An Agent Based Simulation Model of the Potential Impact of Second Generation Bioenergy Commodities on the Grain – Livestock Economy of South-Eastern Saskatchewan

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ABSTRACT

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Second-generation biofuel technology is in its early stages of development in Canada and their impact on the Canadian Prairies is currently unclear. The development of policy incentives for second-generation biofuels must be examined carefully to give the correct signals to encourage farmers to shift land-use into the socially optimal land-use. Traditionally the policy process involves Prairie farmers and the landscape commonly modeled as being homogenous. Agricultural policy tends to be formed on the one size fits all notion through the use of aggregated data and the homogenous stereotype of Prairie farmers. The complex nature of the various soil productivity levels amongst the landscape and farmer characteristics and attitudes create impractical representations at the farm-level using traditional modelling (typically econometric or general equilibrium analysis).

In this thesis an agent based simulation modelling (ABSM) methodology was used to examine the competitiveness of second-generation biofuel crops with existing crops and beef cows at the farm level and their impact on the farm structure building on the work of Stolniuk (2008) and Freeman (2005). ABSM are well suited to problems involving large numbers of interacting actors located on a heterogeneous landscape. In assessing alternative policies, ABSM considers actions between individual farmers in land markets and allows an individual agent (farmer) to make decisions representative to their farm and not from aggregated regional data, avoiding the aggregation bias found in many regional models.

In addition, three sequential (strategic, tactical and recourse) optimization stages are used in order to better reflect the uncertainty and recourse decisions available to Prairie farmers to determine short-run and long-run production decisions using linear and integer programming techniques. In the first decision stage, a Mixed Integer Programming (MIP) model is used to determine long-run strategic decisions associated with herd size, perennial crops, and machinery used in annual cropping systems along with short-run decisions that optimize annual crop

rotations to maximize profits. The second-stage decision is a tactical decision process in the sense that it supports the strategic investment decisions of the farm enterprise by maximizing short-run profits that utilizes linear programming (LP). The third-stage, also a LP model, is a maximization problem, as these are short-run recourse decisions using stochastic yields and stochastic prices to balance feed rations for beef cow enterprises that minimize feeding costs. Each farmer agent's optimal decision is influenced by their own expected prices and yields, variable costs, operating capital/cash flow, and the constraints endowed by the farm agent's land allocation.

The farmer agent profiles are developed using actual census of agriculture and whole farm survey data, with each farmer agent developed differently from the next. The landscape is modelled using the actual soil productivity ratings from Saskatchewan Assessment Management Agency (SAMA) for each 640 acre farmland plot. Due to the importance of transitional and marginal lands, the landscape employed as the case study area is Census Agricultural Region (CAR) 1A of the Assiniboine River Basin of Saskatchewan.

Following Stolniuk (2008), a bootstrapping procedure on historical price and yield data is used to generate 50 different price and yield time paths. The 50 different time paths are used in the model, simulating 30 years into the future to identify the structural change implications from the introduction of energy crops at the farm-level. Three scenarios are simulated including a base case scenario (no energy crops), along with two energy price scenarios ($2/GJ and $4/GJ) based on the identical 50 price and yield time paths.

Perhaps not surprisingly, the simulation results indicate that energy crops have the potential to change the structure of agriculture in this region. Energy crops emerge in the model in both of the energy price scenarios, while total farm sector equity and total sector net income is improved over the base scenario. Farmers with significant quantities of marginal land would experience the greatest change in their farm structures by adopting energy crops if they chose to go down this path. Marginal land-use has a large effect on the energy crop scenarios, primarily on hay and forage acres. Beef cow farmer agents improve their situation the most over the base scenario due to the introduction of energy crops.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.0 Introduction and Background

Energy security and climate change are common global policy concerns. These concerns are likely to only increase in the foreseeable future as fossil fuels become scarce and more expensive while global warming affects more people. Recently, biofuels have been viewed as one alternative to ease reliance on traditional fossil fuels as well as playing a major role in reducing greenhouse gas (GHG) emissions. As a consequence, agriculture is expected to play an important role in meeting world energy needs. To date, most world government policies have focused on first-generation biofuels (FGB) as the primary solution. This is particularly true in the United States (U.S.) where corn-based ethanol production has been an important component in energy security policy (Chen et al. 2009). However, their biofuel policy incentives were so successful in encouraging FGB ethanol plant investment that a failure was created from its own successfulness: corn prices are now highly correlated with energy prices, decreasing profit margins to the point that their survival is at risk (Muhammad and Kebede 2009).

In contrast to U.S. policy and closer to the European stance, Canada has included GHG emission reduction as an important criterion in developing its own biofuel industry. Because of GHG emission concerns and perhaps a more realistic approach, Canada has been much more cautious in developing its ethanol industry (Walburger et al. 2006). Moreover, in moving towards future policy formulation, food and water security have become important additional concerns (Babcock 2008; Becker 2008).

As biofuels move into second-generation technologies, several general characteristics are likely to play an important role in the economic viability and sustainability of biofuels. First, the economical viable biofuel feedstocks are likely to be of relatively low market value and thus need not compete directly with food security. However, reliance on relatively low-valued feedstocks may bring the agricultural biofuel production into direct competition with beef cows for marginal or transitional farmland. Second, to be economically viable, the entire energy value chain must make good use of all by-products. In the past, beef cows and particularly cattle have played an important role in generating a demand for biofuel by-products.

The impact of second-generation biofuels (SGB) on the Canadian Prairies is not clear. Energy crop feedstocks are likely to include woody plants and tall grasses, making them good candidates for marginal and transitional farmland. Hence, it is also likely that beef cow competitiveness may be affected as producers search for alternative crops/enterprises to supply biomass for energy production. Thus, policy incentives for SGB's must be examined carefully to give the correct signals to encourage producers to shift land-use into the socially optimal land-use that takes into account the food versus fuel debate, land-use sustainability and GHG emissions.

1.1 Problem Statement

Accordingly, the problem to be studied: 1) Can SGB feedstocks economically compete with existing agricultural crops on the Canadian Prairies? 2) What is their impact on long-run land use and the beef cattle industry?

1.2 Objectives and Expected Results

The primary objective of this study is to assess the economic role and impact of various biofuel feedstocks in/on Saskatchewan agriculture over the next 30 years under alternative energy price scenarios. More specifically, the economic conditions that would encourage producers to grow SGB crops will be identified and evaluated. In addition, particular emphasis will be placed on assessing the impact of biofuel crops on marginal or transitional land-use. These include lands currently devoted to unimproved pasture, hayland and improved pasture. Finally, the impact of biofuel crops on regional beef cow production and land-use will be assessed.

1.3 Problem Characteristics

Key to the analysis is the competitiveness of SGB crops with existing crops at the farm level. However, Canadian Prairie farms are characterized by extreme heterogeneity in terms of farm type, size, and soil quality and operator characteristics. More specifically, this indicates that although one particular crop/enterprise may be an attractive investment and generate favourable profits for one producer to adopt, another producer may not find it a viable alternative given their characteristics. This means that one size does not fit all.

Another key characteristic is that Canadian Prairie farming is characterized by risk and uncertainty in commodity prices and yields. Accordingly, operator risk attitudes and expectations are important in the adoption of new crops and technologies. In addition, financing becomes crucial in overall farm success. Consequently, biomass risk and government programs that alleviate risk become an important element in adaptation.

Finally, another key characteristic is that farms compete for farmland in ownership and leasing markets and to succeed and prosper over the long-run, farm businesses must eventually all meet opportunity costs and take advantage of new technologies. Hence, the dynamics of growth and adaptation becomes an important component in evaluating the impact of biofuel crop competitiveness.

Agent Based Simulation Models (ABSM) are well suited to problems involving large numbers of interacting actors located on a heterogeneous landscape. In assessing alternative policies, ABSM considers actions between individuals and allows individual agent decisions to be aggregated from each individual to an area or regional level, avoiding the aggregation bias found in many regional models. In addition, model feedback may occur through farmland land markets where farmer agents interact through an auction process. Thus, ABSM is likely the only model that considers individual heterogeneity, feedback, location and complexity associated with adoption of potential second-generation energy crops.

Stolniuk (2008) constructed an ABSM model projecting structural change in Saskatchewan over 30 years including farm numbers, farm size and distribution of size, production characteristics, demographics characteristics, and resource ownership and how the agricultural industry is financed. The Stolniuk model was an extension of the Freeman (2005) model to include beef cow operations and hay and pasture lands as well as a number of additional or dramatically revised components.[1] Because of its ability to handle transitional forage lands, this model

[1] New or dramatically new components include: 1) the landscape is based on actual existing landscape as opposed to a hypothetical one 2) the synthetic farm population is much larger and rigorously developed and placed in the landscape according to individual characteristics as opposed to being randomly assigned, 3) in addition to annual crop land, marginal and transitional farmland is included, 4) farmland market auctions are based on individual plot auctions rather than one large auction, 5) farmland bids are more sophisticated , 6) three farms are considered: grain and mixed grain and livestock, 7) producer attitudes towards beef cows are considered.

provides a good starting base for assessing SGB production. After validation, the Stolniuk model will be expanded to include SGB crops such as woody crops (willow and poplar), and tall grasses (Prairie sandreed). These crops will compete with existing crops in two scenarios under different prices while the base scenario will be run without them. These three scenarios will examine the different projections on structural change that could occur with or without an SGB industry. If SGB's are profitable and feasible at the farm level, it is expected that a SGB industry would emerge. Because of the importance of transitional and marginal lands, the landscape will include portions of the Assiniboine River Basin of Saskatchewan as the case study area.

1.4 Outline of Thesis

This thesis is organized into six chapters. As discussed above, chapter one provides the reader with an introduction and background to the problem under investigation. The remaining chapters of this thesis are organized as follows: In Chapter Two an overview of appropriate literature regarding agent based simulation models (ABSM), second-generation biofuel feedstock and farmland use productivity is examined. Chapter Three presents the MIX-FARM Model, conceptual model, equations and agent's behaviour used to conduct the simulation. Next, in Chapter Four the data used for initialization are discussed. In Chapter Five model verification and validation are compared against Census and other relevant data sources to confirm that the model is a reliable representation of the target. In addition to verification and validation in chapter five, the results from the simulation runs are also presented and summarized. Finally a summary and conclusion are drawn about the thesis in the last chapter.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

In this chapter an overview of agent-based simulation modelling (ABSM) and its advantages over standard economic methods are presented. In addition, relevant ABSM literature and key concepts associated with shifts in long-term land use are discussed in order to better understand the implications that biomass incentives could have on agricultural structure.

2.1 Structural Change

The clearest definition of structural change in agriculture is the change in the number of farms and farm size (Zimmermann et al. 2009; Goddard et al. 1993). Some general factors contributing to structural change in agriculture observed in the literature can be summarized into the organization of the industry, life-cycle hypothesis (including individual characteristics), and macroeconomic conditions.

2.1.1 Organization of the Agricultural Industry

Organization of the agricultural industry is affected by 1) market structure in agriculture, 2) technology and 3) economies of scale and size, and how they relate to structural change. The market structure of an industry also influences structural change. The manner in which prices equilibrate in the market depends on the level of market power that buyers and sellers have in relation to each other in influencing the price (Zimmermann et al. 2009).

Many of the buyers of agricultural commodities are large agribusinesses, a market where entry barriers exist. Due to this, the market structure that often emerges in agricultural processing is oligopsony, where there are many farmers selling commodities to few agribusiness buyers (Rogers and Sexton 1994). Economies of size and scale are so large in the handling of agricultural commodities that the industry is structured with very few firms. Thus, farmers are price takers and must innovate and adapt with respect to their cost of production in order to remain competitive.

In addition, advancements in technology are a primary driving force in the change in the size distribution of farms and number of farms. Technological advances have led to gains in labour productivity and encouraged farm expansion because economies of size have increased in consequence (Bollman et al. 1995). Economies of size and scale are described by Cochrane's technological treadmill, where new technology decreases per unit cost of production and those farmers who adopt the technology early on realize higher returns (Stolniuk 2008). However, as the new technology diffuses through the farm community to other adopters, increased production tends to result in lower commodity prices further exacerbating the treadmill effect. As new technology is introduced, farms will try to expand in order to achieve economies of size and scale. However, because of the lumpiness of machinery investments and land, the expansion path becomes discontinuous past certain thresholds bringing an end to economies of size (Danok et al. 1978; Eastwood et al. 2010; Reid et al. 1987). The lumpy nature of machinery and land result in large jumps in the farm sizing decision farms must make (Stolniuk 2008). In conjunction market structure, technology and economies play an important role in how a biomass energy industry might evolve in Saskatchewan. It will be important to also assess the impact of this evolution on structural change in the region.

2.1.2 The Life-Cycle Hypothesis and Farmer Characteristics

Structural change is also affected by demographics – defined as the stage farmers reside in their life cycle. Perz's (2001) empirical work found that demographic variables influenced by a life-cycle hypothesis captured significant effects in land-use changes as a farmer's age structure changed. This section will highlight the working life-cycle hypothesis as it relates to a farming life stage. This is commonly referred to in the literature as the agricultural ladder. Other important characteristics that influence structural change in this section include a farmer's off-farm employment, human capital and farm succession.

The life cycle hypothesis was first described by Modigliani et al. in the early 1950's. It states that individuals save while they work in order to finance future consumption for the non-working portion of their life (Deaton 2005). This hypothesis introduced wealth into the consumption function. If individuals want to keep spending after their working lives, they need to accumulate wealth to finance the later part of their life-cycle.

The basic life-cycle hypothesis assists in explaining several heterogeneous decisions among farmers. For instance, Potter and Lobley (1996) argue that when viewing all farmers together some are always at different stages in their life-cycle compared to others. They point to the evidence that at any one time it can be observed that some farmers are expanding while others will contract their farms in retirement and old age (Potter and Lobley 1996).

According to the agricultural ladder and life cycle literature, farms have roughly five stages[2] in their life-cycle: 1) entry/establishment 2) growth 3) survival 4) disinvestment/transfer, and 5) exit (Boehjle 1973, 1992; Kloppenburg et al. 1985; Lee 1947; Long 1950; Perz 2001; Potter and Lobley 1996; Wehrwein 1958). However, not included in the stages listed above, farmers also have pre and post stages in their farming life-cycle.

Pre-farming consists of family members starting off as either non-paid or paid farm labourers (Lee 1947). Non-family hired labour also falls into this category as some hired labourers seek farming experience before they enter the industry on their own. For many, the pre-farming stage is seen as the future farmer's apprenticing stage in their life-cycle where they gain knowledge (Lee 1947). The apprenticing aspect might involve some educational training whereby the individual attends college or other training relevant to their future farming career. Off-farm employment is also considered to be part of the pre-farming stage since investment capital might first need to be earned off the farm in order to enter the farming industry (Lee 1947).

In the entry/establishment stage farmers typically are tenants where they rent most of their farm assets (Boehlje 1973). As farmers age, they start building up wealth in the form of owned assets as they expand their farm through the growth stage. Eventually they will get to their desired farm size or they reach a certain age and they enter the consolidation and survival stage where they maintain their current farm size (Boehlje 1973). Finally the farmer will come to the divestment stage where succession to the succeeding generation may occur (Potter and Lobley 1992). If succession does occur, the farmer will enter into the transition stage which likely will overlap with an heir who would be in the pre-farming stage or the entry/establishment stage of

[2] Although five-stages are listed farmers may skip stages or be in a single stage for most of their entire farming career before they exit. Some farmers may spend their entire farming career in the survival stage.

their life-cycle. If succession does not occur, the farmer will relinquish control of the assets to non-family members and equipment and/or farmland are sold (Boehlje 1973). Eventually the farmer will exit the industry and become a non-farmer in the post-farming stage. In the post-farming stage the retired farmer may either be a farm labourer for an heir or landlord to another farmer should they maintain ownership of any farmland (Lee 1947).

Off-farm employment is also an important component to structural change and varies considerably. Goddard et al. 1993; Bollman et al. 1995 argues that off-farm employment assists in the survival of smaller farms as off-farm income primarily is used to maintain the minimum family living expenditures and is not a major tool in farm diversification. Smaller farms more or less tend to have their labour underemployed giving them the ability to increase household income through off-farm employment (Stolniuk 2008). Off-farm employment has allowed many farmers to linger in the survival stage of the life-cycle for long periods.

Zimmermann et al. (2009) describe the nature of farmer human capital and state that it is influenced by a number of factors including their managerial ability and education training from primary school to post-secondary education. Thus, as the level of human capital increases so too does their ability to be a more efficient farm manager as they can process information more effectively giving them a competitive advantage in being able to allocate resources more efficiently (Boehlje 1992; Goddard et al. 1993; Zimmermann et al 2009).

2.1.3 Macroeconomic Conditions

Macroeconomic conditions play a significant aspect in contributing to structural change in agriculture. In this section, macroeconomic conditions refers to government policy with respect to support programs, tax policies, monetary and fiscal policies, interest and exchange rates as well as input and output prices in the market.

Government agricultural policy as argued by Boehlje (1992) tends to view agriculture as a family-farm based agricultural structure and that it is essential for efficient food production, rural development and preservation of the family farm over generations. Support programs and government payments have an impact on farm structure, although it is difficult to measure, it is argued that a large portion of support payments become capitalized into farmland values (Goodwin et al. 2002; Sherrick and Barry 2003). ABSM is one tool that can predict the outcome of government policy on farm structure by tracking the flow of payments in the industry (Happe et al. 2008). The objective of many farm programs is to preserve the number of small and medium-sized farms in the industry offsetting the impact of technology on farm size. Ahearn et al. (2004) found empirical evidence that in most circumstances policies designed to target small family farm survival were likely counterproductive and had adverse effects on structural change.

2.2 Heterogeneity of Land-Quality and Land-Use

In agriculture, farmers tend to use their land in a way which maximizes profits over time. However, choosing an optimal land use is complex due to changing input and crop prices, advancements in technology, government programs, personal preferences and, of course, land quality (Lubowski et al. 2006). Land quality is typically determined by its income generating ability, which solely relates to soil fertility and crop growth potential as the key for agricultural production.

An important component of the SGB problem is the potential shift in the so called marginal land from pasture and forages into biofuels. Farmland that has poor soil characteristics and quality that results in low return is often referred to as marginal land (Parks 1993; Peterson and Galbraith 1932; Spence and Haase 1951). These lands can be thought of as transitional lands: marginal land is the last to be converted to field crops and the first to be taken out of production. This section will discuss the characteristics of marginal land in more detail.

Lands at the economic margin may have alternative uses that can result in greater economic returns. Lubowski et al. (2006) define extensive margin choices as the marginal land alternatives that could result in the movement of land in and out of field crop production. Intensive margin choices refer to the particular crop choices like cereals, oilseeds, pulses and perennials and the specific application rates of inputs (Lubowski et al. 2006). Thus, extensive is the difference between how the land is used in a general sense while intensive relates to the management/agronomic practices specifically.

In maximizing long-run farmland returns with woody biofuel alternatives, change in land-use may carry additional considerations as to economic irreversibility: the cost of converting land back to its previous use may not cover the costs of land clearing (Parks 1995). Thus, a shift in land-use to perennial crops and, in particular, to woody plants may be permanent because of the prohibitive land conversion cost.

2.2.1 Land-Use and Farmer Influence

Land-use choices also depend on farmers' personal characteristics such as varying management skills; price expectations; ability to innovate and incorporate new technology; risk tolerance; and personal objectives (Lubowski 2006; Parks 1995). Of particular interest are life cycle and its effect on a farmer's willingness to adopt different land-use practices.

Potter and Lobley (1996) present five stages of land-use change development amongst farmers to signify the heterogeneity amongst their farmer characteristics and life-cycle influence. The five stages of land-use change are: (1) recent developers, (2) consolidators, (3) stabilizers, (4) disengagers, and (5) withdrawers. Recent developers are defined as farmers on marginal land who have made land improvements and have intensified production on their farm with intensions to increase farm net worth. Consolidators are farmers on cropland soils who have also made changes on their land to increase farm profits. Stabilizers are those farmers who do not make many changes to their land-use either on marginal or cropland and would be classified as being farmers who are in the survival stage of their life-cycle. Disengagers are those farmers who are not relying on agriculture for supporting their family due to better opportunities off the land and make little or no land-use changes. While withdrawers are farmers consistently experiencing negative or low returns and have taken no recourse in search of new opportunities. Withdrawers are farmers who leave the industry within a few years (Potter and Lobley 1996).

2.2.2 Land-Use Summary

Land use conversion is not only dependent on the farmland income-generating ability but also on the individual farmer's characteristics and their personal stage in the farm life-cycle. Crop farmers in the entry and growth stage of their life-cycle who have intentions of increasing their farm net worth, are more likely to convert marginal land-use to energy crops. While mixed farmers who have recently converted marginal land for forage production and/or invested in beef cow production are unlikely to adopt energy crops. The latter would only convert to a new use if they are nearing a point of pasture renewal or considering downsizing or exiting beef cow production. Finally, a change in ownership from beef cows to an annual crop farmer might also trigger change in land-use.

2.3 Second-Generation Biofuels (SGB) versus First-Generation Biofuels (FGB)

Increased interest in developing SGB production from biomass energy crops stems from the limitations of FGB's. The limitations of FGB's are primarily (1) competition with food, (2) lack of further growth, and (3) limited GHG emission reduction (Mandil and Shihab-Eldin 2010).

2.3.1 A Short History of FGB and the Food versus Fuel Debate

The FGB industry in the U.S. experienced above normal profits during the early 2000's for several reasons: 1) high oil prices, 2) low feedstock prices and 3) through various mandates or subsidy programs. The latter was particularly important: a great deal of the rapid expansion of the FGB industry in the U.S. was the result of government policies and regulations, primarily those passed in 2005 (Duffield et al. 2008). The U.S passed legislation that raised the minimum renewable fuel required to be blended in gasoline, as well as introducing a number of tax credits, import tariffs and other incentives (Gustafson 2008). All of the above factors contributed to the rapid growth of the FGB industry impacting both supply of and demand for ethanol (Gustafson 2008). The excess profits ethanol plants earned during this period enticed more firms to enter the FGB industry, causing the industry to mature and become more competitive as profit margins fell (Gustafson 2008). While sustainability and profitability was achieved from the industry's lowest-cost producers, the majority of the industry success came from generous government subsidies and fixed demand as the industry is policy driven (IEA 2008; Kruse et al. 2007). The entry of new firms further increased demand for feedstocks resulting in the capture of a large proportion of the U.S corn crop by ethanol production, driving up commodity prices and sparking competition between food and fuel production. This created an unintended correlation between agricultural commodities prices and energy prices (IEA 2008; Martin 2010).

The food versus fuel debate arises from the shift from food to fuel production on cropland since they both compete for the same arable acres (Bacousky 2010). The limited amount of cropland available to produce crops for food, feed and fuel caused constraints in agricultural inventories (Khanna 2008). Acreage shifted as U.S. farmers grew more corn for ethanol production reducing acres of soybeans and wheat (Duffield et al. 2008). Higher food prices caused major tensions regarding the use of cropland for biofuel production because food expenditures make up a large portion of disposable income for billions of the world's poor (Babcock 2008). This negative impact of biofuels on non-food disposable income in much of the world brings biofuel policies into question particularly those in the U.S. and the EU. The food versus fuel debate ignited when the U.S. biofuels industry experienced a period of enormous growth during 2007-2008, impacting world commodity inventories leading to higher food prices (Gerber et al. 2008). Oil prices soared during the summer of 2008 resulting in increased FGB crops (Xiaodong et al. 2009; Gerber et al 2008).

As energy prices rose, ethanol production increased, putting further pressure on food prices. However, the correlation of energy and corn prices reduced profit margins to the point where the ethanol industry expansion ground to a halt, reducing fears of significant further disruptions in the food and feed markets (Duffield et al. 2008). Note that ethanol production provides a very small proportion of U.S. gasoline consumption and that to meet ethanol mandates and to reduce the correlation of oil prices with agricultural commodities, other sources of feedstocks will be required.

2.3.2 FGB Industry Maturity versus SGB Growth Potential

Over time, more FGB plants emerged in the industry increasing the supply of ethanol and causing their prices to tumble, since growth in demand did not keep pace. The increased demand for feedstocks raised the industry cost of production while market conditions changed simultaneously where oil prices and demand fell. (Martin 2010). The effects of both changes and the emergence of a correlation with energy markets resulted in FGB profit margins being reduced to zero or negative. As the FGB industry matured, the changing market conditions caused the industry to become even more reliant on government subsides (IEA 2008). Any profits earned when market conditions changed were either blending subsidies or subsidies extracted from the farmer through rent-seeking. Kruse et al. (2007) argues that the profit margins would be even lower if the import tariffs and blend subsidies were reduced.

The need to shift ethanol production to other feedstocks has resulted in an interest in ethanol production using SGB technologies (Duffield et al. 2008). The key to producing biofuels without competing for cropland is to use marginal land that is unsuitable for food production but ideal for biomass. SGB's can partially break the food versus fuel link because biomass can be used for biofuel production where there is little, if any, impact on the amount of land available to produce food and biomass can be grown successfully on marginal lands. Nevertheless, because energy crops require some land for production, the link to food will always partially exist as marginal land still may be used for feed production or grazing livestock (Babcock 2008). However, the long-term trend apparent in Canadian agriculture is lower beef cow prices; a decline in beef cow production is expected (AAFC 2010; Thornton 2010; USDA 2010). If a decline in beef cow production occurs it will free up marginal land for biomass production. Thus, SGB's look more ideal from the Canadian perspective than do FGB's. Mussell and Martin state that Canada should focus on SGB's as they are already leaders in cellulosic production technology and can leverage on this success.

SGB's may be able to reduce the correlation of oil prices with agricultural commodities because they can assist feedstock demand by facilitating the fuel demand while traditional annual crops will meet the demand for food and feed. If the correlation of oil prices with agricultural commodities can be reduced, profit margins in the FGB industry may return to normal as margins in the SGB entice firm entry. If ethanol supply can be increased with feedstock sources other than corn and wheat, this will relieve some of the pressure on cropland demand over the long run and ease the tensions for food and feed production. Energy crops used for the biomass feedstocks in SGB tend to have high yields of biomass making them economical for biofuel production. SGB if successful will reduce the impact FGB have on food prices, as increased ethanol production comes from SGB sources (Babcock 2008).

2.3.3 Environmental Improvement and GHG Emission Reduction

Another extremely important drawback of FGB's is their relatively higher GHG emissions over that of SGB's. Biofuel production from energy crops comprising of cellulosic biomass is expected to result in significantly greater carbon sequestration compared to starch and sugar based biofuel[3] (Tilman et al. 2006; Sheehan et al. 2003; Farrell et al. 2006). The increase in GHG emission reduction comes primarily from the significantly higher yield per acre of energy crops compared to sugar or starch crops.

