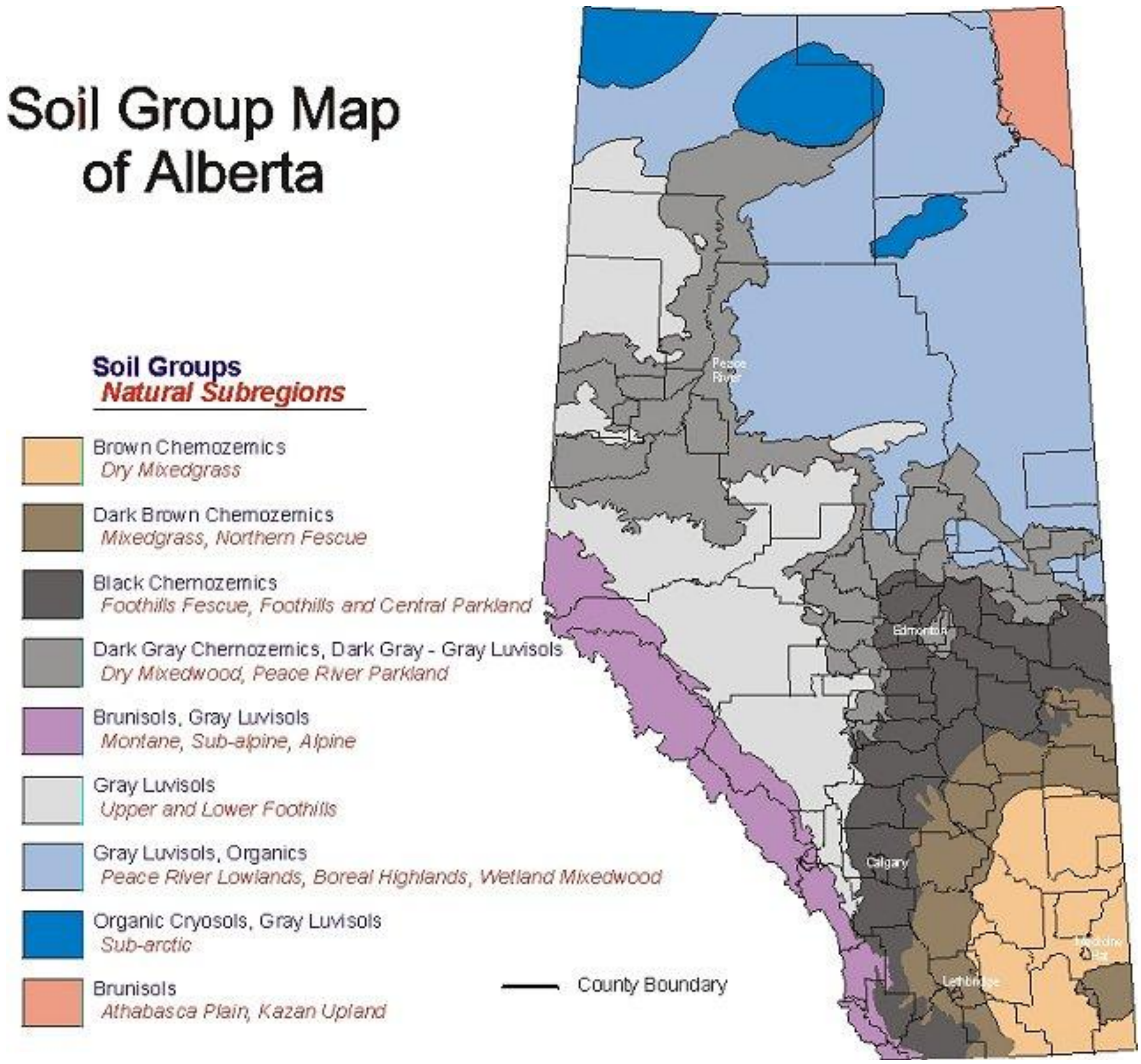
Zentner, R.P., D.D. Wall, C.N. Nagy, E.G. Smith, D.L. Young, P.R. Miller, C.A.Campbell, B.G. McConkey, S.A. Brandt, G.P. Lafond, A.M. Johnston, and D.A. Derksen. 2002. Economics of Crop Diversification and Soil Tillage Opportunities in the Canadian Prairies. *Agronomy Journal* 94: 216-230.

Zentner, R.P., G.P. Lafond, D.A. Derksen, and C.A. Campbell. 2002. Tillage method and crop diversification: effect on economic returns and riskiness of cropping systems in a Thin Black Chernozem of the Canadian Prairies. *Soil and Tillage Research* 67: 9-21.

Zentner, R.P., C.A. Campbell, V.O. Biederbeck, F. Selle, R. Lemke, P.G Jefferson, and Y. Gan. 2004. Long-term assessment of management of an annual legume green manure crop for fallow replacement in the Brown soil zone. *Canadian Journal of Plant Science* 84: 11–22.

Zhang, W., T.H. Ricketts, C. Kremen, K. Carney, S.M. Swinton. 2007. Ecosystem services and dis-services to agriculture. *Ecological Economics* 64: 253-260.

Appendix A: Alberta Soil Zones



Source: *Adapted from* AARD (2005-b) *with permission from Alberta Agriculture and Rural Development*

Appendix B: Counties/Districts Considered in Choosing Representative Farms

Brown	Dark Brown	Black	Dark Grey
Special Area 2	Special Area 4	Cardston County	Lac Ste. Anne County
Special Area 3	County of Lethbridge	M.D. of Pincher Creek	County of Barrhead
County of Newell	Vulcan County	M.D. of Foothills	Westlock County
County of Forty Mile	Wheatland County	M.D. of Rocky View	County of Thorhild
Cypress County	Starland County	Red Deer County	County of St. Paul
M.D. of Taber	County of Paintearth	Lacombe County	Athabasca County
	M.D. of Provost	Leduc County	Two Hills County
		County of Camrose	M.D. of Smoky River
		Beaver County	Birch Hills County
		Minburn County	M.D. of Spirit River
		Vermilion River County	County of Grande Prairie
		Strathcona County	M.D. of Fairview
		Sturgeon County	
		Flagstaff County	
		M.D. of Wainwright	