There are several environmental benefits besides GHG emission reduction from using marginal land for SGB. Environmental concerns are reduced as energy crops require less fertilizer inputs than annual crops reducing the environmental concerns from contaminating water sources. Growing energy crops on marginal land can actually improve soil fertility and restore marginal land if correct agronomic practices are followed (WBGU 2008). Improvements in soil quality on marginal lands devoted to energy crops are primarily derived from the perennial cropping systems. First, the extensive root systems of perennial crops assist in increasing the quality of water on marginal land. Second, energy crops can prevent soil erosion while increasing soil organic matter (WBGU 2008).

2.3.4 Summary of FGB versus SGB

There are several advantages of SGB over FGB. First, SGB do not directly compete with food or feed production on arable land. Second, given the correlation between agricultural commodities and energy markets created from government FGB policy, the FGB industry now suffers from low margins. Third, given the outcome the expansion of the FGB industry had in the U.S. the adoption of FGB would be negative for Canada, as it would threaten the beef cow industry's competitiveness through higher cost of production and dampen its export position (Mussell and Martin 2007). Considering the impact SGB can achieve environmentally and the reductions in GHG emissions SGB appears to be the biofuel direction that Canada should proceed to develop.

[3] Based on the assumption that perennial crops will be grown on existing marginal land and that no deforestation occurs.

2.4 Potential Saskatchewan SGB Energy Crops

Energy crop candidates can be based on a variety of perennial grasses and woody trees using conventional agronomic practices. Biomass energy crops can be burned in a co-firing coal electrical plant or distilled into biofuels (Scheffran and BenDor 2009; Perry and Rosillo-Calle 2006). However, the focus of this thesis is the use of energy crops for biomass production for SGB. The primary reason why biomass would be grown on agricultural lands rather than harvesting biomass naturally occurring in forests is that cultivated biomass is thought to have a significantly higher yield per acre than naturally occurring material (Timmons et al. 2008). The reason cultivated energy crops can achieve higher yield rates stems from the selective breeding programs.

The ideal SRWC energy crops for CAR 1A of Saskatchewan are willow and hybrid poplar because they are native to Saskatchewan, grow well in northern temperate areas and are suitable for marginal lands not appropriate for annual crop production (Konecsni 2010; Volk et al. 2004). Willows are an ideal SRWC energy crop because of their high yield growth in a short-time period and their ability to re-grow after multiple harvests (Volk et al. 2004). In addition, research has focused on willow and poplar and there is a willow research plantation also located within CAR 1A at Estevan, Saskatchewan (Stadnyk 2010). However, in the case of hybrid poplar, it is generally held to be more suitable along the southern border of the boreal forest of Northern Saskatchewan which may limit its potential in the proposed study area of CAR 1A (Steckler 2007).

Tall grasses also have potential to be used for energy crop production on marginal lands. The native range of promising warm season grasses for biomass feedstock is displayed in Figure 2.1. Although Switchgrass and Miscanthus are dominant tall grass species native to North America they are not ideal energy crops for Saskatchewan because of its harsh climate; rather other warm season grasses like Prairie sandreed that are amenable to cool regions are better candidates (Samson et al. 2000; Jannasch et. al 2001).

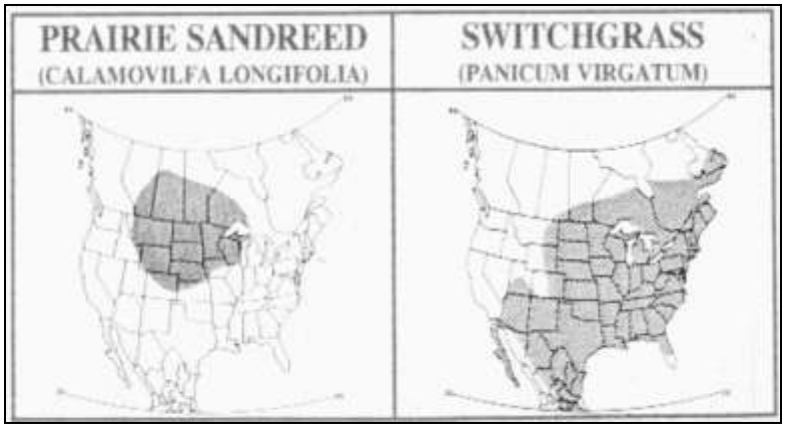

Figure 2.1 Native Range of Warm Season Grasses
Source: Samson (2008).

2.4.1 Farmgate Energy Crop Prices in the Literature

The farmgate price in dollars per gigajoule received by farmers for their biomass production is an important component that needs to be examined in the literature. Wash et al. (2003) use the POLYSYS model to examine energy crop production in the U.S. and discover that at energy prices between \$1.83/GJ and \$2.44/GJ farmers earn higher profits than traditional land uses. The *Biomass Research and Development Board* (2008) in the U.S. also found that the willow farmgate price required for farmers to earn a profit would be in the range of \$1.42/GJ to \$2.50/GJ.

2.4.2 The Potential for the Energy Crop Industry in Saskatchewan

The biomass energy crop industry in Saskatchewan is still in its infancy and given that energy crops have not been planted on a large scale, the relevant economic literature and information is still relatively sparse. However, in order for a biomass industry to emerge in Saskatchewan, energy crops must provide farmers with income that is comparable to what they could earn on the same piece of land through an alternative use (Hesseln 2007).

As discussed in the FGB versus SGB section it is important that energy crops do not trigger competition for land use in a way that puts food security at risk or leads to soil degradation. Evidence and limitations from the U.S. FGB industry should be examined carefully by policy-makers to prevent potential correlations between agricultural commodities and energy markets that could emerge from SGB policies impacting land-use decisions. Hesseln (2007) identifies a few issues that need to be addressed before changes in land-use for biomass production in Saskatchewan take place in order for a SGB industry to emerge. First, it is important to understand the potential demand for biomass. Second, the cost of energy, land conversion and related production costs are essential factors in determining the competitiveness of the SGB industry.

Sustainable biomass production for energy purposes should ideally only be promoted if land-use contributes to nature or soil conservation. In the literature, marginal land has been identified as preferred for the promotion of energy crops (Amichev et al. 2010; BRDB 2008; Mandil and Shihab-Eldin 2010; McKendry 2002; WBGU 2008). The introduction of growing energy crops on marginal land could potentially reduce government payments to farmers in regions characterized by poor growing conditions and low income areas by increasing farmer incomes (Scheffran and BenDor 2009). If SGB energy crops prove to be economical as the chosen feedstock for energy production over FGB, land-use in Saskatchewan may intensify as marginal land-use comes into production.

2.5 Introduction to Agent-Based Simulation Modelling

Agent-Based Simulation Modelling (ABSM) describes computerized simulations of the individual and collective actions of a population of decision-makers known as "agents". These agents then interact through prescribed rules on a virtual geographical landscape (Axelrod and Tesfatsion 2005; Berry et al. 2002; Bonabeau 2002; Gilbert 2008). In economics, ABSM is categorized within computational economics because ABSM is a computational method that simulates the complex dynamic behaviour and interactions of autonomous individual agents in a network or environment (Tesfatsion 2008, 1998; Tesfatsion and Judd 2006). Some argue that the use of ABSM has instigated a shift toward a new paradigm in the social and economic sciences primarily focusing on the emergence of complex behaviour from rather simple individual processes (Beinhocker 2006; North and Macal 2007; Simon 1996).

2.5.1 ABSM in Economics

Traditional economic analysis for policy applications typically involves using either econometric (statistical) estimation of parameters of importance or the development of general equilibrium models for systems analysis. However, in some circumstances ABSM methods permits a much deeper understanding and interpretation of relevant data. Traditional models often assume a closed static, linearized system in equilibrium with aggregated supply and demand functions. In contrast, ABSM permit an open, dynamic system that may exist far from an equilibrium, heterogeneous agent interaction and system feedback (Beinhocker 2006, Nolan et al. 2009). In statistical and econometric analysis of structure, noise terms are added to aggregate equations, while ABSM in turn uses randomness in appropriate instances to help avoid aggregation errors (Bonabeau 2002)[4]. Furthermore, if individual heterogeneity is an underlying component of complex systems, then the use of aggregates or averages as representative of behavior in traditional economic models may yield at best, incomplete or at worst, misleading results (Miller and Page 2007). In summary, ABSM allows for emergent situations, ABSM provides a natural description and spatial representation of complex systems, and ABSM is more flexible in structure (Bonabeau 2002, Freeman 2005, and Stolniuk 2008). Many authors argue that the prior systems models used within the natural and social sciences have been unable to capture system emergent behaviour and self-organization (Berry et al. 2002). The concepts of complexity and emergence will each be discussed in section 2.5.1.1.

However, there are several disadvantages of ABSM as discussed in Tesfatsion (2006) and Robertson (2005). Tesfatsion argues that ABSM models need to be detailed enough so that the results of the simulation are not affected by the initial design of the model. Thus, if outcomes are path dependent on the initial settings, the results could potentially be misleading. Validation and verification of the outcomes using empirical data has also proven to be a disadvantage of ABSM (Tesfatsion 2005). In addition to model design, computations, complexity, amount of interaction and number of agents within the model will be restricted by the memory and processor limits of the computer (Robertson 2005).

2.5.1.1 Complex Adaptive Systems and Complexity Theory

Complex adaptive systems (CAS) and complexity theory are interrelated and provide a connection between systems analysis and mathematics rooted in the idea of self-organization (Dodder and Dare 2000). In both CAS and complexity theory, the central principle is that there is

[4] Aggregation errors are errors that could be introduced by using aggregated data in estimating a modeled value.

usually a hidden order within the behaviour and evolution of complex systems. These systems are generated by interacting individual agents operating independently of each other, yet are somehow interconnected. Complexity theory has its origins in the early 1960's as researchers attempted to rationalize the behaviour of large and complex systems, with the premise that they could be fully explained by the usual rules of logic and analysis (Dodder and Dare 2000). Complexity theory explains how independent agents interacting on a landscape sometimes reveal patterned behaviour or properties that emerge on a large-scale that could not have been predicted by observing the agents individually. It is this interaction amongst individual agents without an explicit central planner that generates emergent patterns, orderly phenomena and properties, at the macro level (Caldart and Ricart 2004). For example, some research has argued that agriculture is a complex system arising from the heterogeneity of farmers, the landscape and the dynamic organizational structure that emerges (Happer 2004, Scheffran and BenDor 2009; Stolniuk 2008).

2.5.1.2 Emergence

> "He intends only his own gain, and he is in this, as in many other cases led by an invisible hand to promote an end to which was not part of his intention."
>
> – *Adam Smith, Wealth of Nations*

Emergence is not a new idea and can be traced back to the father of economics, Adam Smith and his theory of the invisible hand. As discussed in the previous section, emergent properties can result from the interactions of individual entities in complex systems. Emergence makes it difficult to reduce the complex system into constituent parts since the system can have properties that are decoupled from the characteristics of the individual agent (Bonabeau 2002). Emergent phenomena are difficult to understand and predict and are often in contrast to what traditional theories would suggest. In this light, ABSM has become an important and popular approach to identifying emergent phenomena in the social sciences because of its bottom-up approach to systems analysis (Gilbert 2008; Nolan et al. 2009; Srbljinovic and Skunca 2003).

2.5.1.2.1 Complexity, Emergence and the Theory of the Invisible Hand

According to Adam Smith's postulate of the "Invisible Hand", competitive markets send resources to their highest and best economic use without the direct intervention of a higher authority (i.e. government). The invisible hand concept is to be considered self-regulating in nature with respect to allocating resources and prices in the marketplace (Bishop 1995). As an industry, agriculture is composed of a large number of individual farmers handling their own allocation problems in a detached manner through their individual production decisions. According to Smith, each farmer pursues their own self interests for their farm enterprise, one that maximizes profit and personal satisfaction, and in so doing, economically efficient behaviour emerges that not only is in the best interest of the farmer but also for the market as a whole. Since commodity markets play a major role in a farmer's expected output prices, these market prices facilitate a farmer's decision to make the best possible economic choice, a choice that is made as if by "an invisible hand" and a choice that also serves the best interests of the entire market.

2.5.1.3 Model Flexibility

ABSM provides a more flexible and functional framework for modelling than traditional economic models. This flexibility comes with a trade off against the precision which traditional models portray. The benefit of a flexible model is that it can capture a broad range of behaviour, while precision requires the parameters in the model to be described or defined precisely (Miller and Page 2007). Flexibility in ABSM stems from the "bottom up" method of modelling, meaning that each individual agent is programmed to interact with each other and their environment, a situation that produces aggregate (possibly emergent) results within the entire system.

2.5.2 Agent-Based Farm Simulation Models

In this section, ABSM usage in the literature regarding structural change and energy crops is reviewed. The AgriPoliS model requires mentioning since Freeman (2005) developed an ABSM model off the framework of the AgriPoliS (Version 1.0). AgriPoliS was developed to evaluate structural change in European agriculture and Freeman extended the model to Saskatchewan to evaluate structural change (1969-2000), but also added in land markets to enhance it. Stolniuk

(2008) further enhanced the model by including livestock, economies of size and changes in land use. However, the Freeman (2005) and Stolniuk (2008) models did not incorporate the linear programming (LP) and mixed-integer programming (MIP) portion of AgriPoliS into their models. In addition, the Stolniuk (2008) model does not include energy crops, which have been analyzed in other ABSM literature.

Scheffran and BenDor (2009) use an ABSM model to examine changes in land-use amongst Illinois farmers once miscanthus and switchgrass are introduced as energy crops. The model also analyzes the boom and bust of volatile commodity prices from the over and under supply that emerges (Scheffran and BenDor 2009). This study allowed energy crops to be adopted on both cropland and marginal land, however, the authors conclude that energy crops showed significant increase in returns on marginal land where traditional crops (corn and soybeans) were less favorable. However, their model does not apply to CAR 1A of Saskatchewan for a number of reasons: (1) Miscanthus and switchgrass are not suitable energy crops for Saskatchewan farmers (SES 2007; Cunningham et al. 2010), (2) changes in beef cow numbers are not analyzed from the shift to energy crops, and (3) their model does not incorporate the use of LP and MIP to optimize a farmers decision process.

Walsh, De La Torree Ugarte, Shapouri and Slinksy (2003) modified the POLYSYS model to evaluate the economic outcome of switchgrass, willows and poplar on the U.S. agricultural sector under a hypothetical modified Conservation Reserve Program. The POLYSYS model is not an ABSM model but an agricultural policy simulation model that simulates the national demand and regional supply (Walsh et al. 2003)[5]. The POLYSYS model is a regional supply and demand model that does not model land-use changes at the farm level. However, the POLYSYS model incorporates the use of 305 independent regional linear programming models to determine regional supply but these are not at the farm level and may potentially suffer from aggregation bias because of the homogenous production characteristics. Although POLYSYS simulates the regional impacts to U.S. agriculture from changes in policy and economics as

[5] POLYSYS is not considered agent based because there is no interaction of the farm agents.

ABSM models also portray, the POLYSYS model does not capture the individual agent interaction and feedback through land markets and farm level responses to economic incentives that ABSM captures.

While other literature exists regarding ABSM and/or energy crops, the majority of the studies do not address structural change or changes in land use relevant to this thesis (Refer to Balmann et al. 1997; Filatova et al. 2009; Robinson et al. 2010; Zimmermann et al. 2009).

2.5.2.1 Spatial Representation and Heterogeneity of Land Characteristics

Spatial representation of agents and markets is an important advantage of ABSM. This makes it an ideal research tool in agricultural economics (Berger 2001). For example, spatial representations of ABSM agricultural production and land use decisions can be more realistically simulated based upon productivity ratings of soil characteristics that are by their nature heterogeneous. Both Freeman (2005) and Stolniuk (2008) maintain spatial representation in agriculture is key in determining transportation costs and individual competitiveness in land auctions. In this thesis, spatial representation and heterogeneity of land characteristics will play an important role in analyzing whether energy crops emerge in the simulated farming environment.

2.5.3 ABSM Methodology

This thesis will employ ABSM to help assess the competitiveness of biomass energy crops along with existing crops and beef cows at the farm level, as well as determine their impact on structural change in agriculture. The methodology developed in this thesis differs from Freeman (2005) and Stolniuk (2008) in that it uses agent-based modeling in conjunction with mixed integer and linear programming techniques to simulate individual strategic and tactical decisions in this hypothetical farming environment. The software used in the thesis will be discussed in the next section.

2.5.3.1 Repast© Simphony Platform

Repast© is a free and open-source modeling platform used for agent based simulation modeling. Repast© stands for Recursive Porous Agent Simulation Toolkit and was developed by Sallach, Collier, North, Howe, Vos, and other team members at the University of Chicago and the Argonne National Laboratory (Collier et al. 2003). Originally Repast© was established as a java implementation of the Swarm toolkit and many of the concepts can be attributed to the Swarm platform (Collier 2002). Repast© has been constantly improved over time as newer and more sophisticated versions have been released and maintained through the non-profit and volunteer group ROAD.[6] The latest version is Repast© Simphony that was developed to simplify model creation and use through the use of flowcharts as well as the use of both Java and Groovy languages (Repast 2008). One advantage of Repast© is the ability to expand simple simulation models in order to make them more sophisticated in construction (Robertson 2005). For this thesis, the Repast© environment is an example where the previous Stolniuk Netlogo© code was converted to Java language for use in the Repast© platform.

2.5.3.2 lp_solve – Java Wrapper

The free and open-source software *lp_solve* is a linear and integer programming solver incorporating the revised simplex method (LP) and the branch-and-bound method (MIP) for integer programs (lpsolve 2010). The program was originally developed by Michel Berkelaar at the Eindhoven University of Technology, but the actual *lp_solve* program was not object oriented. The program needs to be called via a library in order to be accessed by other programming languages such as Java. A so-called Java wrapper was created by Juergen Ebert (University of Koblenz-Landau, Germany) that is object oriented in order to access the *lp_solve* library. The version of *lp_solve* used in this ABSM model is version 5.5.0.15.

2.6 Chapter Summary

The literature reviewed in this chapter presented an overview of ABSM and its underlying concepts. Literature relevant to biomass energy crops and structural change were also highlighted. It is apparent in the literature that ABSM is advantageous and the appropriate methodology for assessing shifts in marginal land for SGB production. Emergence is a key concept in ABSM and the true value of ABSM is its ability to analyze the interaction of heterogeneous farmers over a heterogeneous farmland that enables a complex system to emerge.

[6] ROAD stands for Repast Organization for Architecture and Development and is managed by a board of directors including academic, government and industrial organizations.

The competitiveness and emergence of SGB energy crops will depend on the opportunity cost of alternative land-uses, technology and economies of size achievable, the stage in a farmer's life cycle and their characteristics, as well as other macroeconomic conditions occurring in the agricultural industry. Many factors will affect the structural change that will occur in agriculture over the next 30 years. ABSM has been recognized as the appropriate methodology for analyzing emergent behaviour that influences structural change.

CHAPTER 3: THE *MIXFARM* MODEL

3.0 Introduction

The ABSM models presented in the preceding chapter are chosen as being the appropriate model to analyze structural change in agriculture. The following model is labelled MIXFARM-ABM for its ability to incorporate different farm enterprise types, primarily livestock, grain and perennial crop farms all into one model. The following chapter gives an overview of the conceptual model, followed by detailed discussion of 1) the farmer-agent including the optimizing decision stages, business financial and accounting equations, 2) non-farmer agents, 3) auctioneer agent and land trading (purchases, leases and sales) 4) farmer exit and possible farm business succession and 5) a chapter summary.

3.1 Model Overview

The MIXFARM-ABM model simulates a complex regional agricultural structure situated on heterogeneous farmland with heterogeneous farmer agents, each strategically trying to grow and prosper[7]. Key to the model is the dynamic and stochastic interaction of four different types of agents in farmland markets: 1) farmer agents, 2) retired farmer agent landlords, and 3) non-farming investor agent landlords, and 4) an auctioneer agent. The farmer agents consist of three types: pure grain farms, mixed farms and pure beef cow farms, farmland can be owned and/or leased. Retired farmer agents and investor agent landlords hold land as an investment and lease land out to farming agents. The auctioneer agent is a *deus ex machina* type of agent who receives bids in the land markets matching the highest bids with the highest land quality through an auction process.

Farm agents need to be efficient and generate sufficient income for their farm business and they must also grow their farm business by being successful in the purchase and lease markets to gain cost efficiency to survive over time. Each farm agent has a different level of risk, price and yield expectations; differing location and farmland quality; and different financial situation all leading to different land auction bids. Success in the farmland markets ultimately depends on obtaining

[7] The heterogeneous landscape is based on (Census Agricultural Region) CAR 1A, located in the southeast corner of Saskatchewan. The landscape and plot details of CAR 1A will be discussed in more detail in Chapter 4.

the appropriate amount of farmland that maintains or improves efficiency while not over bidding. Farmer agents who over pay for farmland may become strained financially and subsequently be forced to downsize or to exit. Farmer agents who consistently under bid may be unable to expand leading to decreased efficiency and competiveness and over a lifetime may be unable to generate sufficient equity to pass their farming unit on to the next generation.

There are two particularly important dynamic feedback mechanisms contributing to model complexity. First, individual farm size is important as it sets the appropriate tillage technologies and machinery replacement options and sets potential cost efficiency, which may or may not be fully realized, depending upon success in farmland markets.[8] Hence, the appropriate success in farmland markets can result in increased efficiency which further enhances agent ability to better compete in future markets. The second feedback is through the "balance sheet effect:" land market values established through the farmland purchase auctions feeds back to the balance sheets of all farm agents holding farm land. In times of increasing farm land values, increased agent equity relaxes some financial constraints, allowing them to potentially borrow more. Conversely, in times of decreasing farm land values, their decreased equity further constrains their ability to borrow and could result in downsizing or a forced exit.

Accordingly, regional structure over several generations is determined by complex interplay of the agents. The dynamic and stochastic economic environment sets the "area" where success/failure determine the long-run structure through 1) the number, 2) farm type, 3) personal and 3) business characteristics of the remaining farmer agents.

The MIXFARM-ABM model builds upon the work of Freeman (2005) and its successor created by Stolniuk (2008). In the Stolniuk model, farm agents make production and land use decisions based on profit maximization from 1) a limited number of annual crop rotations and 2) forage, and 3) beef cow production. The basic Stolniuk agent decision module is modified to include three sequential optimization stages in order to better reflect the degree of information and recourse decisions available to producers. Optimization techniques include the use of both

[8] This is described further in Chapter 4

mixed integer and linear programming. Agent expected value formulations of stochastic variables and the constraints vary according to the relative hierarchy of the decision. Long run decisions include farm size and machine investments; forage, pasture and energy crop rotations; and are based on long-run price and yield expectations and include the most comprehensive set of constraints including resource endowments, credit, cash flow and borrowing constraints. Annual decisions are mostly annual crop decisions. Recourse decisions are associated with feeding livestock.

As described above, the decision making process is a three step process: 1) optimize long run rotations, beef cow herd size numbers, farm size and machinery composition, 2) optimize annual cropland use by maximizing plot gross margins, 3) adjust to actual prices and yields by optimizing herd-related recourse decisions such as ration formulation and forage buying/selling activities (Figure 3.3 Farmer Agent Decision Making Process). The following sections examine in detail each of the three decision stages and delineate the key structural and behavioural equations.

3.2 The Farmer Agents

The farming agent is a critical component to the MIXFARM-ABM. The farm population varies according to demographic and business characteristics, but each agent shares a common set of behavioural, accounting, and decision making rules. In addition, while each farmer agent has an intrinsic desire to prosper and thrive, how this is manifested depends upon their current life stage. As stated in the previous section, the farmer agents include three types: pure grain farmer agents, mixed farmer agents and pure beef-cow farmer agents. The type of farmer agents in the population is determined by the initial endowment of their land base each with different soil productivity ratings, financial, and demographic characteristics. Grain farms have no desire to invest in beef cows and thus have no aspiration to bid on marginal farmland that is unsuitable for grain farming. These grain farms typically have more annual crop acres and can achieve greater economies of scale than mixed farms. A mixed farm includes both grain and beef cows, allowing them to expand towards either enterprise giving them a competitive advantage in bidding for marginal land. Conversely, grain farms have a competitive advantage in bidding for better quality land which has little hay or pasture because of their size advantages.

The following flow diagram (Figure 3.1) illustrates the annual farmer agent production and land use decisions in the three decision stages. Prior to the optimization, all farmer agents are screened for their credit borrowing ability and pre-retirement conditions if they are less than fifty-five years of age. Next, farmers unable to meet the requisite financial criteria for expansion bypass the first stage and enter directly into the second stage tactical optimization LP model. Likewise, producers aged fifty-five and older also bypass the strategic optimization of stage-one because at that life-stage they are statistically unlikely to expand their farm further. These producers enter the stage-two tactical LP where they maximize short-run annual crop returns over variable cost, subject to existing land and machinery mix.[9] After yields and prices are known, all farmers with cattle proceed to the third stage of recourse decisions and minimize ration and feeding costs.

[9] At this stage in the farmer agents life cycle they are no longer trying to grow their farm but rather maintain it or starting the disinvestment of farm assets.

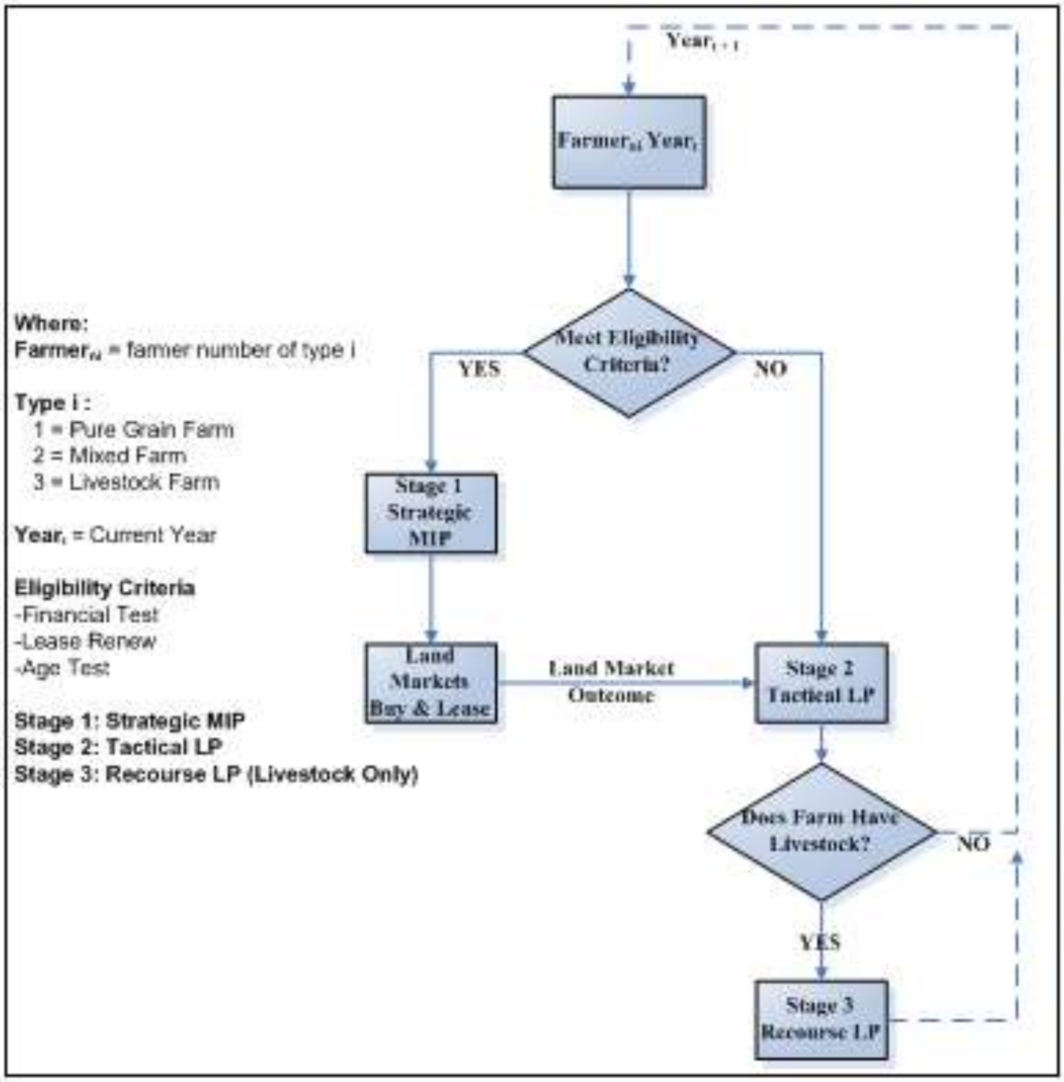

Figure 3.1 An Overview of the Farmer Agent Decision Making Process

3.2.1 First-Stage – The Strategic MIP

In the first-stage of decision making, a Mixed Integer Programming (MIP) model is used to make long-run strategic decisions that generate potential 1) sunk costs and 2) re-conversion costs. Long-run strategic decisions include 1) perennial crops, 2) machinery investment, 3) herd size and land acquisition. Perennial forage crops generate sunk costs in the form of land breaking and establishment costs that cannot be recovered. These crops may have an expected stand life of 7 years or longer but the conversion costs back to forage crops is similar to re-establishing the stand. In the case of woody plants, the plantation life has a much longer time horizon, where a typical rotation can be over 20 years and conversion of land use back to forage crops is quite high[10]. Errors in machinery sizing may require premature replacement to an appropriate size incurring a cost penalty. Errors in farm sizing can incur cost even more severe penalties as land sold may incur distress pricing.

Following Schoney (2010), the long-run strategic investment decision is the following:

$$\max_{I_0} NPV = -I_0 + B_0 + \sum_{t=1}^{n} \left[\frac{NOI_t - Taxes_t - P_t - FL_t - Rent_t - R_t}{(1+d)^t} \right] + \frac{V_n}{(1+d)^n} \tag{3.1}$$

Where: d_t is the real, after-tax, nominal opportunity cost of capital
n is the planning horizon
I_o is the investment capital outlays
(Land and machine are integer variables)
B_o is the amount externally financed (borrowed)
NOI_t is the net operating income from farming activities
P_t is the principal payment on borrowed capital
FL_t is the annual family living expenses
$Rent_t$ is the total land rent of the farm
R_t is the net machine replacement of existing machine, purchases less sales
V_n is the ending value of all assets

Note that I_o is the primary strategic decision variable and includes the amount of capital invested in land, machine and beef cows. It might also include start-up costs such as energy crops establishment and operating capital reserves.

3.2.1.1 An Overview of the Strategic MIP Model

While the above equation gives a general guideline to optimal investment, it is not very useful in actual application because of asset lumpiness, cash flow constraints and borrowing limits and the uncertainty of actually obtaining new land or retaining existing leased land. The primary purpose of the Stage 1 Strategic MIP Model is to determine farm and herd size and their associated lumpy investment requirements. The above equation is modified to maximize the annual equivalent (or annualized) from the various production and investment activities but some terms

[10] In this model once woody plants are sowed they remain in that use until the end of their life-cycle.

as taxes and family living are shifted outside the planning problem for tractability. These are subsequently included in actual farm cash flows. In order to give an overview of the MIP model, a stylized matrix is defined by omitting crop type, land quality and machinery technology and size; the full matrix is reviewed in Appendix A with an example spreadsheet.

The lumpy nature of machinery creates a machinery sizing problem that must be solved simultaneously in the first-stage decision Strategic MIP, Z^1, with long-run crop land use decisions.[11] Using an integer programming method to solve the machinery and annual crop land problem is important for several reasons: 1) equipment ownership costs make up a large portion of total farm investment, meaning that correct machine sizing is critical to the overall farm success and is an important tool in achieving cost efficiency, and 2) producers attempt to expand the size of their farm in an attempt to achieve economies of scale and size. The herd size is optimized subject to available natural pasture and improved pasture limits of the farm enterprise.

Stage-one optimization, Z^1, occurs for each individual producer, each spring, when they make their long-run, forecasts. Land use decision variables include acreage (X) in annual, forage, crops and energy crops. Additional decision variables include plot land (Q=integer) rented in or out; acres of machine operation (X_j^{Jm}), and ownership (M=integer)); forage feeds sold or purchased (T), herd numbers (L) and changes in herd size (ΔL), amount of feed fed (Fd), herd facility capital requirements (K=integer) and borrowing (B).

Annualized costs include gross margins or costs, C, land rents (R), variable machine operating costs (V), annualized machine ownership costs (F^J), herd gross margins exclusive of feed costs (C^L), and but including expansion / contraction costs ($C^{\Delta L}$), net forage sales/returns (D), costs of feeding (C^{Fd}), annualized costs of new herd facilities (F^L) and the real cost of capital (r).

[11] Lumpiness is a term used to refer to the fact that economic indivisibilities do occur and the economic indivisibilities are largely due to the need to achieve machinery large enough to give economies of scale (Batterham and Fraser 1995).

$$\max_{X,T,L,B,Fd;integer:Q,M,K} Z^1 = CX - RQ - VX_j^{Jm} - F^J M + C^L L + C^{\Delta L}\Delta L + DT - C^{Fd}Fd - F^L K - rB \quad (3.2)$$

The MIP has nine basic constraints: equations (3.3) through (3.11). Equation (3.3) the first constraint, where the total acres farmed (X) must be less than or equal to the total of all rented and owned land (Q^+).

$$X - Q^+ \leq Owned \quad (3.3)$$

All annual crops (J) require an acre of machinery capacity, (X_j^J) which can be met by a machinery set, *m*, (X_j^{Jm}) (eq 3.4) which incurs an operating cost, V. However, the operation of *m*, is limited by the associated package acreage capacity, β^m times the number of packages (X_j^{Jm}) and is displayed in equation 3.5.

$$\sum_{j=1}^{n} (X_j^J - X_j^{Jm}) \leq 0 \quad (3.4)$$

$$\sum_{j=1}^{n} (X_j^{Jm} - \beta^m M_j^{Jm}) \leq 0 \quad (3.5)$$

The feeding transfer constraint in equation (3.6) is represented by (-T), the amount of tonnes either produced or purchased while (Fd) is the amount of tonnes fed to livestock. The feed ration requirements for livestock, equation (3.7) are based on the mega calories available from feed (-*McalFD*) and must be greater than the mega calories required (*Mcal*(L)) to maintain the beef herd.

$$-T + Fd \leq 0 \quad (3.6)$$

$$-McalFd + Mcal(\Delta L + L) \leq 0 \quad (3.7)$$

Equation (3.8) is the livestock herd constraint. L, represents non-feed, herd operating costs of the beginning herd size. Changes (Δ) in livestock herd size are generated by expansion (Δ+) or contraction (Δ-). Expansion (Δ+) that has an associated acquisition cost that is greater than contraction (Δ-) revenues associated with culled animals (Δ-). Note that Δ+ also includes an operation cost. The combination of the three must be less than or equal to the current herd size (cows).

$$L - \Delta L^+ + \Delta L^- \leq Cows \quad (3.8)$$

The beef cow herd facility capital requirement constraint (equation 3.9) is similar to the annual crop machinery capacity constraint in equation 3.5 except that instead of capacity in acres the capacity is beef cows. An additional labourer, machinery and handling system are required per 300 cows represented by ∂. The initial facility endowment, (F) is set at 300 cows.

$$-\partial K^{L} + (\Delta L + L) \leq F \qquad (3.9)$$

Each of the activities has an associated cash inflow / outflow (CF) that may be different from the annualized economic costs in the objective criterion. For example, investment variables generate cash flow requirements associated with the investment decision and divestment decisions such as herd downsizing generate cash inflows. Cash outflows in excess of available cash must be financed with borrowing activities (B) equation (3.10).

$$CF - B \leq cash \qquad (3.10)$$

The ninth constraint, equation (3.11) is the debt to asset ratio constraint. The critical debt to asset ratio is represented by (δ); this is often the most binding constraint as additional land animals, labour and machinery can be purchased. Major investment cash outflows include I, the initial investment in energy crops, R is farmland, F^{J} is the cost of machines and M_m^J is the number of machine units (integer) associated with annual cropping, F^{L} is the fixed costs of the beef cow machinery, handling and labour package while K^{L} is the number of units (integer) of beef cow machinery, handling and labour package.

$$\delta\left(I + R + \left(F_m^J M_m^J\right) + L + F^L K^L\right) + B \leq Equity \qquad (3.11)$$

3.2.1.2 Responses to Farmland Sizing--Land Auction Success or Failure

After the stage one optimization is completed, producers enter the farmland purchase and rental market. Land markets are outlined in a later section. After the farmland market has finished and the degree of producer success in purchasing land is reassessed. If the producer investor succeeds in buying some or all of the planned land acquisition, the corresponding machinery is purchased and herd is expanded (beef cow farms) according to the stage-two planning model.

However, if the producer investor is not successful or partially successful, then the farm enters the re-optimized MIP of stage-one that excludes land expansion to optimize the farm to its newly obtained land or reverts back to its previous plan.

3.2.2 Second-Stage (Tactical LP)

The second-stage decision, Z^2 is a tactical decision process in the sense that it follows the strategic investment decisions of the farm enterprise by maximizing short-run profits to the annual crop portfolio; no provision is made for expansion and accordingly, there are no integer variables. The tactical LP is optimized according to individual producer expectations of short-run yields and prices[12]. The second stage tactical LP maximizes the short-run profits (equation 3.12) subject to available cropland and agronomic rotations (equation 3.13) and is very similar to the crop portfolio structure of Z^1.

$$\max_X Z^2 = CX_j^{Jm} \tag{3.12}$$

$$X_j^{Jm} \leq total\ cropland \tag{3.13}$$

The second stage tactical LP is a 10 x 8 Tableau for conventional tillage agents while no-till farm agents have an 11 x 7 Tableau. An example of the no-till tableau is displayed in Appendix A in Table A.2. It is assumed that annual crop rotations have upper and lower limits for pulses, cereals and oilseeds. Annual crop limits vary by both conventional and no-till farms due to the different technologies being employed (Refer to Appendix A for specific rotational constraints).

3.2.3 Third Stage (Recourse LP)

The third stage, Z^3, problem is a linear programming maximization problem of managing feed stock inventories to meet herd nutrient requirements. This stage is called a recourse stage as decisions are made based on now revealed or actual stochastic yields and stochastic prices and decisions are based on reaction to the revealed events. Feed rations are balanced to minimize feeding costs subject to the opportunity cost of the feeds at hand and the cost of buying more and possibly different feeds. Adverse weather events may result in poor pasture and hay yields, with

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[12] Due to heterogeneity of farmland rarely does a farmer obtain the exact proportion of farmland they desired. Thus, following land markets re-optimization in the tactical is a necessary step to re-evaluate the most profitable farm mix.

correspondingly higher purchase prices may have a dramatic impact on overall farm profitability and cash flows. The recourse LP module minimizes feeding costs by feeding the lower valued feeds that were either produced or bought and sells the higher valued feeds in the market place allowing producers to maximize their returns. For, example if a farmer's enterprise consists of a mixed annual crop, perennial crops and cow/calf operation, and is experiencing a low yield for hay and feed barley has a low price, the recourse LP has the potential to buy and feed barley and sell the hay to other local beef cow farmers. The Stage Three LP problem is displayed as (Equation 3.14).

$$\max_{t,Fd} z^3 = DT - C^{Fd}Fd \tag{3.14}$$

Subject To:

$$-T + Fd \leq 0 \tag{3.15}$$

$$-McalFd \leq Mcal(\Delta L + L) \tag{3.16}$$

The maximization problem is subject to the feeding transfer constraint displayed in equation (3.15). This constraint is represented by (-T) the amount of tonnes either produced or purchased while (Fd) is the amount of feed fed to livestock in tonnes. Equation 3.16 is the constraint that requires that the feed requirements be met. This constraint is based on the mega calories fed (-*McalFD*) and must be greater than the mega calories required (*Mcal*(L)) by the long-run herd size.

3.2.4 Farmer Agent Business Accounts

At the end of the year, actual production is calculated and each farmer agent calculates their total gross income and total expenses, including debt repayments for the year for all enterprises of the farm. This section presents the year-end structural accounting equations and other business related activities of the farmer agent. The following diagram (Figure 3.2) shows how the three stages and all the business related accounts interact in the model.

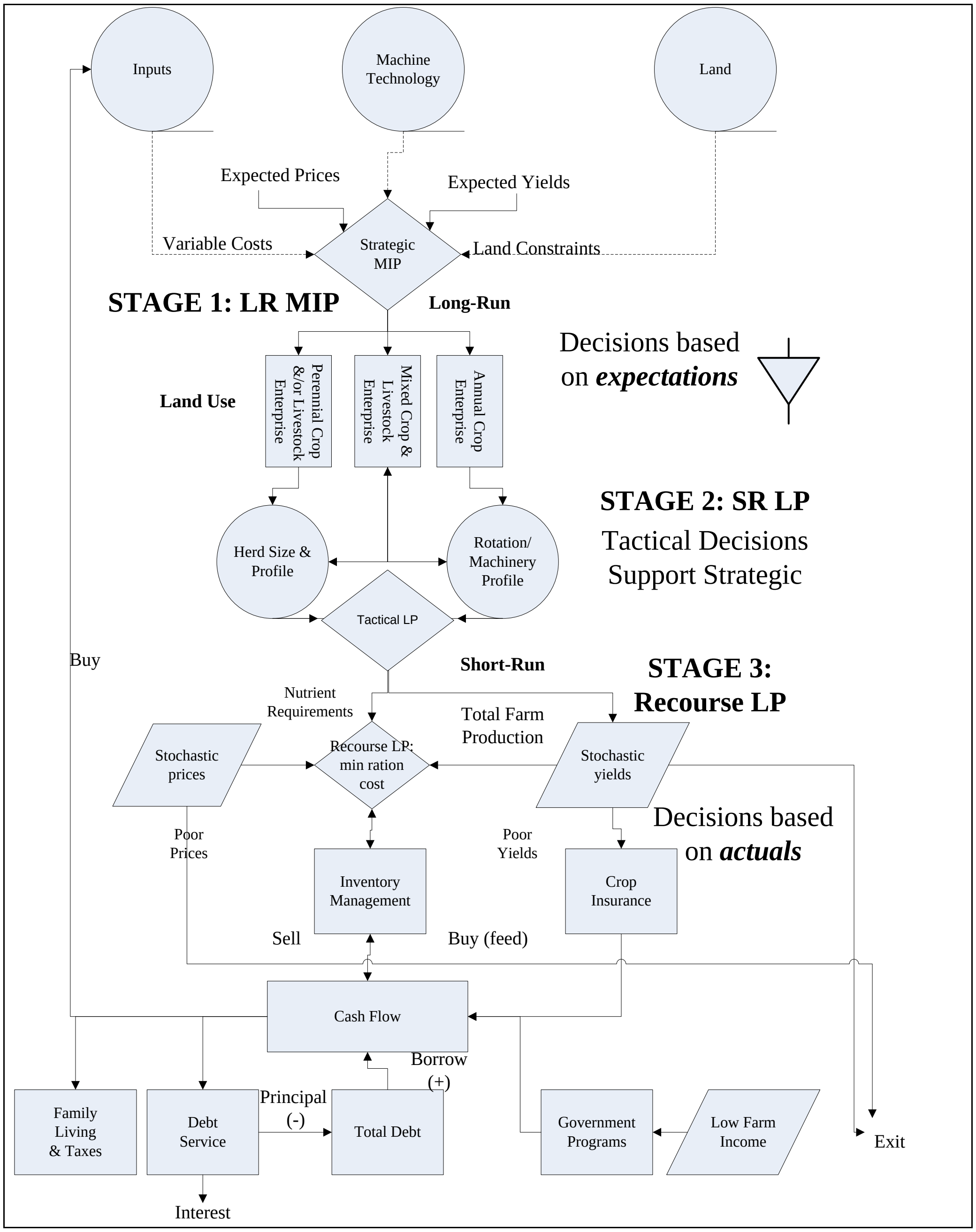


Figure 3.2 MIP Decision Stages and Business Accounts

In the following section, subscripts are used to denote activity or enterprises use or affiliation.

3.2.4.1 Gross Farm Accounting Income

Total gross farm income includes gross income from sales of annual crops (GI_{AC}), calves and cull cows GI_{LS}, hay sales (GI_H), energy crops (GI_{EC}) and stabilization programs (GP_{IS}).

$$TGI = GI_{AC} + GI_{LS} + GI_H + GI_{EC} + GP_{IS} \quad (3.17)$$

Gross income generated from annual crop production is calculated using the stochastic yield (bu/acre) and stochastic prices ($/bu) for each annual crop sowed based on total harvested acres. This becomes:

$$GI_{AC} = Y_{Cj} * P_{Cj} * Acres_{Cj} \tag{3.18}$$

Where: Y_{cj} is actual yield per acre of crop j
P_{cj} is current price of crop j
$Acres_{cj}$ is acres of crop *j*

The gross income generated from beef cows comes from the annual sale of the calf crop and any cull cows sold off and replaced during the year. However the gross income is based on an average weight per calf of 495 pounds[13]. This is then multiplied by the current market price per calf multiplied by the size of the herd. For pure annual crop farms that produce hay, their income from performing this activity is calculated here.

$$GI_{LS} = 495lbs * P_{calf} * Herd_{size} \tag{3.19}$$

$$GI_{H} = T_{hi} * P_{th} \tag{3.20}$$

Where: *495lbs* is weighted average of beef cows sold in pounds[14]
P_{calf} is average price of beef cows sold
$Herd_{Size}$ is total herd size of the farmer
T_{hi} is total tonnes of hay (improved baled or hayland baled)
P_{th} is the current price per tonne based on the local forage market

Not all energy crops produce the same yearly return as their return varies across their life-cycle. However, if it is a harvest year, gross income is calculated in the same manner as annual crop production.

$$GI_{EC} = Y_{ec_i} * P_{ec_i} * Acres_{eci} \tag{3.21}$$

Where: Y_{eci} is total yield of energy biomass crop i in oven-dried tonnes
P_{eci} is price per oven-dried tonne of biomass crop i
$Acres_{eci}$ is the total acres of energy crop i harvested this year

[13] The Western Beef Development Center estimated average weaning weights of 523 and 565 pounds in 2003 and 2006 respectively for an average of 550 pounds per calf. Saskatchewan Agriculture and Food (1999) estimate a 10% death loss bringing the average calf weight to 495 pounds.
[14] Ibid.

3.2.4.2 Total Farm Accounting Expenses

Total farm expenses include all the farm operations including annual cropping, beef cows and energy crop enterprises as well as interest payments and hired custom work[15]. Fixed costs related to each farm enterprise include the debt payment portion of the fixed cost as well as the allowable depreciation expense.

$$TFE = AC_e + L_e + EC_e + Depr_{FA} + D_p + C_w \qquad (3.22)$$

Where: *TFE* is total farm expenses
AC_e is total annual cropping expenses
L_e is total beef cow expenses
EC_e is total energy crop expenses
$Depr_{FA}$ is related depreciation expense on all depreciable farm assets
D_p is interest on debt
C_w is total expense of custom work hired out

The total expenses related to annual cropping include variable costs per acre, operating variable costs per acre of machinery, variable cost per tonne to account for miscellaneous costs including transportation and freight charges of each crop as well as the lease rate per acre of any rented cropland. The annual cropping expenses become:

$$AC_e = VC_{cj} * Acres_{cj} + VC_{mj} * Acres_{mj} + T_{cj} * VC_{t_{cj}} + Acres_l * r_l \qquad (3.23)$$

Where: VC_{cj} is the variable cost per acre for annual crop j
$Acres_j$ is the total acres sowed of annual crop j
VC_{mj} is the variable cost per acre for machine option j
$Acres_{mj}$ is the total annual crop acres used by machine option j
T_{cj} is the total tonnes of annual crop j produced
VC_{tcj} is the Variable Cost per tonne of annual crop j
$Acres_l$ is the total annual crop acres leased
r_l is the lease rate of cropland rented in

Beef cow expenses include all expenses related to beef cow and forage production related activities. However, this excludes the cost of breaking land for forage production.

$$L_e = VC_{pi} * Ac_{Pi} + VC_{bi} * Ac_{hi} + n_c * VC_{cow} + n_{cl} * FC_l + Ac_l * r_l + T_{hi} * P_{th} + T_{hi} * VC_t \qquad (3.24)$$

Where: VC_{pi} is the variable cost per acre associated with pasture type i
Ac_{pi} is the total acres of pasture i

[15] The other component of debt service, principal payment is a cash outflow however.

VC_{bi} is the baling variable cost per acre of pasture type i
Ac_{hi} is the total acres of hay production from pasture i
n_c is the total herd size
VC_{cow} is the variable cost per cow
n_{cl} is the number of full-time cow labourers required
FC_{cl} is the fixed cost per full-time cow labourer of $9,000
Ac_l is the total annual crop acres leased
r_l is the lease rate of cropland rented in
T_{hi} is total tonnes of hay (improved baled or hayland baled)
P_{th} is the current price per tonne based on the local forage market
VC_t is the variable cost per tonne of hay

3.2.4.3 Government Programs

An essential component of analyzing structural change in agriculture and the competitiveness of new farm enterprises with existing ones are the government programs available to farmers. Government programs or farm safety nets are triggered when farm agents suffer from low farm income and poor yields. The government programs used in this model follow the basic rules of *Crop insurance*, *AgriStability* and *AgriInvest* but have been simplified for ease of modelling. The *crop insurance, AgriStability and AgriInvest* sections of this thesis have been adopted from additions Stolniuk (2008) made to his NetLogo© model entitled "*Model Additions After Thesis*" (2008b). Government programs influence farmers' expectations and their ability to compete in the market place. This section outlines the various government programs used in the simulation.

3.2.4.4 *Crop Insurance*

Poor yields will trigger *crop insurance* payouts to farm agents with *crop insurance* coverage[16]. A farmer's total *crop insurance* premium is included in their variable expenses for each particular annual crop depending on coverage level. These premiums are based upon reference values from each individual farmer agent's level of coverage and historical yields from previous years (Stolniuk 2008b). *Crop insurance* payouts are also based on each producer's level of coverage. The farmer agent's expected yield is based upon the weighted average of their own previous five year crop data. The level of coverage for each farm is assigned randomly according to the following generated by Stolniuk (2008b) 1) 4.4% of farmers having no coverage, 2) 13.6% of farmers having 60%, 3) 34.1% of farmers having 70%, and 4) the

[16] *Crop insurance* refers to the Saskatchewan Crop Insurance Corporation program.

remaining 47.9% of farmers having 80% coverage. For modelling simplicity this level of coverage is set at initialization and thus remains constant during the entire simulation period.

Each farm agent calculates their total premium paid according to the total liability encountered by *crop insurance* for each crop. Total liability is the expected insurance crop yield, historical yield index, insurance coverage level of the farmer, and the current market price of the commodity. Total liability is on a per acre basis for each crop.

$$TL_j = IY_j * QI_j * P_j * IC \tag{3.25}$$

Where: TL_j is the total liability for crop j on the plot
IY_j is the insurance expected yield for crop j
QI_j is the yield index for crop j on the plot
P_j is the current market price of crop j
IC is the insurance coverage of the farmer currently farming the plot

The total premium per acre is then the total liability multiplied by the premium calculated for that specific crop based on the level of coverage of the farmer. Following Stolniuk (2008b), the premium for each crop and coverage level is calculated using historic price and yield data specific to the CAR and calculating the premiums that will result in the long-run goal for *crop insurance* of breaking even, assuming that premiums are 40% paid by the producer and 60% paid by government[17] (SCIC 2012).

$$TP^{Plot} = \sum_{j=1}^{7} TL_j PR_j \tag{3.26}$$

Where: TP^{Plot} is the total premium of the plot
PR_j is the premium for crop j based on the coverage level of the current farmer

The total premium paid by the farmer agent is then the sum of all crop acres in their control (Stolniuk 2008b). The total *crop insurance* payout is again calculated for each individual plot and then the farmer sums all the plots in their control. To calculate if a farmer agent is eligible for a crop insurance payout, the farmer agent determines the total insured production for the plot of each commodity.

$$IS_j = IY_j * IC * QI_j \tag{3.27}$$

[17] In 2006, under the Agriculture Policy Framework crop insurance premiums moved to a single tier cost share agreement 40% paid by producers and 60% paid by the government (SCIC 2007). Although this cost share agreement may change in the future the cost share agreement was still in place as outlined in the 2012 General Information on Crop Insurance (SCIC 2012).

Where: IS_j is the insured production of crop j for the plot

Once the actual yield is known, the actual yield is subtracted from the insured yield, multiplied by the current market price as well as total crop acres of that crop. If the payout is negative, no payment is made. However, if the calculation is positive, a payment is triggered and the farmer will receive a payout from *crop insurance*.

$$CIP_{Cj} = \sum_{j=1}^{7} (IS_j - AP_j) * P_j * Acres_{Cj} \qquad (3.28)$$

Where: CIP_{cj} is the total *crop insurance* payment for crop j on the plot
AP_j is the actual production of the crop on the plot

3.2.4.5 *AgriStability*

Farmers that experience large income declines can participate in *AgriStability* a margin-based program. The program is based on the whole farms' income margin and compared with the average historical margin of the farm. However to simplify and to allow for structural changes in this simulation the margin is calculated by comparing it on a per unit production basis. In the case of annual crops, the margin is calculated on a per acre basis and for beef cow farms it is calculated per head of cattle, while hay is also on a per acre basis. An Olympic average is used to calculate a farmer agent's margin by using the last 5 years discarding the highest and lowest values, using the three remaining values as the producer's average margin. Following the per unit reference margin calculation instructions from above; a farms total reference margin for the year is:

$$RM = TCA * RC + NC * RL + THA * RH \qquad (3.29)$$

Where: *RM* is the total farm reference margin
TCA is the total crop acres of the farm
RC is the reference margin for a crop acre
NC is the total number of cows
RL is the reference margin per cow
THA is the total hay acres of the farmer
RH is the reference margin for a hay acre (Grain farms only)

AgriStability's farmer agent's costs include a $55 administration fee plus $4.50 for every $1,000 of reference margin coverage with a minimum of $45. The program calculation then calculates actual income following allowable farm income and expenses. For the crop enterprise the net income is:

$$NCI = TCI - HL - VC_i - CI_{pr} + CI_{po} + \Delta AC_{in} \tag{3.30}$$

Where: *NCI* is the net annual crop income of all crops
TCI is the total crop income
HL is the full-time hired labour for the crop enterprise
VC is the variable cost for annual crop production
CI_{pr} is the total *crop insurance* premium paid for the farmer
CI_{pa} is the *crop insurance* payouts to the farmer
ΔAC_{in} is the change in value of crop inventories

The actual beef cow income is:

$$NLI = LI - VC_{cow} - HL_{cow} - H_P + H_I + \Delta H_{in} - VC_{pe} \tag{3.31}$$

Where: *NLI* is the net beef cow income
LI is the total beef cow income from sales
VC_{cow} is the variable cost for cow production
HL_{cow} is the hired full time labour for calving
H_I is the hay income from hay sales
H_P is the cost of hay purchases
ΔH_{in} is the value of changes in hay inventory
VC_{pe} is the cost to establish/seed new land to pasture or hay

The total actual farm income is then[18]:

$$TFI = NACI + NLI \tag{3.32}$$

Where: *TFI* is the total farm income for the year

An *AgriStability* payment is triggered when total farm income falls lower than 85% of the total farms reference margin. The program is designed to pay 70% of the total decline below 85% of the reference margin. However, payments have a maximum of $3 million that can be received by any farmer. Accordingly the payment is:

$$AgStab = 0.7(0.85 * RM - TFI) \tag{3.33}$$

To set the list of reference margins for the last year the total actual income is divided by the unit of output. The reference margin for each of the previous 5 years is calculated as follows:

$$RM_{ac_{t-i}} = \frac{TACI}{Acres_{ac}} \tag{3.34}$$

[18] To simplify the model energy crop income is not included in government programs because harvesting is not done annually and thus may trigger payouts during not harvest years.

$$RM_{l_{t-i}} = \frac{TLI}{n_c} \tag{3.35}$$

$$RM_{h_{t-i}} = \frac{THI}{Acres_h} \tag{3.36}$$

Each year, the five-year reference margin is updated by removing the oldest year and adding on the preceding year's margin (AAFC 2008).

3.2.4.6 *AgriInvest*

This program provides flexible coverage as it is designed to cover small declines in margins (Stolniuk 2008b). Farmers can make a deposit up to 1.5% of their allowable net sales into their *AgriInvest* account where it is then matched by the government. The *AgriInvest* account is divided into two separate funds. Fund one is made up of the farmer contributions; while fund two is made up of the matched contribution from the government plus interest from fund one and from fund two. Total eligible net sales are equal to the total annual gross income of the farmer agent from crop production, beef cow production, and hay sales less hay purchases. The maximum allowable net sales are $1.5 million, which will result in the maximum amount that the government will match. The total balance of both *AgriInvest* fund one and fund two have a maximum level balance and this is set at 25% of the average of the previous two years allowable net sales. If farmers have sufficient cash flow they will contribute into their *AgriInvest* account to receive the matching funds from the government. However, if they do not have positive cash flow, no contribution is made and they do not receive the matching contribution on the government's part. Farmers will contribute until their total balance reaches the maximum. If their account exceeds the maximum balance farmers are required to withdraw an equivalent amount to bring their balance to the maximum level.

Farmers are allowed to withdrawal this money from their *AgriInvest* account whenever they feel they need the cash. However, for model simplicity, withdrawals are made when the total farm reference margin is less than 90% or when a farmer agent's cash flow becomes negative. Rules following withdrawal from *AgriInvest* accounts are as follows, requested withdrawal amounts are first paid out to farmers from fund two and are taxed as income when they are withdrawn. Once fund two has been depleted, farmer's withdrawals are then accessed from their fund one

AgriInvest account. The withdrawals from fund one are not taxable as it only contains farmer's personal contributions (AAFC 2008).

AgriRecovery is another business risk management government program that allows the federal and the provincial government to respond to natural disasters in a speedy time frame allowing farmers to mitigate any natural disaster results to an individual producer as fast as possible. However, this is a case by case basis and governments will determine the level of coverage required according to each natural disaster. This makes it complicated to predict what compensation is required when a natural disaster strikes. Thus, *AgriRecovery* has not been incorporated into this model.

3.2.4.7 Net Cash Flows

Monitoring cash flows in farming are important because the industry is extremely capital intensive. Therefore it is essential that farmers maintain positive cash flows including enough to cover income taxes and the minimum family living withdrawal. Net cash flow is calculated as:

$$CashFlow = Cash + NFI + OFI - Income_{taxes} - Family_{Living} \tag{3.37}$$

Where: *OFI* is off-farm employment income of the farm family
$Income_{Taxes}$ is the amount of income taxes paid
$Family_{Living}$ is the family living withdrawal

3.2.4.8 Income Taxes

After the total farm expenses are deducted from total gross income of the farm, the net income of each farmer is known and is added to the farmers cash account. Income taxes are calculated on the net farm income amount. For model simplicity the income tax rate is set at a constant 20%.[19] Income taxes paid are deducted from each farmer's cash account. Thus, the income tax calculation is as follows:

$$Tax_{Income} = NFI * Tax_{rate} \tag{3.38}$$

Where: Tax_{Income} is the amount of income tax paid from farmer i
NFI is the net farm income of the farmer

[19] The income tax rate is based upon a weighted average of the small business tax corporate rate for Saskatchewan of 4.5 % and the regular rate of 12 % (SMF 2007) and the 2008 federal small business corporate tax rate of 11 % and regular rates of 15 - 19.5 % which will be implemented between 2008 – 2012 (CRA 2010) thus a simplified 20 % rate is used.

Tax_{Rate} is the total income tax rate

After income taxes have been deducted off-farm employment income is added to the cash account. Off-farm income does not have income tax deducted from it since it is assumed income taxes are deducted by the non-farm employer. Employment off the farm is based on a probability factor and is set at model initialization. Smaller farms have a higher probability for off-farm income than larger farms. Family living is then subtracted from the remaining cash flow.

3.2.4.9 Non-Land Asset Valuation

Capital farm assets including annual cropping machinery, beef cow machinery and beef cow handling systems are depreciated following the same method used by Stolniuk (2008). This depreciation method allows the remaining capital value to be depreciated at a constant rate, with the exception of 50% of the capital value following the first year rule. Based on Schoney (1980) the estimated parameter of 0.948 uses a larger depreciable amount in the first year assuming new machinery. According to the following formula the current market value is:

$$V_n = V_0 * 0.948 * 0.901^n \qquad (3.39)$$

Where: V_n is the capital asset value at n years
V_0 is the new capital asset value
n is years of the capital asset value

3.2.4.10 Family Living Withdrawals

There is a minimum family living expense that must be deducted from cash each year to cover basic family living requirements of the farm family. However, following Stolniuk (2008) farm families also have an increasing propensity to consume. The farmers increasing propensity to consume a portion of the profits is built into the simulation as well. Therefore the living expense deducted is the larger value of either the minimum family withdrawal amount or the propensity to consume. However, propensity to consume farm profits eventually diminishes and an upper bound is placed on family living withdrawal. The remainder of farm profits is reinvested back into the farm. The family living expense is as follows:

$$Family_{Living} = Max(Fam_{min}, \delta NFI) \qquad (3.40)$$

Where: Fam_{min} is the minimum family living withdrawal
δ is the propensity to consume farm profits
NFI is the net farm income or retained earnings before new investments

3.2.4.11 Balance Sheet

As in any business entity balance sheets must be updated and maintained to track changes in owners net worth and liabilities of the farm. The balance sheet in this model includes changes in asset values such as land value, inventory value of cows, capital, cash flows as well as the farmer's remaining debt. Total farmer's equity is calculated as follows:

$$Farm\ Net\ Worth = \sum_{t=1}^{n} Assets - \sum_{t=1}^{n} Debt \tag{3.41}$$

The land value of each farmer is calculated using the current market price of land times the average land quality divided by the average productivity rating multiplied by total acres owned. Capital value includes the annual crop machinery options and the beef cow equipment and handling system of each farmer. Capital values are updated yearly to reflect new purchases, sales of old capital as well as the loss in depreciation. Total beef cow value is calculated as the herd size times the price of a cow multiplied by an average cow weight of 1300 lbs. These assets are then calculated as follows.

Where:

$$\sum_{t=1}^{n} Assets = Land_{Value} + Capital_{eq} + Cash + Cow_{Value} \tag{3.42}$$

Where:

$$Land_{Value} = \frac{P_L * Avg_{Land}}{Avg_{Prod} * Acres_{owned}} \tag{3.43}$$

$$Capital_{eq} = Machine_{ac} + Livestock_{eq_{Value}} \tag{3.44}$$

$$Cow_{Value} = n_{cows} * P_{cow} * 1300lbs \tag{3.45}$$

Total debt of each farm agent is updated each period to reflect new debt taken on during the course of the year as well as any old debt that has been reduced through principal payments. Updated debt is calculated as the following:

$$\sum_{t=1}^{n} Debt = Debt_{old} + Debt_{new} - Principal_{pay} \qquad (3.46)$$

Where: $Debt_{Old}$ is any previously held debt
$Debt_{New}$ is any newly obtained debt
$Principal_{Pay}$ is principal payment made on old debt

3.2.5 Farmer Agent Land Bid Value Formulation

All farm agents are screened prior to entering the strategic MIP by age, debt load and minimum cash flow, all farmers with results from the MIP with requirement of land expansion must pass the financial bid screen prior to entering the purchase market. If they cannot enter the purchase market, these farmers proceed to the land rental market. Farmers that do meet the financial bid screen will first enter the purchase market where they try to submit bids high enough to obtain the parcel of land while sufficient cash flows projected are maintained. The bids submitted are an effort to gain enough land used in crop production to get to the next efficient point for their machinery package. The maximum bid a farmer can make is their calculated financial bid. The financial bid equation is:

$$Bid_{Fin} = Min(Bid_{cash,} Bid_{d/a}) \qquad (3.47)$$

Where: Bid_{Fin} is the financial bid
Bid_{Cash} is the bid based on available cash
$Bid_{D/A}$ is the maximum bid to maintain sufficient debt to asset ratio

Available cash represents the cash flow needed to maintain a positive cash balance for the expansion phase. The definition of total available cash is based on Stolniuk (2008) and includes the following requirements, minimum cash per acre and per cow for all farm enterprises, and down payments for new capital investments. The available cash formula is:

$$Cash_{Avail} = Cash - min_{cash} - min_{cow} - min_{fam} - \propto (Cap_{Value}) - Cash_{res} \qquad (3.48)$$

Where: Min_{cash} is the minimum cash per acre for each farm enterprise
Min_{cow} is the minimum cash per cow required
Min_{fam} is the minimum family withdrawal expense
α is the down payment percent required on new borrowing
Cap_{Value} is the new land asset value
$Cash_{Res}$ is the cash reserves required of the farm

The maximum debt-to-asset ratio bid is calculated as follows:

$$Bid_{d/a} = \frac{\gamma*(Assets_{new} + Land_{Value}) - Debt_{new}}{\gamma*(\alpha+(1-\alpha))} \qquad (3.49)$$

Where: γ is the maximum debt-to-asset ratio allowed
α is the down-payment
$Assets_{new}$ is the new assets required (plus old assets)
$Land_{Value}$ is the market value of the land being bid on
$Debt_{new}$ is the new debt (plus old debt) of the new assets being financed

These purchase bids are income based and are the net present value of the certainty equivalent of future income earning ability (R_t^{XY}) and ending land value (EV_n) using r, the risk-free rate.

$$Buy\ Bid_{income}^{xy} = \sum_{t=1}^{n}\left(\frac{E[CE(R_t^{XY})]}{(1+r)^t} + \frac{E[CE(EV)]}{(1+r)^n}\right. \qquad (3.50)$$

Where: r is the risk-free discount rate

Expected income comes from the objective function from the MIP solution. This is calculated by using the annual contribution margins less variable and fixed costs for machinery and labour variable costs as well as costs associated with additional land acquisitions less expected income taxes and family living. If the $Income_{bid}$ is larger than the $financial_{bid}$, the highest bid submitted into the auction becomes the $financial_{bid}$.

3.3 Farm Business Exit and Farm Business Succession

As discussed in Chapter Two, farmers go through a life-cycle where they eventually come to the end of their farming career and either exit the industry or pass the farm on to an heir. However, farm exits not only occur because of retirement but also because of inadequate cash flows. Farms exiting due to cash flow issues are either forced exits (bankruptcy) or voluntary exits from eroding farm net worth. For modeling simplicity, farmers that experience cash flow deficits more than five years in a row have an increasing probability of voluntarily exiting the industry. Following the rules of Stolniuk (2008) the model uses the calculation below on when farmers exit the industry:

$$TFL \geq TFA * 0.9\ (Bankruptcy)^{20} \quad (3.52)$$

Where: *TFL* is total farm liabilities (debt) of the farmer
TFA is total farm assets of the farmer

$$NCF \leq 0 \quad (3.53)$$

$$Rand_{prob} < Pre_{prob} \quad (3.54)$$

Where:

NCF is net cash flow of the farmer
$Rand_{Prob}$ is the probability generated randomly
Pre_{Prob} is the pre-determined probability[21]

Once farmers reach the age of 55 years old they have an increasing probability that they will retire based on their current age. Retirement tendency probability is increased in five year increments.

$$Age \geq LB_{age}\ and\ Age < UB_{age} \quad (3.55)$$

$$Retire_{prob} < Pre_{prob} \quad (3.56)$$

Where: *Age* is the current age of the farmer
LB_{age} is the lower bound age in that increment
UB_{age} is the upper bound age in that increment
$Retire_{Prob}$ is the probability generated randomly
Pre_{Prob} is the pre-determined probability for that age increment[22]

If a farmer agent does retire they then go through another series of calculations to determine the likelihood of farm transfer to an heir. Minimum financial requirements are required for both retiring farmer and new farm entrant for generational transfer to take place. The retiring farmer must first have the minimum equity amount. This amount as used by Stolniuk (2008) is set at $500,000 per farmer. If the retiring farmer has excess equity a portion of the remaining equity is first paid to debt, then a portion will be transferred to the new farmer. The transfer value then becomes:

$$Trans_{Value} = \propto (Equity - Min_{retire}) \quad (3.57)$$

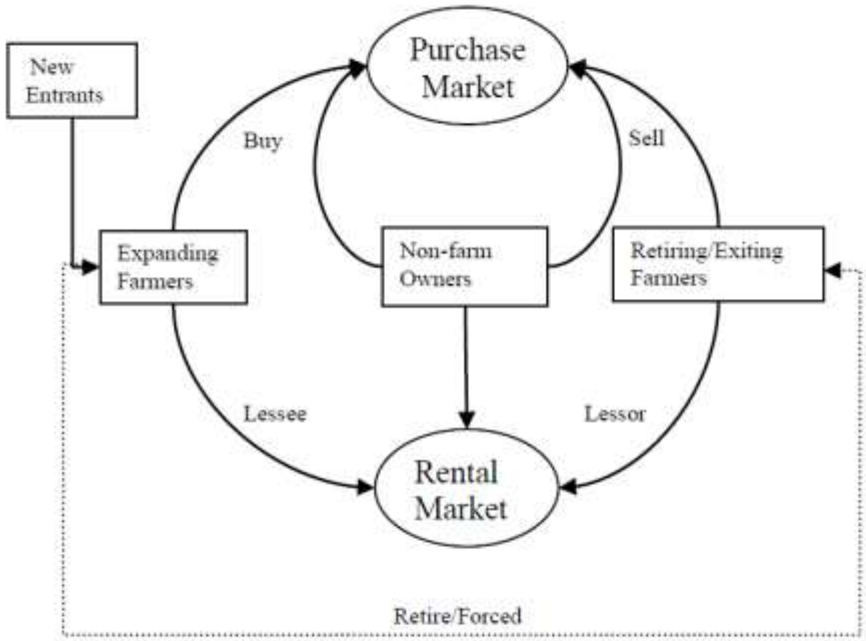
[20] Note: This farm would file for bankruptcy in the above formula.
[21] Each year a farmer experiences negative cash flow the pre-determined probability of exiting increases.
[22] At each age increment the probability of a farmer retiring increases.

Where: $Trans_{Value}$ is the amount of equity transferred to the next generation
α is the share of farm equity transferred
Min_{retire} is the minimum amount needed for retirement by the retiring farmer

In situations where the exiting farmer has less equity than the minimum needed for retirement, the entering farmer is forced to purchase and finance the assets excluding cash from the retiring farmer. If the entering farmer does not meet financial obligations the farm is not transferred.

3.4 Farmland Auctions: Purchases and Leases

An overview of the farmland markets is presented in Figure 3.3. Demand for land comes from farm agents wishing to expand farm size and from non-farm investors. Farmers who can meet cash flow and financial criteria submit land bids for land purchase and lease markets based upon their own price and yield expectations and variable production costs associated and subject to the accounting equations of the Stolniuk (2008) model. Supply of farmland comes from 1) farmers who either exit the industry voluntarily or 2) are forced to exit and 3) from non-farming land investment owners. Forced exits will automatically result in land available on the purchase market, where as a voluntary exit will enter either a purchase or lease market based upon a probability factor. In the auction market, each parcel is auctioned separately and consecutively. In the purchase market, the highest bid value wins if it is greater than the buyer reservation price. Unsold land becomes available for leasing in the secondary leasing market. There are no reservation prices in the leasing market. However, if no leaser is identified the land becomes idle for the period.



Source: Stolniuk (2008)

Figure 3.3 Farmland Markets

After the land auctions and the third stage, individual farmer agent financial statements are updated and information is fedback to farm agents and additional financing may be needed to meet cash flow deficits. If the agent is unable to maintain sufficient cash and their financial position erodes, they may voluntary exit or in extreme cases be forced to exit.

All land sales and leases are conducted through auctions. Building on the Stolniuk (2008) model, land markets are divided into two types: cropland and marginal land auction. It is through the land markets in the ABSM model where the majority of the interaction between the farmer agents occurs (Stolniuk 2008). Farmers first try to acquire their desired plots of land through the purchase market as it is assumed that farmers prefer to own land over renting it. However, farmers must meet all financial obligations to do so. Non-farming investors submit bids in the land purchase market randomly 10% of the time on available plots. Following Stolniuk (2008) 25% of the land that enters the purchase market has an amplified urgency to sell because of various reasons including death, divorce or other circumstances and thus the minimum acceptable selling price is reduced by 65%.

3.4.1 Agent Seller/Renter Minimum Acceptable Bid Formulation

All land for sale enters the auction process with a minimum acceptable selling price. Minimum acceptable prices by the land owners are calculated based on the capitalized expected lease rate. The capitalized lease rate is calculated using the last updated lease rate and the expected change in the lease rate for the coming year based on expectations on all commodities.

$$E(Cap_{Lease}) = L_{r_{t-1}} + \sum_{i=1}^{2} \frac{\left(E(P_{t,i}) - E(P_{t-1,i})\right)}{E(P_{t-1,i})} * L_{r_{t-1}} \quad (3.58)$$

Where: $E(Cap_{Lease})$ is the expected capitalized lease rate
L_{rt-1} is the lease rate from last year
$E(P_{t,i})$ is the expected price of commodity i
$E(P_{t-1,i})$ is the expected price of commodity i last year

The minimum accepted price then becomes:

$$Min_{accept} = \frac{Risk_{Owner} * Cap_{Lease} * (1 - Adm_{Fee})}{r} \quad (3.59)$$

Where: $Risk_{Owner}$ is the risk level of the current owner based on random probability
Cap_{Lease} is the adjusted lease of the capitalized lease rate
Adm_{Fee} is the management fee for the auction process
r is the discount rate

The land rental market is also determined from results of the strategic MIP model. The rental bid value is income based and is calculated from the after-tax expected income less family living divided by the total crop acres multiplied by a risk parameter. This equation is as follows:

$$Rent\ Bid_{income} = \frac{AI}{TCA}\ \alpha \quad (3.60)$$

Where: AI is the After-tax expected Income
TCA is the total crop acres
α is the risk parameter of the farmer

Farmland markets for both beef cows and energy crops are conducted in a similar manner with the exception that the sizing decision is not as critical a component in setting efficient size as it is with annual crop production.

3.4.2 The Auctioneer Agent and the Auction Process

All farmers and investors submit bids to the auctioneer agent. The auctioneer agent collects all farmland for sale and sorts it according to its productivity rating, into either the cropland or marginal land markets and in each subsequent market sells the best quality farmland first. The auctioneer agent then matches the farmland with the highest productivity rating with the highest bid from farmer agents or investor agents. The highest bid submitted is the purchaser of the plot sold if it exceeds the minimum acceptable price. If the bid is a farmer bid, their bid is readjusted to be the average of the minimum acceptable bid and their own bid. The new adjusted bid is created to prevent the winners curse[23]. Farmers that have unsuccessful bids at acquiring additional land in the purchase market or do not meet the financial screening enter the land rental market. The land lease market follows the same process as the purchase market where farmer agents submit lease bids to the auctioneer agent. However, unlike the purchase market the lease market has no reservation price. If the auctioneer agent receives no bids the auctioneer declares the farmland unmanaged and the plot remains idle until the next year's auction process starts the process over again.

3.4.3 Lease Renegotiation

Leases are renegotiated based upon a farmer's age following the same random probability factor farmer agents use to determine retirement probabilities. If the random number generated is greater than the lease renew probability, the leased plot is renewed at that time for a specified period. If the random number generated is less than the renew probability, the farmer agent does not renew the lease and the parcel enters the purchase market. Lease values are readjusted to the prevailing market lease values if they have either increased or decreased by 20% since the last adjustment to the lease to reflect current market conditions.

3.5 Changing Farm Structure Over Time

As Stolniuk (2008) indicated, farmland markets directly impact the farm structure over time as a new farmer agent takes control of the land the land-use changes. In addition, because farmers

[23] The Winner's curse is known as the highest bidder getting the contract or lease but as a result going bankrupt because they over bid. The Winner's curse comes from the fact that the winning bid was too high and because the highest bid is the one that wins, it causes farmers to over bid in the first place. Thus, the adjusted bid is chosen.

are profit maximizing they are constantly adapting their short-run and long-run production decisions to the marketplace and thus the farm structure is constantly changing over time.

3.6 Chapter Summary

In this chapter the conceptual model, structural equations and agent behaviour are presented. Overall farm profitability and long-run strategic farm growth are essential for farm survival. The expectations farmers perceive and the level of risk they take on will influence the outcome of the simulation. The use of linear and integer programming techniques to maximize the net present value of each farm enterprise allows the land-use of each farmer to be used at the most competitive advantage for each individual farmer agent. The next chapter will describe the data inputted into the simulation.

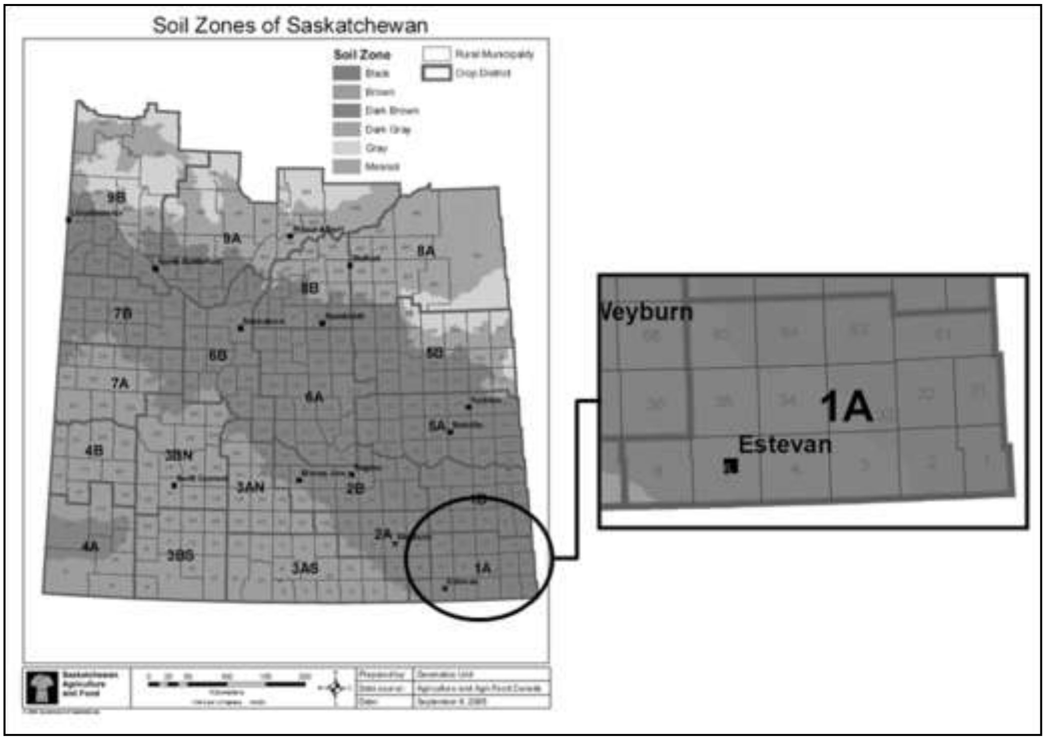
CHAPTER 4: DATA

4.0 Introduction

In this chapter the data used to build the population profile for Census Agriculture Region (CAR) 1A, of Saskatchewan are presented. Characteristics associated with the landscape and land quality are incorporated into the simulation using Saskatchewan Assessment and Management (SAMA) Agency data. The synthetic individual farm population used to populate the landscape in the simulation will also be outlined in this chapter based on the actual known population from the *Whole Farm Survey* of CAR 1A (*Statistics Canada* 2006). The annual cropping machinery data used to build the machinery options utilized in the MIP model are also explained in this chapter. The variable costs associated with all farm enterprises are also presented. A bootstrap procedure is used to simulate historical prices and yields for all commodities based on yields from Saskatchewan *Crop insurance* Data.

4.1 Study Landscape

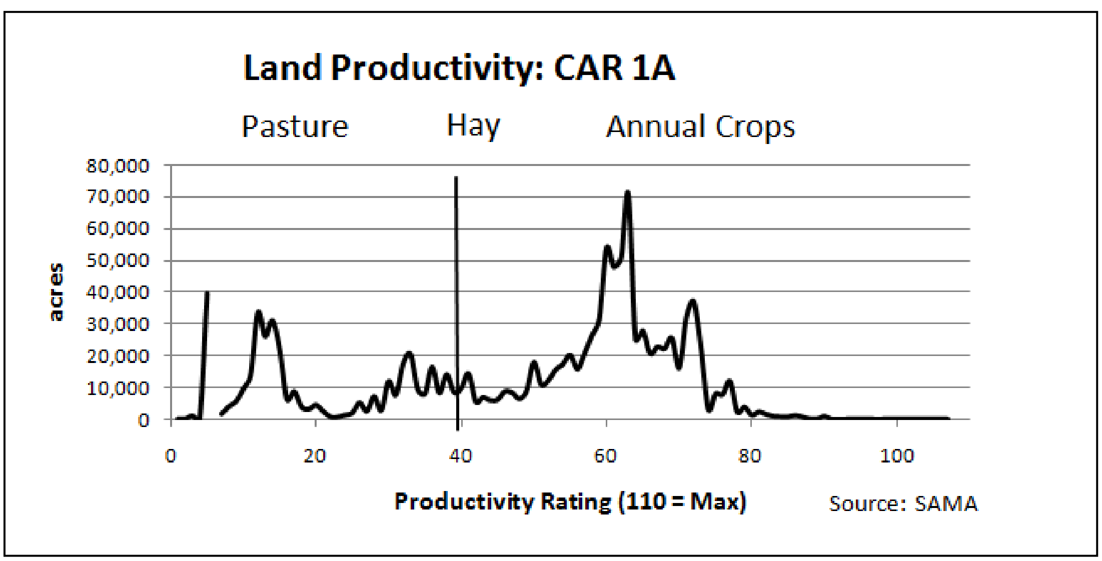
The landscape used as the study area includes CAR 1A a portion of the Assiniboine River Basin of Saskatchewan and is located in the southeast corner of the province (Refer to Figure 4.1). In the 2006 *Census of Agriculture* there were a total of 1,823 farms in this CAR with an average farm size of 1,474 acres. According to the census data there are 557 beef cow farms and 1,017 grain farms. This CAR is unique in that it includes both black and dark brown soils. This CAR has a total of 337,732 acres of marginal land used for hay, improved pasture and unimproved pasture (Census of Canada: Agriculture Saskatchewan CAR 1A 2006).



Source: Saskatchewan Agriculture and Food (2005)

Figure 4.1 Census Agricultural Regions and Soil Zones of Saskatchewan

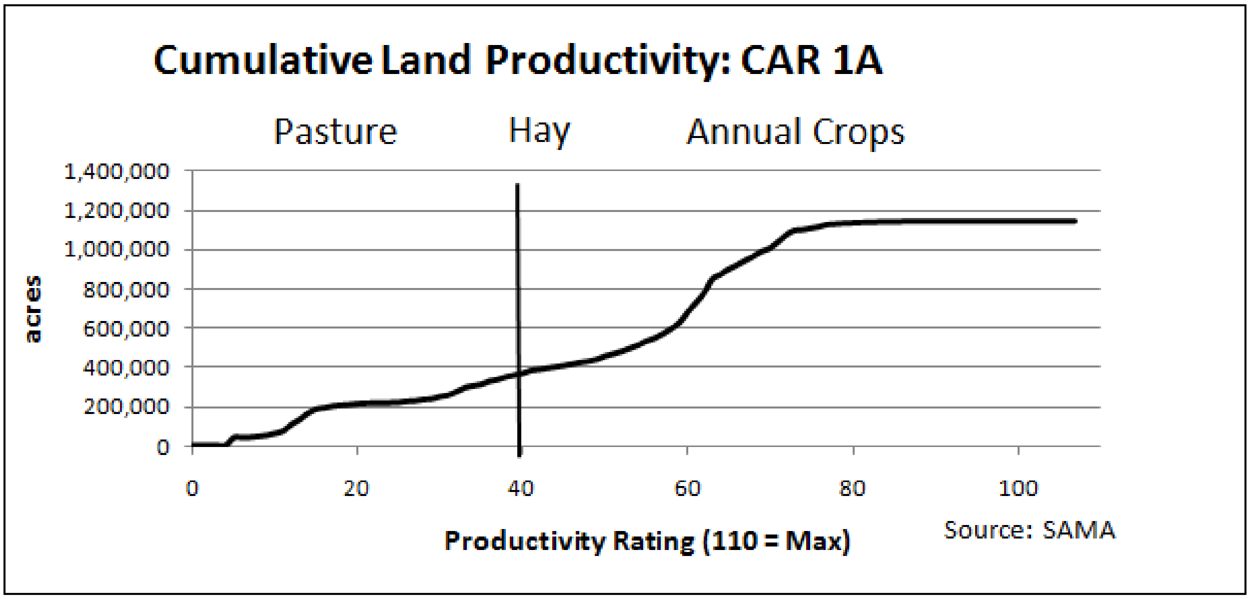
Land falling below a productivity rating of 40% is considered marginal or transition farmland and these lands are not suitable for annual crop production but instead will be available for either beef cows or perennial crop production (Refer to Figure 4.2).



Source: Saskatchewan Assessment Management Agency

Figure 4.2 Farmland Soil Rating Productivity

Thus, energy crops will only be produced on marginal lands (Class 4 and 5 soils). In particular the areas of specific interest are farmland that is currently in pasture and hayland. As mentioned above the total acreage of potential marginal lands is 337,732 acres as indicated in Figure 4.3.



Source: Saskatchewan Assessment Management Agency

Figure 4.3 Cumulative Land Productivity

In order to clearly understand the true heterogeneity of the farm land in CAR 1A aerial photographs were obtained through Google™ Earth. Some of the highest productive quality soil used in annual cropping is shown in Figure 4.4 while farm land with lower quality soil productivity ratings is displayed in Figure 4.5.

Source: (Google™ 2010)

Figure 4.4 Aerial Photograph of High Quality Annual Cropping Land

Source: (Google™ 2010)

Figure 4.5 Aerial Photograph of Lower Quality Marginal Land

4.1.1 Saskatchewan Assessment and Management Agency (SAMA) Data

All farmland in Saskatchewan has a corresponding classification and productivity quality rating index. In terms of arable land the productivity is determined based on a soil classification system that is based on historical wheat-yields. The heterogeneity of soil quality and historical wheat yields on cropland is correlated allowing for different productivity ratings to be assigned to corresponding parcels of land. In terms of marginal land the productivity rating is based on potential beef cow carrying capacity and forage production yields (SAMA 2009). Using these productivity ratings for each parcel of land a yield-index is generated for each annual crop and forage.

4.2 Synthetic Farm Population

The farm population used in the ABSM follows the same process as used by Stolniuk (2008). A synthetic farm population is constructed from the *Whole Farm Survey* of CAR 1A (*Statistics Canada* 2006). The statistics from the *Whole Farm Survey* are extended to represent the actual population for the CAR involved considering farm characteristics, farm size and numbers, regional beef cow production, financial health of the farmer including level of debt as well as farmer age, land value and off-farm income.

4.2.1 Assets and Debts

Following Stolniuk (2008) a farm agent's assets and debts are set at initialization and updated each year through the balance sheet. Assets include the following, cash, land, annual cropping equipment, beef cow herd, handling system and machinery. Annual cropping equipment assets at initialization are based upon farm size and the equivalent machinery package. Beef cow handling and equipment assets are based upon initial beef cow herd size. The farm's cash account has been updated from Stolniuk to a balance of $50 from $30 plus an error term that is $5 or less, which is then multiplied by their crop acres and four times their herd size[24] (Stolniuk 2008). The initial cash balance was increased to better represent the need to account for inventory of the previous year's production.

Farm debt is randomly assigned a per acre value when the synthetic population is created. Initial farmer debt in the synthetic population averages $67.73 per acre or $103,765 per farm. The debt allocation by farmer age is shown in Table 4.1.

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[24]This corresponds to the following formula: $\boldsymbol{Cash} = (\$50 + \varepsilon) \cdot (TCA + 4 \cdot NC)$ (Stolniuk 2008).

Table 4.1 Initial Farmer Debt by Age

Farmer Age	No Debt	$1 - $100,000	$100,001 - $200,000	$200,001 - $300,000	$300,001 - $400,000	$400,001 - $500,000	$500,001 - $600,000	$600,001 - $700,000	$700,001 - $900,000	$900,001 - $1,000,000	>$1,000,001	Total
>30	1	24	4	2	1	0	1	0	0	0	0	33
31-34	1	21	7	4	3	0	0	1	0	1	2	40
35-39	13	31	10	4	0	1	0	1	1	0	2	63
40-44	8	47	12	5	1	0	0	0	0	0	0	73
45-49	19	53	22	13	2	3	0	2	0	0	0	114
50-54	29	60	26	8	4	1	0	0	1	0	1	130
55-59	21	50	13	6	3	1	1	0	0	0	0	95
60-64	17	24	11	1	1	0	1	0	0	0	0	55
65-69	19	18	7	4	0	0	0	0	0	0	0	48
>70	31	23	4	4	1	1	0	2	0	0	0	66
Total	159	351	116	51	16	7	3	6	2	1	5	717

Source: (Synthetically Generated Based upon Whole Farm Financial Survey *Statistics Canada* 2006)

All farms follow a probability factor of having off-farm income, with smaller farms having a larger probability (Refer to Table 4.2).

Table 4.2 Probability of Off-Farm Income by Farm Size

Total Acres Farmed	Probability of Off Farm Income
<640	100%
641-1280	85%
1281-1920	75%
1921-3200	50%
>3200	40%

Source: Stolniuk (2008)

Using the probability factors in Table 4.2, off-farm income is assigned randomly to all farms at initialization and that income level stays constant throughout the entire simulation. The off-farm income generated for the synthetic population is presented in Table 4.3.

Table 4.3 Off-Farm Income by Farm Size

Total Acres Farmed	No Off Farm Income	$1 - $20,000	$20,001 - $40,001	$40,001 - $60,000	$60,001 - $80,000	$80,001 - $100,000	$100,001 - $120,000	$120,001 - $140,000	>$140,001	Total
<640	89	50	46	50	17	11	11	2	2	278
641-1280	63	40	26	27	15	6	7	4	3	191
1281-1920	29	29	11	6	3	2	3	2	2	87
1921-2560	17	12	14	7	3	0	1	0	2	56
2561-3200	9	13	3	8	1	3	2	0	0	39
3201-3840	6	10	5	5	3	2	1	0	0	32
3841-4480	4	4	1	3	1	0	2	0	0	15
4481-5120	1	2	0	1	0	0	0	1	0	5
>5120	6	2	2	1	1	0	2	0	0	14
Total	224	162	108	108	44	24	29	9	9	717

Source: (Synthetically Generated Based upon Whole Financial Survey *Statistics Canada* 2006)

Farm allocation by age and size is also randomly assigned to all farmers at initialization. The synthetic population allocation of farms by age and size is shown in Table 4.4.

Table 4.4 Synthetic Population Allocation of Farms by Age and Size

Farmer Age	<640	640 - 1278	1279 - 1917	1918 - 2566	2557 - 3195	3196 - 3834	3835 - 4473	4474 - 5112	>5752	Total
>30	20	10	2	1	0	0	0	0	0	33
31-34	18	10	4	3	0	1	2	0	2	40
35-39	23	15	7	6	4	1	2	2	3	63
40-44	26	14	18	4	4	5	1	0	1	73
45-49	40	29	10	12	10	5	4	2	2	114
50-54	49	36	14	14	4	9	1	0	3	130
54-59	33	29	13	7	6	4	2	0	1	95
60-64	23	10	6	7	5	2	1	0	1	55
65-69	17	17	5	1	3	2	3	0	0	48
>70	27	22	9	2	2	2	1	0	1	66
Total	276	192	88	57	38	31	17	4	14	717

Source: (Synthetically Generated Based upon Whole Financial Survey *Statistics Canada* 2006)

4.2.2 Plot Assignment to Agents

While the agents are synthetic, the landscape is real. Farmland plots are aggregated to nominal 640 acre plots and assigned to one of three land use classes according to the land quality composition: 1) pure grain, 2) mixed grain and forage for beef cows and 3) primarily forage for beef cows. In a similar fashion agents are also assigned to one of three land use classifications according to the proportion of beef cows.

In the case of pure grain land, the synthetic grain farm population is matched to the actual corresponding farmland in 640 acre plots using average land values based on land quality productivity rating of SAMA[25]. As in the Stolniuk model (2008) the highest valued farmland is matched with the land quality with the highest rating. Next, the mixed grain and forage for beef cows are assigned in a similar fashion. Finally, land assigned to primarily forage for beef cows class is assigned according to the relative beef cow intensity rankings. As stated in the previous section, land with a productivity rating falling below 40% is not only assumed to be available to produce beef cows but also perennial energy crops.

4.2.3 Stochastic Prices and Yields

Historical yields and detrended prices are updated from the Stolniuk (2008) model to include yields and prices up to the year 2008. The historical years used in the data range from 1968 – 2008, reflecting 40 years of observations[26]. Both prices and yields are stochastic throughout the entire simulation using the historical data to generate 50 different time paths based on a bootstrap procedure (Refer to Appendix B). The bootstrap procedure allows for almost an infinite number of time paths to be generated (Huang and Willemain 2006). The time paths are randomly chosen from a historic period using a normal distribution method[27]. The summary of the simulated bootstrapped price and yields showing mean, standard deviation and coefficient of variability within replicates are displayed in Table 4.5.

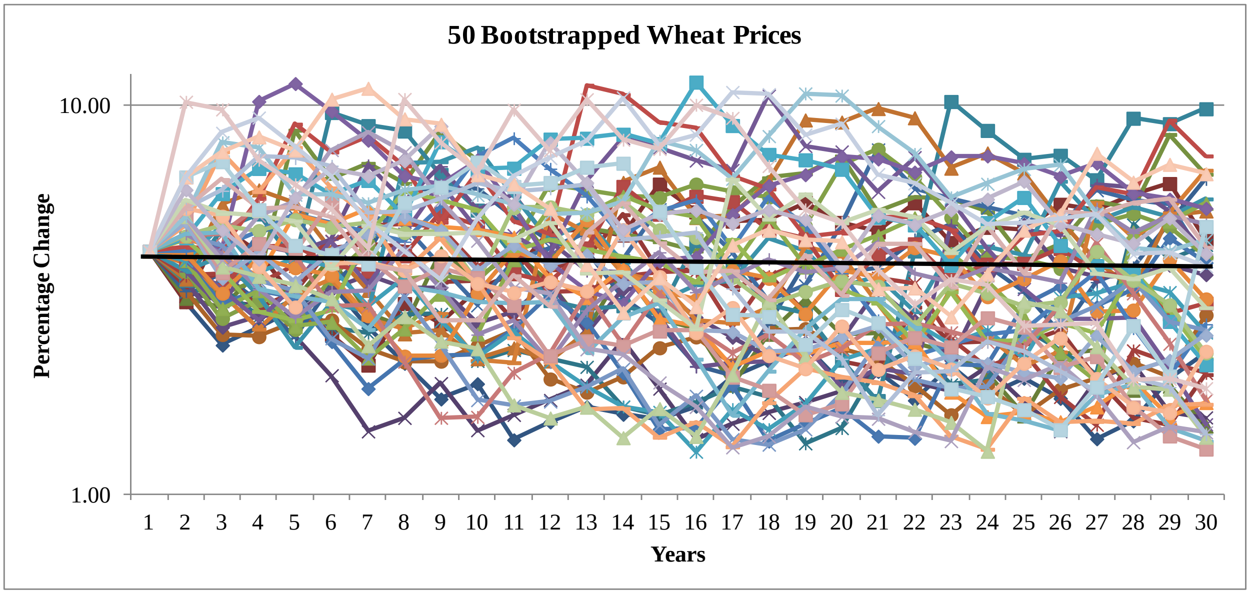
[25] The SAMA data has acres of each category of farmland, natural pasture, improved pasture, hay, and tilled, along with a productivity rating for each category of land down to the quarter section.
[26] The Saskatchewan Ministry of Agriculture did not have historical data for Durum, Lentils and Peas for the entire 40 years for CAR 1A, thus where appropriate alternative data is used. For Durum the range of data is from 1970-2008. The data for lentils and peas until 1991 are the historical provincial average data while the 1991-2008 period is historical data specific to CAR 1A.
[27] The bootstrap procedure was also used in the Stolniuk (2008) model.

Table 4.5 Summary of Bootstrapped Simulated Prices and Yields

Statistic	Barley	Canola	Durum	Flax	Hay	Lentil	Pea	Wheat	Calf
Units	**$/bu**	**$/bu**	**$/bu**	**$/bu**	**$/bu**	**$/bu**	**$/bu**	**$/bu**	**$/lb**
Prices									
Replicate Summary									
Mean	2.96	7.88	5.72	8.23	81.33	18.19	7.4	3.89	1.44
StDev	1.16	2.49	1.85	3.63	26.96	5.7	2.32	1.22	0.5
Coefficient of Variablity within Replicates									
Mean	38%	32.10%	40.50%	44.80%	29.50%	40.30%	34.50%	33.30%	33.40%
Min	15.20%	12.70%	17.70%	21.40%	15.50%	19.10%	15%	17.10%	19.20%
Max	66.20%	62%	85.50%	86.70%	53.80%	73.70%	68.40%	67%	62.90%
Units	**bu/Acre**	**bu/Acre**	**bu/Acre**	**bu/Acre**	**t/Acre**	**bu/Acre**	**bu/Acre**	**bu/Acre**	**n/a**
Yields									
Replicate Summary									
Mean	49.04	23.58	19.35	12.65	1.25	18.81	30.4	28.01	
StDev	1.89	0.8	0.87	0.61	0.06	0.61	0.71	0.7	
Coefficient of Variablity within Replicates									
Mean	20.20%	21.60%	28.40%	29.70%	27%	19.70%	14.10%	17.20%	
Min	13.20%	11.40%	19.20%	21.40%	18.30%	14.10%	11.20%	10.90%	
Max	27.30%	33.50%	34.40%	35.60%	34.50%	24.10%	16.10%	22.40%	

Data are based on bootstrapped 1968-2008 historical farm prices and CAR 1A yields

The bootstrap procedure represents the percentage change in yield and price from the 2008 base constructed upon the detrended historical 1968 – 2008 period and is further illustrated in Figure 4.6 using wheat prices as an example. The black line exemplifies that no trend exists within the bootstrapped generated prices and yields.



Source: (Authors Bootstrapped Calculations, Schoney (2010b)

Figure 4.6 Fifty Time Paths of Wheat Bootstrapped Prices

Following Stolniuk (2008), hay yields and prices remain at a reasonable correlation. The expectations for hay are the corresponding historical match from the year in which it was sampled. The average historical yields and prices are shown in Table 4.6 below (Refer to Appendix C for the entire 1968 -2008 historical yields and prices).

Table 4.6 Average Historical Yields and Prices

Historical Yields								
Canola bu/ac	Spring Wheat bu/ac	Durum bu/ac	Lentils lbs/ac	Peas lbs/ac	Barley bu/ac	Flax bu/ac	Hay t/ac	Calf lb
23.62	28.18	19.42	1118.66	1829.08	53.81	12.63	1.28	n/a
Historical Prices								
Canola $/bu	Spring Wheat	Durum $/bu	Lentils ¢/lb	Peas $/bu	Barley $/bu	Flax $/bu	Hay $/t	Calf $/cwt
7.32	4.21	5.12	15.97	6.48	2.81	7.68	72.47	140.35

Source: Saskatchewan Ministry of Agriculture (2008)

4.3 Farm Enterprise Data

This section discusses the different types of farm enterprises available for investment for each individual producer agent. There are essentially three different types of enterprises, these being as follows: 1) annual crop enterprise, 2) mixed crop and beef cow enterprise and, 3) perennial crop and/or beef cow enterprise. Perennial crops are incorporated into the same enterprise as beef cow enterprise because they both compete for the same land quality.

4.3.1 Annual Crops

Annual crops available to each farmer have been updated from the Stolniuk (2008) model to include a larger variety of crop mixes. The crop mixes available now include pulses (peas and lentils) as well as an additional oilseed (flax), with the exception that lentil production is only available to no-till farms. Although crop mixes can vary depending upon which soil zone a producer agent is in, for simulation simplicity all crop mixes available to producers are available for both soil zones based on the fact that both soil zones in this CAR are located in the south-eastern portion of the province allowing for more degree days to grow these crops and that these crops are found in these areas in the southeast. The following crops are available in the simulation: cereals (wheat, durum and barley), pulses (lentils[28] and peas), and oilseeds (flax and canola).

4.3.1.1 Annual Crop Variable Costs

The variable costs associated in the production of annual crops are based on the 2008 dark brown and black crop planning guides from the Saskatchewan Ministry of Agriculture. These variable costs differ slightly from one soil zone to the next, thus a representative variable cost per acre for CAR 1A was constructed by using a blended average of both soil zones for conventional farms as well as no-till enterprises (refer to Tables 4.7 and 4.8). The variable costs included are as follows: seed, fertilizer, chemicals, and utilities. Fuel, repair costs and *crop insurance* premiums are excluded from this calculation because they are included in the machinery variable cost assumptions while *crop insurance* premiums are calculated internally based on each farm agents coverage level. The variable costs for both conventional and no-till farms are found in the table below.

[28] Lentil data is based on Green Lentils taken from the Crop Planning Guides from the Saskatchewan Ministry of Agriculture.

Table 4.7 Conventional Farm Variable Expenses Per Acre

Variable Expenses	Chem Fallow	Wheat on Fallow	Wheat on Stubble	Durum on Stubble	Barley on Stubble	Peas on Stubble	Flax on Stubble	Canola on Stubble
Seed	$ -	$ 11.72	$ 11.72	$ 13.50	$ 9.20	$ 19.80	$ 9.80	$ 36.25
Fertilizer								
Nitrogen	$ -	$ 11.28	$ 22.55	$ 20.50	$ 22.55	$ 2.46	$ 22.55	$ 22.55
Phosphorus	$ -	$ 9.60	$ 9.60	$ 9.60	$ 9.60	$ 4.80	$ 4.80	$ 6.40
Sulphur & Other	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 5.25
Chemical								
Herbicides	$ 13.81	$ 19.94	$ 19.94	$ 19.94	$ 19.66	$ 26.24	$ 19.99	$ 23.85
Insecticides/Fungicides	$ -	$ 2.23	$ 2.23	$ 1.49	$ -	$ 0.50	$ -	$ 1.44
Other	$ -	$ 2.70	$ 2.70	$ 2.70	$ 2.38	$ 3.60	$ 2.10	$ -
Utilities & Miscellaneous	$ 5.61	$ 5.61	$ 5.61	$ 5.55	$ 5.61	$ 5.61	$ 5.61	$ 5.61
Total Variable Expenses	$ 19.41	$ 63.07	$ 74.35	$ 73.28	$ 68.99	$ 63.01	$ 64.85	$ 101.34

Source: Saskatchewan Ministry of Agriculture (2008)

Table 4.8 No-Till Farm Variable Expenses Per Acre

Variable Expenses	Wheat	Durum	Barley	Lentils	Peas	Flax	Canola
Seed	$ 11.72	$ 13.50	$ 10.80	$ 36.00	$ 19.80	$ 9.80	$ 36.25
Fertilizer							
Nitrogen	$ 22.55	$ 20.50	$ 22.55	$ 2.46	$ 2.46	$ 22.55	$ 22.55
Phosphorus	$ 9.60	$ 9.60	$ 9.60	$ 6.40	$ 4.80	$ 4.80	$ 6.40
Sulphur & Other	$ -	$ -	$ -	$ -	$ -	$ -	$ 5.25
Chemical							
Herbicides	$ 23.19	$ 23.19	$ 23.05	$ 34.50	$ 29.49	$ 20.91	$ 28.31
Insecticides/Fungicides	$ 2.23	$ 1.49	$ 0.74	$ 5.75	$ 0.50	$ -	$ 1.44
Other	$ 2.70	$ 2.70	$ 2.54	$ 1.80	$ 3.60	$ 2.10	$ -
Utilities & Miscellaneous	$ 5.61	$ 5.61	$ 5.61	$ 5.61	$ 5.61	$ 5.61	$ 5.61
Total Variable Expenses	$ 77.60	$ 76.59	$ 74.89	$ 92.52	$ 66.26	$ 65.76	$ 105.80

Source: Saskatchewan Ministry of Agriculture (2008)

4.3.1.2 Annual Crop Trucking Costs

The transportation expense data used in the model for annual crops is based upon the average trucking rate of $0.22 per mile per metric tonne and is obtained from Weyburn Inland Terminal and is deflated to 2008 equivalent (WIT 2010).

4.3.2 Perennial Crops

In the Stolniuk (2008) model, forage was the only perennial crop available for farmers. Perennial crops have been updated to include energy crops for biofuel production in addition to forage for livestock. Energy crops include short-rotation woody crops (SRWC) as well as perennial grasses.

4.3.2.1 Energy Crops

In this simulation model farms are not initialized with energy crops, after initialization it is observed how energy crops emerge as the energy price per gigajoule is changed. However, all the necessary information required by a farmer to make the decision to adopt energy crops is incorporated into the model. Three energy crops have been chosen for farmers to adopt in this model, two SRWC's, (willows and hybrid poplar) and one perennial grass (Prairie sandreed). This section presents the cost data and yield relevant to energy crops.

4.3.2.2 Energy Crop Prices and Energy Content

The energy content of oven dried woody plants ranges approximately between 18 – 22 GJ/T (NCSU 2008). The energy content in willows used in the simulation is 19.6 GJ/T (Samson and Chen 1995; Murray 2010) while poplar[29] has an energy content of 19.8 GJ/T (Samson et. al 1999 and 2009). Prairie sandreed energy content is 13.5 GJ/T and is based upon averages of tame hay and agricultural residues[30] (NCSU 2008; Samson et al. 2008).

Farm gate price for biomass energy crops is set initially at $2 per GJ in the simulation based upon the price ranges indicated in the literature review from Chapter two. A higher price range of $4/GJ is used in the simulation to represent a higher price range.

4.3.2.2.1 Willows

The SRWC Willows as identified in Chapter two is one potential energy crop available for producers to grow on marginal land. The total estimated establishment cost for a willow plantation is $1,538.94 per acre with a seeding density of approximately 5,817 cuttings per acre (14,376/HA). Willow cuttings attribute a significant portion of the estimated establishment costs. A cuttings price of $0.10 is used based on the fact that as the industry develops the cuttings price will be reduced and that after initial establishment farmers will be able to use their own cuttings

[29] The energy content of poplar is based upon the pellet energy content.

[30] Prairie sandreed specific energy content was not obtainable so an approximation was used.

for future plantations.[31] Other establishment costs include cultivation and herbicide costs in preparing the soil for planting. The total establishment costs are outlined in Table 4.9

Table 4.9 Willow Plantation Establishment Costs

Establishment Costs		$/Acre
Variable Costs	$	4.05
Cultivation	$	28.72
Cuttings @ $0.10	$	581.80
Planting	$	890.34
Herbicide	$	31.57
Insecticide	$	2.47
Total	$	1,538.94

Source: Hangs et al. (2010)

According to willow test plots in Estevan, Saskatchewan which is located within CAR 1A, the average willow yield of seven rotations is approximately 13.1 tonnes/Acre (34.29 tonnes/HA). The average willow yield is based upon minimum and maximum yields from different stages of the willow plantation's life in Table 4.10. The expected and actual yields in the simulation will vary around these averages based upon the productivity rating of the soil[32].

Table 4.10 Average Yields of Willows

Years	3	6	9	12	15	18	21	Average Yield
Min Acre	3.7	6.4	9.7	12.1	12.1	12.1	12.1	9.7
Max Acre	5.2	9.0	13.6	21.9	21.9	21.9	21.9	16.5
Average Tonnes/Acre	4.5	7.7	11.7	17	17	17	17	13.1

Source: Hangs et al. (2010)

4.3.2.2.2 Hybrid Poplar

Establishment cost for hybrid poplar per acre is $1,108.36 based upon data obtained from the Canadian Wood Fibre Centre. The majority of the establishment costs of Hybrid Poplar come from cuttings, at a cost of $524.09 per acre based upon a density of 2,600 stems per acre. Fertilizer is not applied during plantation as it tends to benefit weeds more than hybrid poplar (Sidders et al. 2010). The breakdown of establishment costs can be found in Table 4.11.

[31] Hangs et al. state that early research showed a price of $0.31 per cutting but it is expected to drop to $0.10 as it has dropped in other countries around the world.
[32] To see how willow yields are calculated refer to Appendix G.

Table 4.11 Hybrid Poplar Establishment Costs

Establishment Costs		$/Acre
Breaking Cost	$	161.88
Weed Control	$	60.71
Marking	$	60.71
Cuttings	$	524.09
Planting	$	89.03
Split Cultivation	$	121.41
Mechanical Cultivation	$	80.94
Total Establishment Costs	$	1,098.76

Source: Canadian Wood Fibre Centre (2010)

Biomass oven-dried tonne yields vary depending on the rotation year as well as the productivity rating of the soil. The poplar yields used in the simulation are based upon the following minimum and maximum yields presented in Table 4.12[33].

Table 4.12 Average Yields of Poplar

Years	3	6	9	12	15	18	21	Average Yield
Min Acre	0.8	1.6	2.2	2.3	2.3	2.3	2.3	2.0
Max Acre	2.2	3.0	3.7	6.4	6.4	6.4	6.4	4.9
Average Tonnes/Acre	1.5	2.3	3	4.3	4.3	4.3	4.3	3.4

Source: Amichev et al. (2010); Cees Van Oosten (2008) ; Steckler (2007) ; Welham et. al (2007)

4.3.2.2.3 SRWC Harvesting Costs

The high hourly usage of harvesting equipment required yearly, make it highly unlikely that a willow or poplar plantation will purchase harvesting equipment. Thus, in light of this custom rates applicable to harvesting SRWC have been estimated. Harvesting and transportation costs of SRWC are based on calculating a custom work rate using forage harvesting and transporting equipment[34]. Before a custom rate can be determined the estimated throughput and time variables must be calculated. Accordingly the forage harvesters' rate of 5 acres per hour and the average willow yield of 13.1 tonnes per acre and the average tonnes harvested per hour works out to be approximately 69.4[35]. Using an average throughput of 69.4 tonnes per hour and the

[33] Poplar yields in this thesis have been observed to be low, refer to Appendix G for poplar yield calculation.
[34] The following equipment is used: New Holland® Forage Harvester FR9040 424hp engine with the New Holland® 130 FB Coppice Header with a high dump wagon pulled behind forage harvester, two 2WD tractors 170HP pulling two forage dump trailers, three semi-tractor 450hp with three tridem end dump trailers and one conveyor
[35] Willow was used to determine the custom rate because more data was available for willow than for poplar, it was assumed that poplar would be similar in harvesting.

assumption of approximately 15 hour days the average tonnes per day is approximately 1,050 tonnes (Table 4.13).

Table 4.13 Tonnes of SRWC Harvested Per Day

Speed t/hr	Tonnes Harvested Daily by Hours per Day										
	10	11	12	13	14	15	16	17	18	19	20
50	500	550	600	650	700	750	800	850	900	950	1000
60	600	660	720	780	840	900	960	1020	1080	1140	1200
70	700	770	840	910	980	1050	1120	1190	1260	1330	1400
80	800	880	960	1040	1120	1200	1280	1360	1440	1520	1600
90	900	990	1080	1170	1260	1350	1440	1530	1620	1710	1800
100	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000

Source: (Based Upon Author's Calculations)

Fifteen hour days were calculated based upon the days available to harvest SRWC and the required amount of machine hours a custom harvest operator would require in order to achieve economies of scale in the industry. The days available to harvest SRWC are based upon Environment Canada's normalized climate data for Estevan, Saskatchewan and stat holidays observed by the province of Saskatchewan thus approximate available days to harvest were estimated[36]. The approximate harvest days come to approximately 73 days available per growing season (Table 4.14)[37].

Table 4.14 Approximate Days Available to Harvest SRWC

Month	Total Days	Days with Rain >=0.2mm	Days with Snow Depth >=5cm	Holidays	Possible Harvest Days
October 15th	16	2.7	0.5	1	11.7
November	30	1.6	7.2	1	20.2
December	31	1	19.1	2	8.9
February	28	0.8	18.8	1	7.4
March	31	2.8	13.7	0	14.5
April 15th	15	2.9	1.1	1	10
Total	151	11.9	60.4	6	72.7

Source: Environment Canada (2010)

[36] Stat holidays in Saskatchewan are currently as follows: October – Thanksgiving, November 11th – Remembrance Day, December 25th and 26th – Christmas and Boxing Day, February – Family Day, April – Good Friday. It is also noted that custom harvest operators may be willing to work through some holidays.

[37] Note that the calculated custom rate and days available may be optimistic and only achievable under perfect conditions, day length, winter weather road conditions may further limit days available.

With an average of 73 days per season and 15 hour work days total machine hours per year become approximately 1100 hours (Table 4.15).

Table 4.15 Days Needed to Harvest SRWC

Hours per	Days Need to Harvest by Hours per Day										
Year	10	11	12	13	14	15	16	17	18	19	20
600	60	55	50	46	43	40	38	35	33	32	30
700	70	64	58	54	50	47	44	41	39	37	35
800	80	73	67	62	57	53	50	47	44	42	40
900	90	82	75	69	64	60	56	53	50	47	45
1000	100	91	83	77	71	67	63	59	56	53	50
1100	110	100	92	85	79	73	69	65	61	58	55
1200	120	109	100	92	86	80	75	71	67	63	60

Source: (Based Upon Author's Calculations)

Operating costs and annualized repairs have been estimated based on 1,100 annual machine hours, machine work rates and associated labour costs required. Due to the high number of hours annually put on the forage harvester and coppice header it is more cost efficient to replace them every two years.[38] Machine harvest costs are presented in Table 4.16 below.

Table 4.16 SRWC Harvest Machinery Costs

Year	Number Machines	Machinery	HP/Capacity	Rate	Purchase Price	Replacement Age	Annualized Repairs	CRC	Operating Cost/hr	Labour Cost/hr
2009	1	Forage Harvester	424	5 Acre/hr	$ 438,282	2	$ 19,612	$ 75,113	$ 83.06	$ 15.00
2009	1	Coppice Tree Header		86 t/hr	$ 147,623	2	$ 12,751	$ 26,313		
2009	2	2WD Tractor	170		$ 235,800	5	$ 12,310	$ 26,261	$ 66.60	$ 30.00
2009	2	Forage Dump Trailers	$53.8m^3$	16.3 t/load	$ 94,000	10	$ 2,172	$ 11,153		
2009	3	Tridem End Dump Trailers	$38.2m^3$	14.7 t/load	$ 165,000	15	$ 2,172	$ 15,485		
2009	1	High Dump Wagon - Behind Harvester	$36.3m^3$	10.94 t/load	$ 40,000	10	$ 2,172	$ 4,746		
2009	1	Conveyor			$ 20,000	10	$ 400	$ 2,373		
2004	3	Semi	450		$ 300,537	15	$ 40,917	$ 27,357	$ 264.46	$ 45.00
				Total	$ 1,441,241	5	$ 92,506	$ 188,801	$ 414.12	$ 90.00

Source: (Based on Author's Calculations)

Calculating the approximate annual tonnage and costs associated with 1,100 machine hours the custom rate for harvesting SRWC biomass is $14.65/tonne and is displayed in Table 4.17.[39]

[38] This calculation assumption is based upon the capital recovery charge and the estimated annual repairs.
[39] This is based upon a price of fuel of $0.69 per liter and a labour rate of $15/hr per person and a 35 % margin to cover overhead costs involved in custom operations.

Table 4.17 SRWC Custom Harvest Rate

Tonnes/hr	Hours/Year	Annual Tonnes	Fuel Cost (Includes Transportation)	CRC	Repairs	Labour per Year	Total Cost	Cost per Hour	Cost per Tonne	Suggested Custom Rate per Tonne w/35% Margin
70	900	63000	372709	173006	102065	81000	728780	810	11.57	15.62
70	1000	70000	414121	179559	105313	90000	788993	789	11.27	15.22
70	1100	77000	455533	188801	92506	99000	835840	760	10.86	14.65
80	600	48000	248473	167745	64704	54000	534922	892	11.14	15.04
80	700	56000	289885	167745	79058	63000	599688	857	10.71	14.46
80	800	64000	331297	173006	87234	72000	663537	829	10.37	14

Source: (Based Upon Authors' Calculations)

4.3.2.2.4 Prairie sandreed

Prairie sandreed is an ideal perennial grass for restoring marginal land (Kusler 2009). Establishment costs for prairie sandreed are similar to forage establishment costs with the exception of the higher cost of seed for prairie sandreed. Fertilizer recommendations were sparse in the literature for prairie sandreed, and thus forage fertilizer rates have been applied based on Stolniuk (2008). Seed for prairie sandreed costs $9.46/lb and is seeded at a rate of 4.5lbs/acre resulting in a total seed cost of $42.56/acre[40]. Establishment costs total $96.80 per acre and are detailed in Table 4.18.

Table 4.18 Prairie Sandreed Establishment Costs

Establishment Costs	$/Acre
Custom Spraying	$ 2.97
Weed Maintenance	$ 13.81
Custom Seeding Rate	$ 12.52
Prairie Sandreed Seed 4.5lb/Acre @ $9.46/lb	$ 42.56
Fertilizer (15lb Phosphorous/Acre)	$ 4.80
Breaking Cost	$ 20.14
Total Establishment Cost	$ 96.80

Source: BrettYoung™ (2011), Saskatchewan Ministry of Agriculture (2008), Stolniuk (2008)

Harvesting prairie sandreed occurs annually with yields varying between 0.27 tonnes/acre and as high as 4.18 tonnes per acre with an average of approximately 1.54 tonnes/acre (Jefferson et al. 2002, 2004 and 2005). The variations of yields in the simulation occur based upon the productivity rating of the soil[41]. Harvesting costs are relatively inexpensive for prairie sandreed, as the cost associated with cutting and baling, and transporting are minimal at $18.31 per acre in comparison to the costs of harvesting willows or poplar.

[40] Seed costs were obtained from BrettYoung™ seed grower.
[41] To see how prairie sandreed yields are calculated refer to Appendix G.

4.3.2.3 Energy Crop Trucking Cost

Transportation expenses relative to energy crops differ from annual crop trucking rates because of different trucks used in hauling as well as the fact that biomass from energy crops are usually lighter in volume and thus require a higher trucking rate per mile per metric tonne. The variable cost trucking rate used in the simulation is $0.40 per tonne per mile and is based upon forestry trucking costs in 2008 dollars (Bradley 2007)[42].

4.3.3 Beef Cows

The beef cow data used in the simulation is based primarily on Stolniuk (2008) with some updates made to the data. This section includes the herd profile, energy content (Mcals) of different feeds, and variables costs of beef cow production.

4.3.3.1 Nutritional Herd Profile and Feed Nutrition

The nutritional herd profile of Stolniuk (2008) was modified to four time periods per year from the three time periods used in that study. The addition of this extra (fall) period more accurately reflects the Mcal (maintenance and growth) nutritional requirement throughout the year. The four periods and the corresponding Mcal and days required for that intake are as a follows: early pasture (June – July) 61 days, 1970 mcals, late pasture (August – September) 46 days 1237 Mcals, Fall (October – November 15) 61 days 1636 Mcals, and Winter (November 15 – May 31) 197 days 5075 Mcals. These four periods have a total energy requirement of 9918 Mcals[43] (Refer to Table 4.19). The higher early pasture period energy requirement in comparison to the fall period reflects the higher energy requirements of a lactating cow.

Table 4.19 Nutritional Herd Profile

Time of Year	ME (Mcal) Required
Yearly Pasture (June - July) 61 Days	1970
Late Pasture (August - September) 46 Days	1237
Fall (October - November 15) 61 Days	1636
Winter (November 15 - May 31) 197 Days	5075
Total Energy Requirements	9918

Source: Author's Calculations; Stolniuk (2008); NRC Feed Composition (1982)

[42] The trucking rate is based upon a 50 km trucking rate radius round trip and has been converted to per mile equivalent.

[43] Based on author's calculations assuming 1300lb Cow (Averages includes 1 Bull per 25 Cows) Maintenance and Growth.

Energy content available to meet nutritional requirements varies by the type of feed used and the timing of the year. For instance in forages, the Mcal content per ton of feed is different depending on the time of year and type of forage. In the simulation there are three different types of forages used: natural pasture, improved pasture and hayland pasture (grass 2-00-956) with energy contents of 1933, 2196 and 2680 Mcal/tonne in its natural environment. However, due to cattle not being able to capture 100% of the energy content available, the following assumptions have been applied: 50% waste from cattle in early pasture timings leaving 967, 1098 and 1340 Mcals/Tonne available for energy use respectively. Late pasture deteriorates in energy content an additional 20% leaving only 580 Mcals/tonne for beef cows to obtain. In the fall period, energy content available on pasture deteriorates even further by an additional 80% leaving only 116, 132 and 161 Mcals/tonne available as pasture feed (Table 4.20).

Table 4.20 Energy Content on Pasture Timings

Pasture	Natural Pasture	Improved Pasture	Hayland Pasture
Natural	1933	2196	2680
Early Pasture	967	1098	1340
Late Pasture	580	659	804
Fall	116	132	161

Source: Stolniuk (2008); NRC Feed Composition (1982)

When forage and cereal straw is cut and baled for beef cow feed, the energy content available also varies. The energy content for baled feed is as follows: improved pasture baled (1st cut) 1098 Mcals/tonne (2nd cut) 659 Mcal/Tonne, hayland baled (1st cut) 1340 Mcals/Ton (2nd cut) 804 Mcals/Tonne, while barley and wheat straw have energy content of 664 and 823 Mcals/Acre respectively (refer to Table 4.21).[44] The Mcals used in the MIP optimization model for the feeding hay activities are a weighted average of the producers expected Mcal production based on the productivity rating of their own land. A weighted average is used in setting feeding hay activities because production of hay can come from either the first or second cut of both improved pasture land or hayland.

[44] It is noted that removing straw refuge from crop land has a fertilizer value, however for model simplifications it is also assumed that manure fertilizer value is of equal or greater value thus the value of fertilizer lost from removal of the straw refuge is gained back in manure fertilizer. Refer to Appendix D for Cereal Straw Calculation.

Table 4.21 Baled Feed Energy Content

Baled Feed	Energy
Improved Baled (1 cut)	1098 Mcal/ton
Improved Baled (2 cuts)	659 Mcal/ton
Hayland Baled (1 cut)	1340 Mcal/ton
Hayland Baled (2 cuts)	804 Mcal/ton
Barley Straw	664 Mcal/Acre
Wheat Straw	823 Mcal/Acre

Source: NRC Feed Composition (1982); Stolniuk (2008)

The energy content of the cereal straw is based on average expected yields of 1.2 and 0.95 tonnes/acre (Calculation in Appendix D). In regards to cereals being fed to beef cows during the fall and winter months the following energy content is 3394 Mcals/Ton of feed barley and 3724 Mcals/Ton of feed wheat (refer to Table 4.22).

Table 4.22 Cereal Feed Energy Content

Cereal Feed	Energy Mcal/ton
Feed Barley	3394
Feed Wheat	3724

Source: CowBytes© (1998)

4.3.3.2 Beef Cow Production Costs

Beef cow production costs are based on Stolniuk (2008) but have been updated to reflect changes that occurred in the market place. The values of a new cow and cull value are generated from the following formulas y = 0.7679x and y = 0.3038x based on the expected calf price using regression analysis from historical cow prices. Using the new and cull values from the above formulas of a cow, the appropriate capital recovery charge per cow is generated internally. The value of a new bull is set at $2,500 while the cull value is set at $500 respectively[45]. The capital recovery charge for the bull (Table 4.23) is kept constant throughout the simulation based on the fact that the relatively small cost of the bull has little impact on changes in the bull's capital recovery charge as the expected calf price changes. The beef cow capital recovery charge is used to represent an annual replacement value on the herd (Stolniuk 2008).

[45] Based on the following assumptions, average life of a cow is eight years; average bull life span is four years; an interest rate of 5%.

Table 4.23 Bull Capital Recovery Charge

New Bull Cost	$	2,500
Cull Bull	$	500
Interest Rate		5%
Years		4
CRC	$	589.02
CRC/Cow 25	$	23.56

Source: (Based on Author's Calculations).

Other variable costs associated with beef cow production include veterinary care, fuel and machinery repairs, bedding, manure cleaning, utilities, building repair, trucking and marketing expenses. Total variable cost is $127.69 per head shown in Table 4.24, these total variable beef cow production costs exclude feeding costs because the recourse LP determines feeding costs.

Table 4.24 Total Variable Beef Cow Production Cost Per Head

Production Cost		$/Cow
Veterinary Medicine	$	20.50
Fuel	$	19.16
Machinery repairs	$	13.67
Custom Work/Manure	$	16.80
Utilities	$	17.21
Building Repair	$	5.53
Trucking and Marketing	$	7.90
Bedding	$	26.92
Total Variable Cost	$	127.69

Source: Western Beef Development Centre (2005); Saskatchewan Ministry of Agriculture (2008) inflated to 2008.

4.4 Whole Farm Costs--Lumpy Inputs

This section discusses the data used for lumpy inputs; particularly fixed capital including land, machinery and full time hired labour. Fixed economies of scale in agriculture have been attributed to indivisibility of fixed capital. The term lumpiness has been recognized by economists as inputs that cannot be increased in fractional amounts but rather must be purchased in large amounts or numbers to achieve low cost per unit (Hall and Lieberman 2007). For instance machinery, land and full time labour cannot be purchased in fractional amounts and have limits on their capacities bringing to an end economies of scale above certain thresholds.

4.4.1 Farmland Purchasing and Renting

In terms of inputs and in this model, land is the most obvious lumpy input and it can only be purchased or rented in 640 acre plots. The MIP model determines the optimal amount of additional land the farm should have if growth in farm size is feasible and an efficient step in farm expansion can be reached. This farm expansion size decision is set by the fixed cost associated with equipment and plots of land. The land sizing decision follows Fisher's separation theory in finance meaning the farm manager's decision to increase their farm's present value is their main concern. Therefore, the farmer's objective in farm expansion is to gain control of additional farmland either through purchasing or renting. The investment decision of obtaining control of the additional farmland is separated from or irrelevant to whether the additional land is obtained through the purchase or rental market.

The average purchase price for farmland at initialization is set at $450 per acre for cropland and $280 per acre for marginal land, in terms of the 640 acre section these result in an average value of $288,000 for the section of cropland and $179,200 for a section of marginal land (FCC 2010). Land lease rates are set at $23 per acre and $13 per acre respectively for cropland and marginal land at initialization following a required rate of return of 5% to the landlord[46]. However, these values are averages and will vary for each farm agent depending on the productivity rating of the plot accordingly.

4.4.2 Annual Crop Machinery and Labour

In terms of machinery, sizing plays an important role in determining cultivated land use and farm size in annual cropping decisions (Anderson 2008; Stolniuk 2008). Thus, because of the lumpiness nature of machine investment, correct machinery sizing is critical to achieving cost efficiency. As explained above the expansion path is discontinuous and producers can become caught at an inefficient point due to equity capital constraints, credit limitations or the inability to secure more land. Hence, the expansion process is one of the most difficult processes of growing a farm business in part due to the lumpiness of farm equipment, full time labour and the difficulty of securing more land. Larger farms are able to make more efficient utilization of

[46] The capitalization rate of farmland is typically between three and eight percent in North America, with Saskatchewan at approximately five percent (Schoney 2007).

lower-cost technology resulting in greater economies of scale. Thus, in light of this, correct annual crop machinery package options have been designed using real agricultural annual crop machinery data for specific cropland farm acreage limits (refer to Table 4.25 for summary)[47]. The fixed cost component of machinery is made up of the capital recovery charge[48] and the fixed cost of full time labour.

Table 4.25 Annual Crop Machinery Package Options

Option	Max Acres	New Value (Replacement Cost)	Current Value	Ending Value	Total CRC	Fixed Labour	Total Fixed Costs	Variable Costs	Annualized Repairs
0	500	$ 370,900	$ 86,379	$ 37,738	$ 7,643	$ -	$ 7,643	$ 56.51	$ 5,451
1	1300	$ 1,153,600	$ 352,686	$ 175,414	$ 38,121	$ -	$ 38,121	$ 15.60	$ 16,014
2	2000	$ 1,449,500	$ 683,596	$ 265,099	$ 470,122	$ 24,000	$ 94,122	$ 11.52	$ 16,298
3	3200	$ 1,778,640	$ 1,020,873	$ 448,495	$ 107,509	$ 40,000	$ 147,509	$ 10.48	$ 18,076
4	4300	$ 1,936,695	$ 1,323,114	$ 575,338	$ 145,424	$ 40,000	$ 185,424	$ 9.18	$ 19,253
5	9000	$ 3,135,890	$ 2,645,325	$ 1,181,842	$ 269,233	$ 80,000	$ 349,233	$ 10.21	$ 34,210
6	12300	$ 4,107,385	$ 3,575,302	$ 1,655,214	$ 369,769	$ 80,000	$ 449,769	$ 1.80	$ 41,378
7	18000	$ 5,693,157	$ 4,959,834	$ 2,279,768	$ 513,614	$ 120,000	$ 633,614	$ 9.95	$ 64,368
8	23500	$ 7,304,685	$ 6,464,993	$ 3,001,115	$ 671,012	$ 120,000	$ 791,012	$ 10.18	$ 80,746
9	28000	$ 8,691,602	$ 7,704,085	$ 3,598,035	$ 801,308	$ 160,000	$ 961,308	$ 9.91	$ 92,578

Source: Saskatchewan Ministry of Agriculture (2008)

Hired labour is a complex process and the amount of labour varies depending on the availability of the local labour services, machine technology complements, farm size and the opportunities of family labour for off-farm employment (Monke et. al 1992). Labour for the farm is a mixture of family labour, part-time and full-time labour. Hence, labour is partially lumpy and thus full-time hired labour is included as a part of the machinery packages. For model simplicity, it is assumed that each farm can supply 1.5 family labourers, while any additional labour is hired. Following Stolniuk (2008), part-time and full-time labour costs are $15 per hour for part-time seasonal workers on an annual crop farm, while a full-time labourer salary for farms over 3200 acres is $40,000 per year. The 2,000 acre farm hires one full-time labourer at an annual cost of $24,000[49]. Part-time labour is included in the machinery package variable costs (Table 4.26)[50].

[47] For complete annual crop machinery package options refer to Appendix E.

[48] The capital recovery charge (CRC) reflects the opportunity cost associated with holding a capital asset. It has two basic opportunity cost components – The first is associated with holding capital and the second is associated with the loss in asset value over time. The CRC is a single year period “snap shot” of opportunity costs (Schoney 2010).

[49] This salary is based on actual farmer workshop values reported through the AgriBenchmark® network.

[50] Variable costs for labour are missing for certain farm sizes as these farms have no part-time labour as their full-time labour is sufficient.

The variable costs are calculated using the rates of acres per hour for particular equipment (Refer to Appendix F).

Table 4.26 Part-Time Labour Variable Costs

Option	Max Size (Acres)	Seeding	Spraying	Harvesting	Total Labour VC
0	500	$ -	$ -	$ -	$ -
1	1300	$ -	$ -	$ 1.55	$ 1.55
2	2000	$ -	$ -	$ -	$ -
3	3200	$ -	$ -	$ -	$ -
4	4300	$ -	$ -	$ -	$ -
5	9000	$ -	$ -	$ 0.64	$ 0.64
6	12300	$ 0.23	$ -	$ 1.15	$ 1.37
7	18000	$ -	$ -	$ 1.18	$ 1.18
8	23500	$ 0.18	$ 0.07	$ 1.38	$ 1.63
9	28000	$ 0.19	$ 0.07	$ 1.37	$ 1.62

Source: (Based Upon Authors Calculations)

One alternative to reducing the impact or jump size of lumpy inputs is through part-time hired labour and renting additional machine hours or the use of custom work. However, part-time labour can be difficult to find on short notice and renting additional machines is not always an option, as custom or rental machine hours are not always available for use when needed. As a result of the risk of the timing of events and the transaction costs incurred to hire in custom work or part-time labour many farms will choose to over invest in machinery rather than rent a fractional unit (Monke et. al 1992).

However, as stated above machinery packages have been designed in the most realistic process to aide producers in this model to move from one “sweet spot” to another in the most efficient manner during farm expansion. Table 4.27 provides the average total cost per acre including fixed and variable costs for each machinery package.

Table 4.27 Annual Crop Machinery Package Average Total Cost Per Acre

Option	Max Acres	New Value (Replacement Cost)	Current Value	Ending Value	Total CRC	Fixed Labour	Total Fixed Costs	Variable Costs	Annualized Repairs	Total Cost/Acre
0	500	$ 741.80	$ 172.76	$ 75.48	$ 15.29	$ -	$ 15.29	$ 56.51	$ 10.90	$ 82.70
1	1300	$ 887.38	$ 271.30	$ 134.93	$ 29.32	$ -	$ 29.32	$ 15.60	$ 12.32	$ 57.24
2	2000	$ 724.75	$ 341.80	$ 132.55	$ 35.06	$ 12.00	$ 47.06	$ 11.52	$ 8.15	$ 66.73
3	3200	$ 555.83	$ 319.02	$ 140.15	$ 33.60	$ 12.50	$ 46.10	$ 10.48	$ 5.65	$ 62.22
4	4300	$ 450.39	$ 307.70	$ 133.80	$ 33.82	$ 9.30	$ 43.12	$ 9.18	$ 4.48	$ 56.78
5	9000	$ 348.43	$ 293.93	$ 131.32	$ 29.91	$ 8.89	$ 38.80	$ 10.21	$ 3.80	$ 52.82
6	12300	$ 333.93	$ 290.67	$ 134.57	$ 30.06	$ 6.50	$ 36.57	$ 1.80	$ 3.36	$ 50.73
7	18000	$ 316.29	$ 275.55	$ 126.65	$ 28.53	$ 6.67	$ 35.20	$ 9.95	$ 3.58	$ 48.73
8	23500	$ 310.84	$ 275.11	$ 127.70	$ 28.53	$ 5.11	$ 33.66	$ 10.18	$ 3.44	$ 47.27
9	28000	$ 310.41	$ 275.15	$ 128.50	$ 28.62	$ 5.71	$ 34.33	$ 9.91	$ 3.31	$ 47.55

Source: (Based Upon Authors Calculations)

The machinery and labour options designed for this thesis were graphed in Figure 4.7 for each increment farm size to illustrate the end to economies of scale and the jumps required to get to the next sweet spot[51].

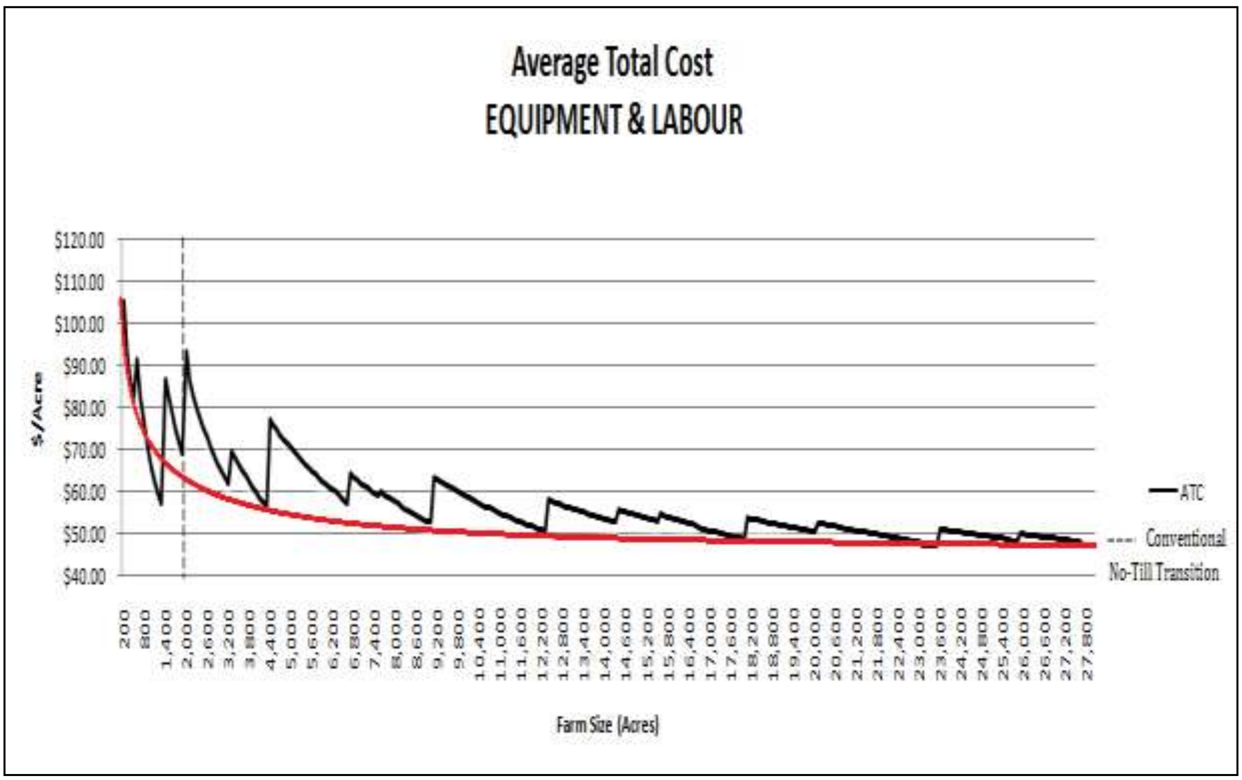


Figure 4.7 Annual Crops Average Total Cost - Equipment Including Labour

[51] The high cost at 2,000 acres represents the transition from conventional to No-till farm technology, as well this graph represents the use of newer machinery, were in reality farms at this step likely employ used machinery. The high spot after 9,000 acres appears due to the fact that no machinery package was designed between 4,300 and 9,000 acres, resulting in a large jump. However, in reality a farm package likely does exist.

4.4.3 Beef Cow Equipment and Hired Labour

The beef cow industry also has lumpy inputs although not as severe as the annual cropping industry, but the economies of size and scale are still present. Some basic beef cow equipment and handling facilities have been incorporated to reflect the economies of beef cow production. The new replacement costs and capital recovery charges for beef cow machinery and handling systems are outlined in Table 4.28. Both the beef cow machinery and equipment handling system are based on a herd of 300 cows. Beef cow calving labour is also lumpy, and follows Stolniuk (2008) with a required labourer per 300 calves with a seasonal cost of $9,000.

Table 4.28 Beef Cow Machinery and Handling System CRC

Machinery & Equipment	New Replacement Cost	CRC
Tractor with Loader	$ 128,000	$ 9,410
Cattle Trailer	$ 14,000	$ 1,114
3/4 ton Truck (Diesel)	$ 19,085	$ 1,945
Total Livestock Machinery	$ 161,085	$ 12,469
Handling System	$ 10,800	$ 830
Handling Equipment	$ 1,000	$ 769
Containment and Feeding Equipment	$ 10,000	$ 769
Total Livestock Handling Equipment	$ 30,800	$ 2,368
Total Fixed Cost Livestock Machinery & Handling Equipment	$ 191,885	$ 14,837

Source: Saskatchewan Minsitry of Agriculture (2008) and Author's Calculations

4.5 Government Programs

Historical government stabilization programs were included in the Freeman (2005) model. This model has been updated to include government programs relevant to today's farmer. Government programs included are *crop insurance*, AgriInvest and AgriStability.

4.5.1 *Crop Insurance*

Crop insurance premiums are calculated using the historical yields and prices specific to CAR 1A. Using the *crop insurance* formulas presented in Chapter 3, the following producer and government premiums for 60%, 70% and 80% coverage levels respectively are shown in Table 4.29.

Table 4.29 *Crop Insurance* Premiums

Level of Coverage	Rate & Payment Portions	Crops							
		Canola	Spring Wheat	Durum	Lentils	Peas	Barley	Flax	Hay
60%	Premium Rate	1.21%	0.31%	0.49%	4.14%	0.30%	0.47%	1.37%	1.20%
	Government Portion	0.72%	0.18%	0.29%	2.48%	0.18%	0.42%	0.82%	0.72%
	Producer Portion	0.48%	0.12%	0.20%	1.66%	0.12%	0.28%	0.55%	0.48%
70%	Premium Rate	1.89%	1.07%	1.22%	6.74%	0.61%	1.88%	2.50%	3.27%
	Government Portion	1.14%	0.64%	0.73%	4.04%	0.37%	1.13%	1.50%	1.96%
	Producer Portion	0.76%	0.43%	0.49%	2.69%	0.25%	0.75%	10.00%	1.31%
80%	Premium Rate	3.13%	1.95%	1.98%	9.41%	1.20%	3.27%	4.73%	5.33%
	Government Portion	1.88%	1.17%	1.19%	5.65%	0.72%	1.96%	2.84%	3.20%
	Producer Portion	1.25%	0.78%	0.79%	3.77%	0.48%	1.31%	1.89%	2.13%

Source: (Stolniuk 2008b and Authors Calculations)

4.5.2 *AgriStability* and *AgriInvest*

Due to privacy legislation, real *AgriInvest* and *AgriStability* data are not available at the farm level for CAR 1A. Synthetic reference margins for individual farms have been generated using aggregated historical provincial gross sales and acres sown per commodity from the time when these programs were implemented[52]. Each farmer agent will generate their own initial reference margins based on the productivity of the soil and will vary from the provincial average. Reference margins by annual crop farm type and for calf are presented in Table 4.30.

Table 4.30 Initial Reference Margins

Year	Conventional	No Till	Calf
2002	$ 119.41	$ 121.06	$ 1,218.49
2003	$ 96.20	$ 101.20	$ 751.03
2004	$ 117.10	$ 119.60	$ 742.49
2005	$ 97.37	$ 99.73	$ 890.55
2006	$ 125.32	$ 128.92	$ 940.03
2007	$ 162.08	$ 177.91	$ 1,034.76

Source: (Based Upon Authors Calculation and AAFC 2008)

Initial *AgriInvest* account balances have also been generated based upon the 2006 and 2007 reference margins above and less the associated variable costs for that commodity. The initial average *AgriInvest* account balance is $9,729 per farm participant or an average of $5,428 if including all farmers with no account balance.

[52] Initial reference margins were calculated by taking total provincial crop gross receipts for each commodity divided by the total crop acres sown for the appropriate period. Conventional and no-till reference margins were generated based upon a representative crop rotation determined by the crop constraints presented in chapter 3.

4.6 Family Living Expenses

The required minimum family living expenditure for a rural family of four is $26,228 and is the same value used by Stolniuk (2008) based on the 2002 poverty line amount according to the Canadian Council on Social Development (CCSD 2002)[53]. As discussed in Chapter 3, farm families have a propensity to consume farm profits; however, this amount is capped at $125,000 per year.

4.7 Retirement

Following Freeman (2005), once farmers reach the age of 55 their probability of retiring increases in 5 year increments, (Table 4.31). Although, census data reveals that some farmers are actively farming past 80 years of age, the reality is highly unlikely that they are the main farm manager. Thus, once a farmer reaches the age of 80 they are forced to retire.

Table 4.31 Farmer Retirement Probability

Age	5 Year Increments	Annual Probability of Exiting
55 - 59	25%	6%
60 - 64	40%	10%
65 - 69	64%	18%
70-79		30%
80		100%

Source: Freeman (2005)

4.8 Farm Succession

The likelihood of a farm having a successor is based on the assumptions of Stolniuk (2008) where transfers only take place on 95% of the farms that meet financial conditions. Accordingly the minimum equity required by the exiting farmer is $500,000 for family living for the next 30 years.[54] If farms have excess farm equity, the remainder is transferred to the new farm generation at a rate of 20%.

If the retiring farmer had off-farm employment, it is independent of whether the next generation will have off-farm income. Instead, the new generation farmer will have a probability of having off-farm income calculated in the same manner as all the farm agents at model initialization.

[53] The 2005 poverty line amount was $21,296 however, lowering the minimum family living expenditure to this amount did not seem realistic for a farm family and thus the value was left at the 2002 withdrawal of $26,228.

[54] Stolniuk assumed a retirement cash flow of $40,293 per year for 30 years earning 7% from the minimum farm equity amount.

4.9 Chapter Summary

This chapter presented the data used to build the farmer agents, landscape, farm enterprises and corresponding machinery packages available to farm agents. Accurate and reliable data used to build the synthetic farmer agents and environment are essential to creating a ABSM system representative of the real farm population and agriculture industry of CAR 1A. The initialization values and simulation data results are verified and validated in the next chapter.

CHAPTER 5: VERIFICATION, VALIDATION AND RESULTS

5.0 Introduction

In brief review, the primary objectives of this thesis are to 1) explore the economic conditions that would encourage producers to grow SGB crops and 2) explore how alternative energy price scenarios would affect farm structure of agriculture over the next 30 years. Of particular interest are the potential impact of energy crops on marginal and transitional land-use and their associated effect on regional beef cow numbers. An agent based simulation model, (ABSM) is constructed representing individual farm level decisions of grain and beef cow producers. The model is populated with producer characteristics and endowed with the physical land resources of CAR 1A, located in south-eastern Saskatchewan. Three different scenarios are evaluated: the base and two different energy price scenarios. The base scenario excludes energy crops while the other two scenarios examine different energy crop prices. Each scenario is simulated for 30 years with identical 50 different price and yield time paths[55].

Before the simulations can be evaluated, the process of verification and validation must be attempted. These are important steps in ABSM development and should always be performed when building simulation models (Parker et al. 2001). Accordingly, model verification and validation and the simulation results are first presented. Next, the results are assessed to determine the impact on agricultural structure at the farm-level, and are based upon the mean value from the output of fifty different time paths.

5.1 Model Verification

Verification refers to the method of checking the model to ensure it is "built right" as well as verifying that internal equations are free of errors and that the model conforms to its specification (Gilbert 2008; Balci 1998)[56]. Verification is essential in monitoring the input data used in the farm population, land base and bootstrapped generated prices and yields. The integer and linear programming models were verified by first creating and solving representative models using the Microsoft Excel©Solver© add-in to ensure no errors were present either in model logic

[55] The different yield and price time paths are based on the bootstrap procedure described in section 4.2.5
[56] The MIXFARM-ABM Repast© Java source code and documentation is all available open source at www.openabm.org or by contacting thesis author.

and formulation, the constraints on the coefficients[57] [58]. This is an important step because it would be easy to mistakenly use an incorrect sign for a particular model coefficient. In addition, the land use section allows suboptimal land use, while the mixed integer model itself is relatively complicated. Other equations in the model were verified by comparing simulated values with calculated values.

The synthetic farm population as discussed in Section 4.2 is constructed from the *Whole Farm Survey* and represents actual CAR 1A farms. Initial synthetic population farm characteristics, land tenure and landscape, and farm financial structure, including assets and debt, are compared against the 2006 Census of Agriculture. The bootstrapped prices and yields are compared against the historical values.

5.1.1 Land Tenure and Use

Since the synthetic population omits small farms, it is a subset of the population and it differs slightly from the 2006 Census.[59] In addition, note that the synthetic population is also assigned by 640 acre "patches" so that it may also differ by the "lumpiness" effect. Accordingly comparisons can only be approximate (Table 5.1).

Initial land tenure is assigned to each farmer based on the 2005 *Whole Farm Financial Survey* and according to farm size and type. The initial synthetic population has 68.9% owned and 31.1% leased land, roughly comparable to the Census data for CAR 1A at 65.5% and 34.4%, respectively (*Statistics Canada* 2006). In terms of land use, the initial proportion of total land in annual crops is 77.6% while the 2006 Census has only 77.3% of land use in annual crops. Assigned marginal land use is consistent with Census data at 22.7% in the model and 22.4%, respectively. Initial land tenure and land use is displayed in Table 5.1 below.

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[57] Because the IP and LP problems may have solved for each farmer agent and each year, there could be over 2,000 IP and LP problems.
[58] Refer to section 3.2.1.6. for the integer and linear programming examples.
[59] Note that the 2006 Census uses the ending 2005 for farm net worth and other financial statements so that these are the same business year.

Table 5.1 Initial Land Tenure and Land Use

Data Source	Land Tenure		Land Classification	
	Owned	Leased	Cropland	Marginal Land
2006 Census	65.5%	34.4%	77.3%	22.7%
Model Initialization	68.9%	31.1%	77.6%	22.4%

Source: Census of Agriculture (2006)

Average farm size in CAR 1A is 1,474 acres according to the Census of Agriculture as mentioned in Chapter 4. Average farm size at initialization is 1,533 acres, a level that is reasonable given that very small farms are omitted.

5.1.2 Forage Acres

Initial forage acres are generated based upon the *Repast* patches built from the SAMA data and thus match the pasture acres presented in Chapter 4. The forage and natural pasture acres remain constant throughout the base case scenario, but can be shifted to energy crops in the alternative scenarios. However, improved pasture and hay pasture are either grazed or baled depending on the farmer's strategic use of the pasture. In the energy crop scenarios, pasture use can change but it is initialized to be the same as the base scenario. The initial pasture acres are shown in Table 5.2 below.

Table 5.2 Initial Pasture Acres

Hayland	Improved Pasture	Natural Pasture	Total Hayland and Pasture Acres
103,254	57,821	85,292	246,547

Source: Land base, SAMA

5.1.3 Prices and Yields

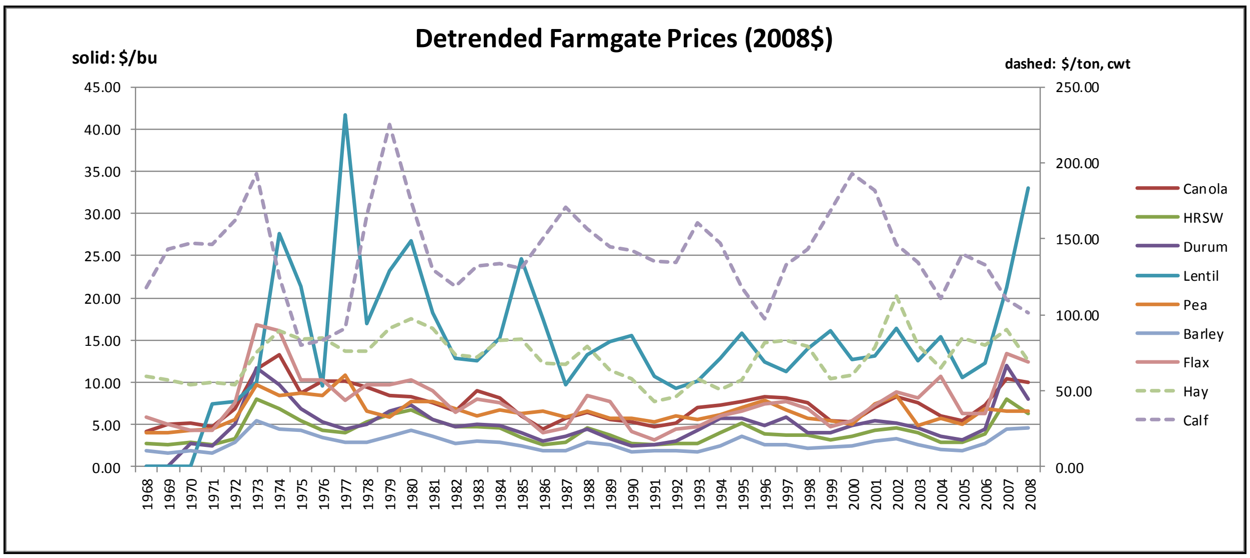
Bootstrapped commodity prices and yields are exogenous and are based upon detrended, historical prices and yields from the 1968 – 2008 periods. The 2008 starting point is important as it represented a period of relatively low calf prices. Table 5.3 compares the historical and simulated mean prices.

Table 5.3 Comparison of Historical and Simulated Mean Prices

Statistic	Canola	Wheat	Durum	Lentils	Peas	Barley	Flax	Hay	Calf
					Prices				
Simulated	7.88	3.89	5.72	18.19	7.40	2.96	8.23	81.33	143.62
Historical	7.32	4.21	5.12	15.97	6.48	2.81	7.68	72.47	140.35
Difference	8%	8%	-12%	-14%	-14%	-5%	-7%	-12%	-2%

Source: (Author's Calculation and Saskatchewan Ministry of Agriculture 2008).

Although the prices and yields are detrended, some of the differences between the simulated and historical prices show positive or negative variability in the mean value. While the year 2008 data is based on actual values, the remaining years are generated using the bootstrapping method. This means that the data moves ahead from that point and because there are fifty different starting points generated using the bootstrapping method, the difference between the simulated and historical mean values is not zero. This detrended variability in farmgate prices is graphed in Figure 5.1.



Source: Saskatchewan Ministry of Agriculture (2008) and Schoney (2010b)

Figure 5.1 Detrended Farmgate Prices (2008$)

5.1.4 Initial Farmer Assets, Debt and Equity

Initial farm financial data used and generated in the simulation are compared and validated against weighted average data for CAR 1A from the farm financial survey obtained from AAFC and *Statistics Canada* (Statistics Canada 2008)[60]. Initial weighted average assets in the model are

[60] A weighted average of farm financial variables is used to represent the overall weighted average of different farm types.

slightly lower than the farm financial survey with an average of $1,168,067 per farm compared to $1,102,173. The higher initial assets are the result of higher initial *AgriInvest* account balances that will be described in a later section, while machinery values are based upon newer equipment. Initial farm debt in the simulation is slightly lower when compared to the farm financial survey with an average of $99,441 per farm while data obtained from the farm financial survey averages $118,822 (as described in chapter 4). Average farm equity is $1,068,625 per farm at model initialization, an amount that is $85,268 more than the farm financial survey data for average farm equity but still consistent with the subpopulation of larger farms.

5.2 Model Validation

Validation answers the question "Are we building the right model?" (Balci 1998). This tells us whether the model can be relied on to accurately represent the real world. Performance measures in this regard are generally based on comparing simulated results to real world data (Gilbert 2008; North and Macal 2007). Validation seeks to guarantee that the results generated endogenously are correct and the model performs accurately. Model complexity, stochasticity and the number of internal computations associated with the optimizing models used here, plus the lags in government program payments make it extremely difficult to validate our results in a typical fashion.

In fact, the base scenario is used for model validation. The first simulation year, 2008, is based on actual prices and yields so that simulated beef cow numbers and land use can be directly compared to the *Statistics Canada* data. Likewise, simulated farmland lease rates and purchase values can also be compared to FCC reported statistics and are representative of the region[61].

While the model subsystems of the base model can be compared to real world data this is not the case with the SGB scenarios as they are beyond historical experience. Hence, they can only be

[61] While the model initialization represents the year-end of 2007 and the first year in the simulation is 2008, the 2006 Census of Agriculture is used as a rough guide to facilitate verification of the model, values used in the thesis are either inflated or deflated to a 2008 equivalent. Land values obtained from FCC in 2010 are an average of land values over the 2007 – 2009 time period from the applicable rural municipalities in Census Agricultural Region 1A.

qualitatively examined against the expert knowledge and experience gathered through research and consultation[62].

5.2.1 Initial Beef Herd Population

Beef herd numbers are internally generated based on initial available pasture resources and feed supplies. The simulated initial total herd numbers averaged 29,310 animals over the 50 replications in the base scenario. Unfortunately, these cannot be directly compared to Census data as dairy farms and farms of less than 640 acres are excluded. However, by adjusting for the herd profile, these can be compared to the 2006 *Census of Agriculture* numbers using the total cows and bulls for CAR 1A. Based upon the initial number of 354 mixed and beef cows farms in the simulation, the simulated mean number of beef cows per beef farm is 83. This appears to be consistent with the Census number of 78 cows and bulls per beef farm, again considering the subpopulation characteristics[63]. However, because the simulated beef cow numbers are a subset of the population, validation is only an approximation over the actual population. Table 5.4 below outlines the census beef cow numbers.

Table 5.4 Census Beef Cows Numbers CAR 1A

Total Cows	68,265
Total Bulls	3458
Total Cows and Bulls	71,723
Beef Cow Farms Reported	921
Mean Herd Size	78

Source: Census of Agriculture (2006)

5.2.2 Initial Land Use

Annual crop acres are endogenously optimized subject to rotation constraints and thus can be used to validate the crop module. Note that because only grain and beef cow farms are included, the remaining farm types such as dairy are excluded. In addition, exclusion of the smaller farms

[62] Research included the information obtained in various literatures in addition to consultation with thesis advisors and professionals in the willow, poplar and tall grass industry.

[63] While the total livestock number from the census is 149,062; for model simplicity it is assumed that all steers aged one year plus are not on farm and are sold in the fall and that constant herd replacement occurs and thus heifers aged one year plus are not included. The 354 farms that have livestock are out of a total of 375 that potentially could have livestock as farms that generate a livestock carrying capacity of less than 10 cows are set to zero.

may potentially introduce a bias in the aggregated results. Accordingly, comparisons to Census data can once again only be approximate. [64]

Simulated crop acres for the first two production years are based on the mean results of 50 replicates and are compared to actual crop acres. The simulated crop production results are similar when based upon the percentage of crop mix for canola, durum and flax. While total cereal acreage is similar due to the rotation constraint, the allocation among barley, durum and wheat differs considerably, particularly for wheat. Again, this is likely due to the exclusion of small farms that typically have very large proportions of wheat and fallow acres.

Historically, lentils are volatile in terms of profitability and in 2008 have a lower contribution margin, which has a spillover effect on the pulse constraint. Because the pulse constraint only includes lentils and peas, the lower lentil margin increases the simulated crop acreage of peas to be greater than the actual production of peas. The inclusion of annual crop rotation constraints could also potentially limit the consistency of simulated production outcomes. The annual constraints are used to represent crop rotations (refer to Section 3.2.1.5.1 on land constraints). Although, agronomic practices suggest three to four year rotations for certain commodities, in reality, it is well known that producers will stretch rotations when it is profitable to do so.

Simulated fallowed acres are considerably less (0.0%) than actual (9.1%) acres. Again, this is probably attributable to the exclusion of small farms that typically employ older technology. The comparison of actual and simulated crop production for the 2008 and 2009 crop year for CAR 1A is displayed in Table 5.5.

[64] It is likely that more efficient farms have a larger effect on agricultural structure at the farm-level because they are more productive, adopt new technology and grow a diverse range of annual crops and these are our main area of interest.

Table 5.5 Comparison of Actual and Simulated Crop Production, CAR 1A

Year	Statistic	Fallow	Wheat	Durum	Peas	Flax	Canola	Barley	Lentils	Total
2008	Simulated	0.0%	4.6%	16.7%	27.2%	5.3%	29.2%	16.0%	0.0%	99%
	Actual	9.1%	23.2%	11.3%	8.3%	10.7%	23.7%	11.8%	1.9%	100%
	Difference	-9.1%	-18.6%	5.4%	18.9%	-5.4%	5.5%	4.2%	-1.9%	-1%
2009	Simulated	0.0%	7.7%	16.2%	27.1%	8.0%	25.4%	15.3%	0.0%	100%
	Actual	7.8%	25.9%	10.3%	7.1%	12.2%	25.2%	9.1%	2.4%	100%
	Difference	-7.8%	-18.2%	5.9%	20.0%	-4.2%	0.2%	6.2%	-2.4%	0%

Source: Saskatchewan Ministry of Agriculture[65]and Simulated Annual Crop Production – Base Scenario[66]

5.2.3 Government Programs

Validating government programs in the simulation is difficult because of the confidentiality of the information available and the lack of detailed farm information. Further complicating any such comparisons are the exclusion of supply-managed, hog, specialty and hobby farms. However, an approximate comparison is done based on the aggregated data available from *Agriculture and Agri-Food Canada (AAF*C). Participation in government programs is generated endogenously (see sections 3.2.4.3 and 4.5).

According to AAFC data, 40,924 and 32,681 Saskatchewan farmers participated in *AgriInvest* in 2007 and 2008 for participation rates of 92% and 74% respectively[67]. Saskatchewan farmers had a total *AgriInvest* account balance of approximately $196 million at the end of 2007, which works out to $5,686,867 for CAR 1A with an average farmer account balance of $4,801[68]. The simulated participation rates are much lower at 56.2% and 67.3% at the 2007 initialization and for the simulated 2008 year, with total account balances of $3,828,532 and $3,626,977 with an average of $9,495 and $7,651 per farmer agent participant. While participation in the program is lower, average *AgriInvest* account balances per farm agent participant are higher in the simulation from the aggregated AAFC data. The slightly higher account balances are likely a function of the initial producer reference margins based upon provincial averages[69]. Furthermore, the higher simulated average account balance per farmer agent is due to the fact

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[65] The percentages are based upon the annual crops used in the simulation and excludes other minor and specialty crops actually grown in CAR 1A.

[66] The total percentage of annual crops does not total 100% because of rounding error, farms exiting due to financial reasons where land remained idle and is the mean of 50 replicates.

[67] Participation rates are based upon the total number of farmers in Saskatchewan of 44,329 from the 2006 Census.

[68] Based upon the provincial participation rate for total farm participation of 1,184 famers out of the census total of 1,823 farmers.

[69] Initial reference margins were generated using Provincial historical prices and yields as described in Chapter 4 and thus these reference margins may not be entirely representative of CAR 1A.

that the sample size used that includes larger farms while excluding small hobby farms, skewing the average balance per farm. Although these initial account numbers and participation rates do not match the provincial data, the results are still reasonable for what might be expected for a given CAR.

In terms of *AgriStability*, the participation rate and the payments in the simulation seem to be a reasonable representation of the provincial data. The simulated participation 2008 rate is slightly under at 30.4% as compared to the provincial average of 49.4%. The provincial total compensation paid to farmers under *AgriStability* in 2008 was $53,631,884 or approximately $2,205,574 in terms of CAR 1A, while the total simulated payment was $756,588. The actual 2008 payout per farmer participating works out to be approximately $2,449, while the simulated payout is slightly higher at $3,528 per farmer agent participating. Again the initial reference margins used in the simulation might trigger higher compensation payouts under *AgriStability* because this simulation excludes smaller older farmers.

Overall, simulated government program participation rates are tricky to properly validate and in my case, seem to over pay producers primarily because of the use of aggregated Provincial data to generate initial reference margins. However, government payments are an important part of analyzing structural change in agriculture so excluding these programs from the simulation is not a viable alternative.

5.3 Simulated Long-run Structure of CAR 1A

This section presents the simulated structural change outcomes for each of the three scenarios. The three scenarios comprise the following: 1) base, 2) inclusion of energy crops at a constant price of $2/GJ and 3) inclusion of energy crops at a constant $4/GJ. Following Stolniuk (2008), farm structure, sector performance and energy crop adoption is simulated for each scenario using the same 50 bootstrapped price and yield 30-year time paths. In the following sections, simulation results are presented for 1) energy crop adaption, 2) farm financial structure and performance, 3) beef cow numbers, 4) general farm structure, 5) land market tenure and pricing and 6) government programs participation and payouts.

5.3.1 Simulated Land Use Overview

In the base scenario, marginal land use remains relatively stable over time with minor fluctuations in the source of marginal land that farmers use for forage. [70] The marginal land type used for baled hay is largely influenced by the price of hay, expected hay yield and herd profitability and therefore size. The proportions of one cut hayland [71]decrease over time while the proportions of other forage increase (Figure 5.2)[72, 73]

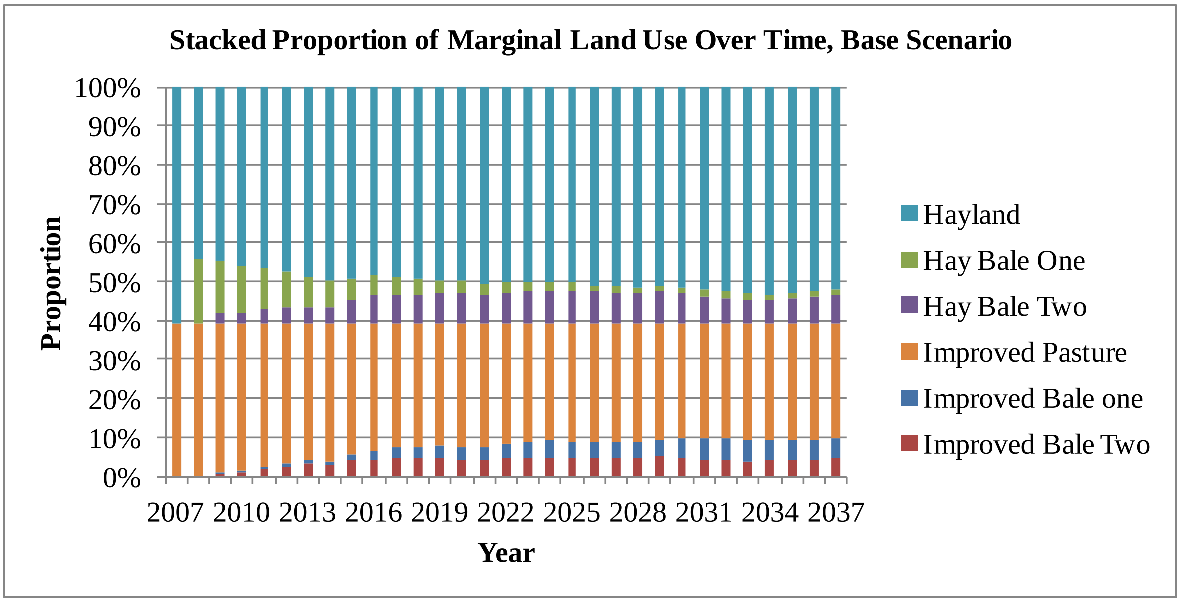

Figure 5.2 Marginal Land Use Over Time, Base Scenario

Consolidating all the hayland and improved baled acres into a single baled category allows the marginal land use over time to be more easily assessed. It is clear that total marginal land use remains virtually unchanged during the entire simulation (Figure 5.3)[74].

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[70] Note: 2007 represents the initialization period, while 2008 represents year one in the simulation. The 2007 period indicates the total proportion of hayland and improved pasture available allowing for comparisons of marginal land use over time.

[71] This refers to one early cutting followed by pasture.

[72] Other uses include: two- cut hayland, one and two cut improved land.

[73] The proportion of natural pasture is not included in the base scenario of land use over time because its land use does not change since its only use in the base scenario is for beef cow grazing.

[74] Note: The 2007 baled acres are zero percent because the LP/IP determines the baled acres in the initial year (2008).

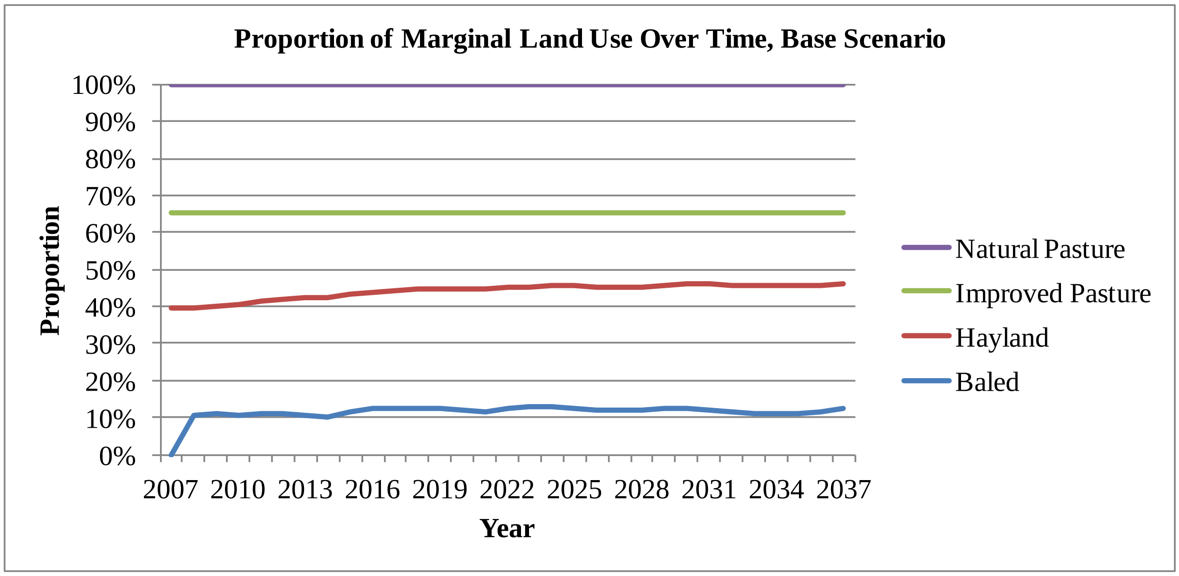

Figure 5.3 Marginal Land Use Over Time, Base Scenario by Land Use Type

In sharp contrast to the base scenario, marginal land use immediately shifts towards energy crops and continues to slowly change throughout the simulation period, as more acres are devoted to energy crops, for both the $2/GJ (Figure 5.4) and $4/GJ (Figure 5.5) energy scenarios. Over time, baled hay and pasture acres decline as more willow production increases and alters the use of marginal land. Natural pasture for beef cow grazing is displaced shortly after 2009 and is used entirely for energy crops. Improved pasture follows a similar pattern to natural pasture where it is displaced by 2012, with the exception of a small portion of improved baled acres that remains for forage.

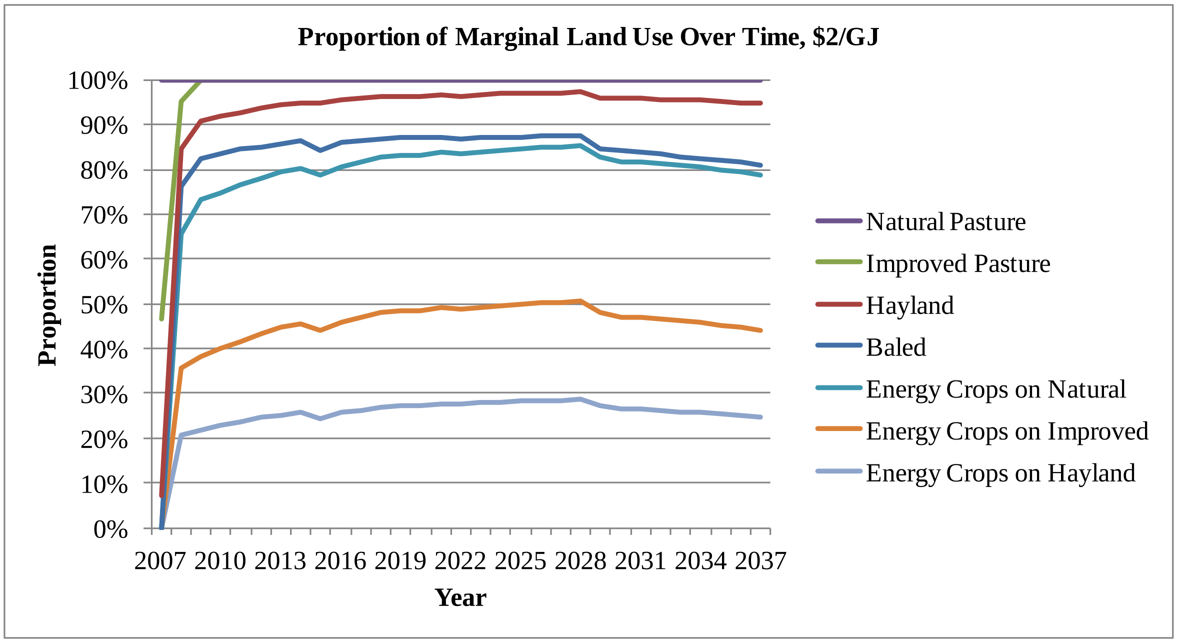

Figure 5.4 Land Use Over Time, $2/GJ Scenario

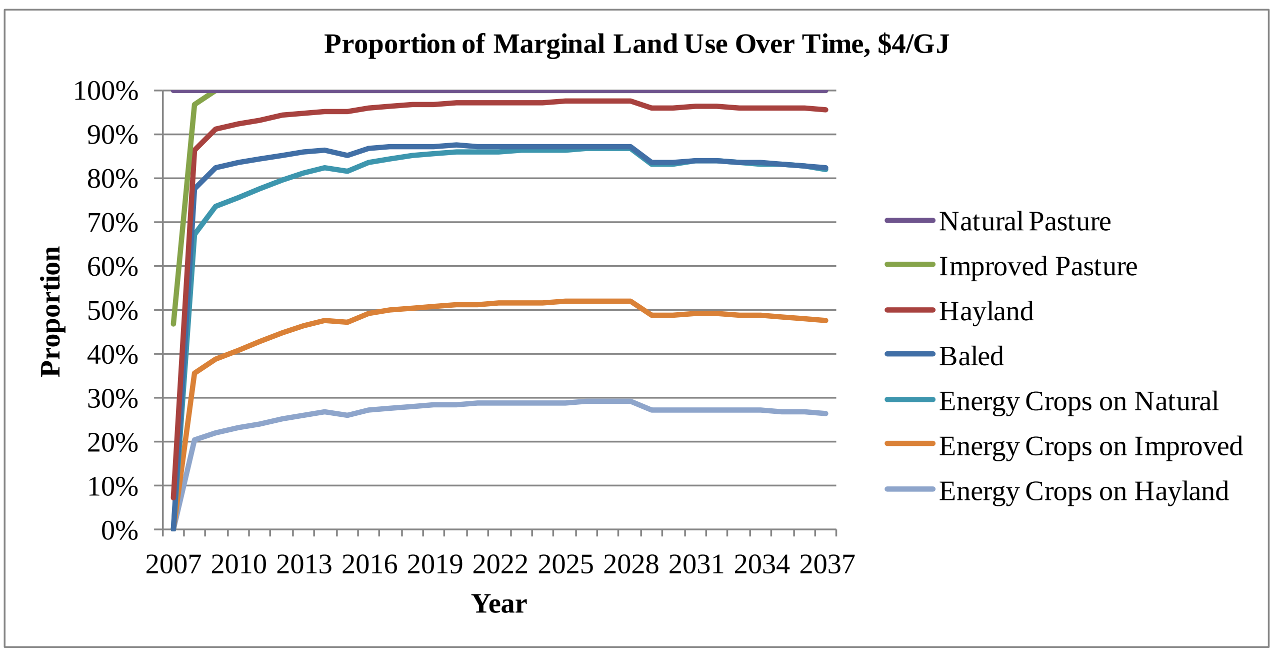

Figure 5.5 Proportion of Marginal Land Use Over Time, $4/GJ Scenario

5.3.2 Trends in the Adoption of Energy Crops

Energy crop acres are displayed for years 2008, 2014, 2021, 2029 and 2037 in Tables 5.6 and 5.7. These years were chosen to illustrate the change in acres over the simulated time period.

With the introduction of energy crops, farmer agents immediately respond by planting energy crops in both the $2/GJ and $4/GJ price scenarios. The $2/GJ scenario starts off in year 2008 with 160,597 acres of energy crops, of which 139,997 acres is for willow. Willow plantations seem to be the choice amongst farmer agents as these are the most profitable of the alternatives. Hybrid poplar generates a lower yield than willow and for this reason, the expected contribution margin to the farmer agent is always less than a willow plantation, thus we find that no acres are assigned to hybrid poplar[75]. This is not surprising, as implied in the discussion of Chapter Two: hybrid poplar would be better suited to the boreal forest of Northern Saskatchewan. Note finally that in the $4/GJ scenario, farmers increase energy crops by approximately an additional 2% of acres to 163,943 acres.

In both scenarios, energy crops shift into pasture lands first, followed by hayland. Since energy crops yields are similar between the two land types, this effect is as expected. Total energy crop acres reach approximately 80% of marginal lands by the years 2014 and 2020 in the energy price scenarios and approximately 86% of the marginal acres by 2020 in the $4/GJ scenario[76].

[75] Poplar was assumed to be harvested on the same rotation as willows; in future simulations longer poplar stands might produce different results.
[76] The percent of marginal land in Tables 5.6 and 5.7 refers to the total energy crop acres out of a total of 246,547 marginal acres.

Table 5.6 Simulated Total Average Energy Crop Acres, $2/GJ Scenario

Total Energy Crop Acres - $2/GJ Scenario									
Year	Willows Natural Pasture	Willows Improved Pasture	Willows Hayland Pasture	Prairie Sandreed Natural Pasture	Prairie Sandreed Improved Pasture	Prairie Sandreed Hayland Pasture	Total Energy Crop Acres	Energy Crop Percent of Marginal Land	Total Hay and Pasture
2008	67,469	31,880	40,648	6,008	4,970	9,623	160,597	66%	84,347
2014	79,369	43,619	52,381	5,388	5,155	10,336	196,248	80%	48,022
2020	82,947	49,813	62,283	1,708	1,855	4,077	202,683	83%	40,714
2021	83,351	50,576	63,957	1,631	1,703	3,803	205,020	84%	39,787
2029	84,056	49,566	63,514	1,180	1,291	3,058	202,664	83%	42,598
2037	84,294	46,595	57,972	1,006	1,036	2,548	193,451	79%	52,082

Table 5.7 Simulated Total Average Energy Crop Acres, $4/GJ Scenario

Total Energy Crop Acres - $4/GJ Scenario									
Year	Willows Natural Pasture	Willows Improved Pasture	Willows Hayland Pasture	Prairie Sandreed Natural Pasture	Prairie Sandreed Improved Pasture	Prairie Sandreed Hayland Pasture	Total Energy Crop Acres	Energy Crop Percent of Marginal Land	Total Hay and Pasture
2008	70,975	32,916	42,485	5,852	4,356	7,358	163,943	67%	81,065
2014	79,654	48,596	58,454	5,628	4,433	7,978	204,744	82%	43,789
2020	83,404	55,235	68,327	1,688	1,687	3,071	213,411	86%	35,002
2021	83,624	55,613	68,539	1,475	1,341	2,805	213,396	86%	34,806
2029	84,257	52,601	65,138	1,063	949	2,258	206,267	83%	41,057
2037	84,492	51,352	63,119	896	834	1,931	202,624	82%	44,217

Over time, energy crop acres in prairie sandreed shrink as land shifts into willow acres. Initially, Prairie sandreed is adopted by the agents because of the high investment cost associated with adopting willow production and credit constraints. As tall grass prairie sandreed comes to its life-cycle end, the marginal acres are then converted to willow production. Once again, Prairie sandreed is displaced by willow because of the higher contribution margin associated with willows.

5.3.2.1 Simulated Adoption of Energy Crops by Farmer Type

Initially, beef cow farms are the predominant farm type adopting energy crops. They account for 74.3% of the energy acres, while mixed farms and crop farms have 15.4% and 10.4% of these acres respectively. The reason is simply because they have the most marginal land. What is surprising within the simulation is that a reduction in herd size does not accompany reduced pasture and hay acreages. This seems to be something of an artifact of the model assumptions since beef cow farms are able to maintain their herd size through their existing higher quality hayland and through purchased forage and grains.[77] Apparently herd gross margins in the model are sufficient to maintain existing numbers in the short-run with purchased feeds.

Over time, both grain and mixed farms include more energy crops, increasing their overall share (Table 5.8). At the end of the simulated period, mean energy crop shares are 10.9%, 23.4%, and 65.0% respectively, for grain, mixed farms and beef cow farms in the $2/GJ scenario. Similarly, the $4/GJ scenario generates mean crop shares of 10.4%, 23.9% and 65.3% for grain, mixed and beef cow farms. Mixed farms increase their energy acres relatively more than the others as they have the greatest flexibility in utilizing all land types.

Table 5.8 Simulated Mean Energy Crop Acres by Farm Type

Scenario $/GJ	Year	Grain Farmer Agent	Mixed Farmer Agent	Livestock Farmer Agent
$2/GJ	2008	49	169	533
	2037	95	373	1003
$4/GJ	2008	52	177	538
	2037	96	396	1009

The total energy crop acres grown by farm classification are shown in Table 5.9. Beef cow farms grow the majority of the energy crops with 119,944 and 121,059 acres initially, for the $2/GJ and $4/GJ scenarios respectively. Mixed farms have the greatest increase in energy crop acres with 45,351 and 48,487 for each of the $2/GJ and $4/GJ scenarios by the year 2037. The average annual increase in these acres for the mixed farms is approximately 2.2%, while the grain and livestock farms both had an average annual increase of less than one percent in both energy scenarios.

[77] Forage and hay markets are determined exogenously in the simulation and the local demand for hay is not fed back for a price response, thus future simulation models might want to have the price of forage determined endogenously through a local hay market.

Table 5.9 Simulated Total Energy Crop Acres by Farm Types

Scenario	Year	Grain Farms	Mixed Farms	Beef Cow Farms
$2/GJ	2008	16,365	24,284	119,944
	2037	21,000	45,351	125,656
$4/GJ	2008	17,367	25,517	121,059
	2037	21,086	48,487	132,311

5.3.3 Beef cows and Forages

The implications on beef cows and forage structure from the introduction of energy crops are discussed in this section. Beef cows and forage structure includes beef cow numbers, baled hay and forage production acres for the base and energy crop scenarios.

5.3.3.1 Estimated Mean Beef Cow Numbers

In all scenarios, simulated mean beef cow numbers decrease initially for the first ten years and then steadily increase over the remaining simulated period (Table 5.10 and Figure 5.6). At the simulation starting point, 2008 is a point in time when the beef-cycle is at its bottom. The initial herd sell-off is due to prices, while the health of the beef cow sector depends primarily on the price and yield time paths of calves, barley and hay (Stolniuk 2008). Calf prices initially start out very low and through five-year adaptive expectations, producers deplete herd numbers. Calf prices then recover and it takes a few years to convince farm agents that the beef cycle is turning upwards and that they should rebuild their herds. This effect is shown in Figure 5.7. Next, the response is not immediate because heifers must be purchased or raised and there is a natural biological lag before calves are finally sold. Also note that hay prices are somewhat negatively correlated with both herd size and the price of hay, and hence hay prices increase. This appears to be a much larger factor in the energy crop scenarios where more purchased feed is used. Beef cow profitability is also affected by the lumpiness of herd investment, meaning that after a certain size, some associated facilities must be expanded.

In the base case scenario, beef cow numbers stop at a herd size of 29,487, a number that is essentially unchanged from its starting value of 29,284 – translating to an average annual increase of only 0.02%. In the energy crop scenarios, initial herd size also decreases in the first ten years and then remains relatively constant around 12,000 to 15,000 cows, depending on the energy scenario. The final beef cow numbers for $2 and $4 per GJ scenarios are 19,206 and 17,167 respectively. And the average annual decline in beef cow numbers in the energy scenarios are -1.41% and -1.76% for the $2/GJ and $4/GJ prices.

Table 5.10 Simulated Mean Beef Cow Numbers, by Scenario

Year	Base	$2/GJ	$4/GJ
2007	29,284	29,413	29,251
2008	28,635	29,402	29,242
2014	17,682	14,822	14,189
2020	19,837	13,172	12,012
2021	19,655	12,992	11,660
2029	23,648	14,466	13,293
2037	29,487	19,206	17,167
Mean Annual Change	0.02%	-1.41%	-1.76%

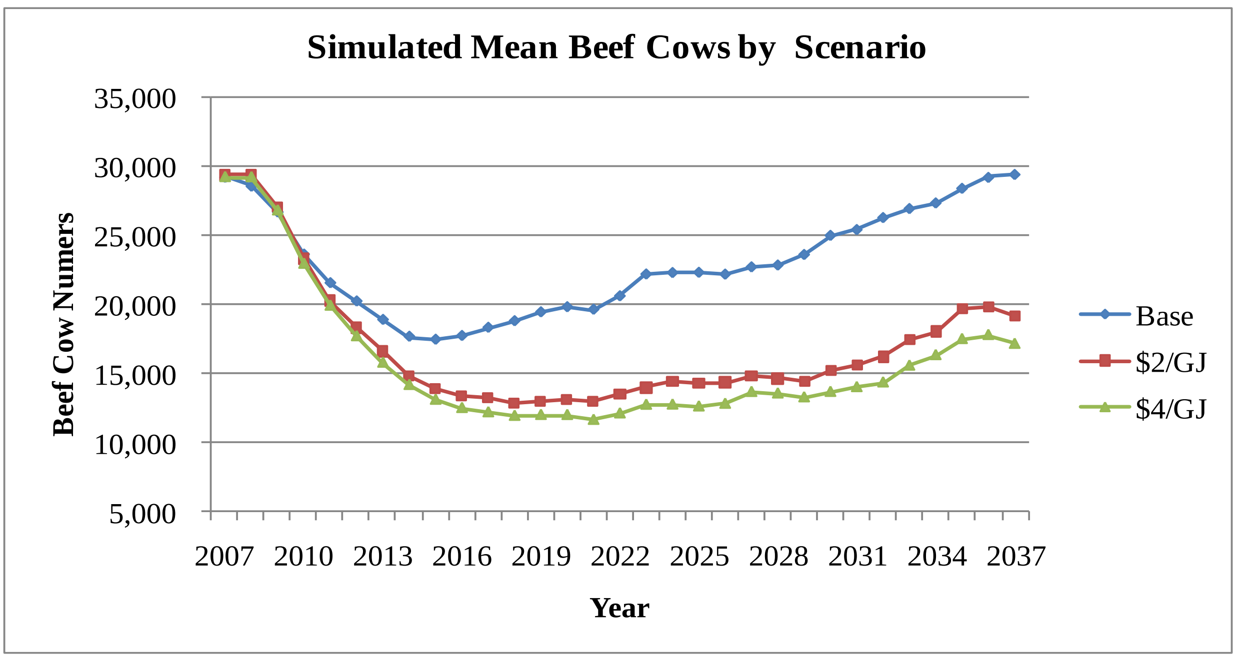

Figure 5.6 Simulated Mean Beef Cow Numbers by Scenario

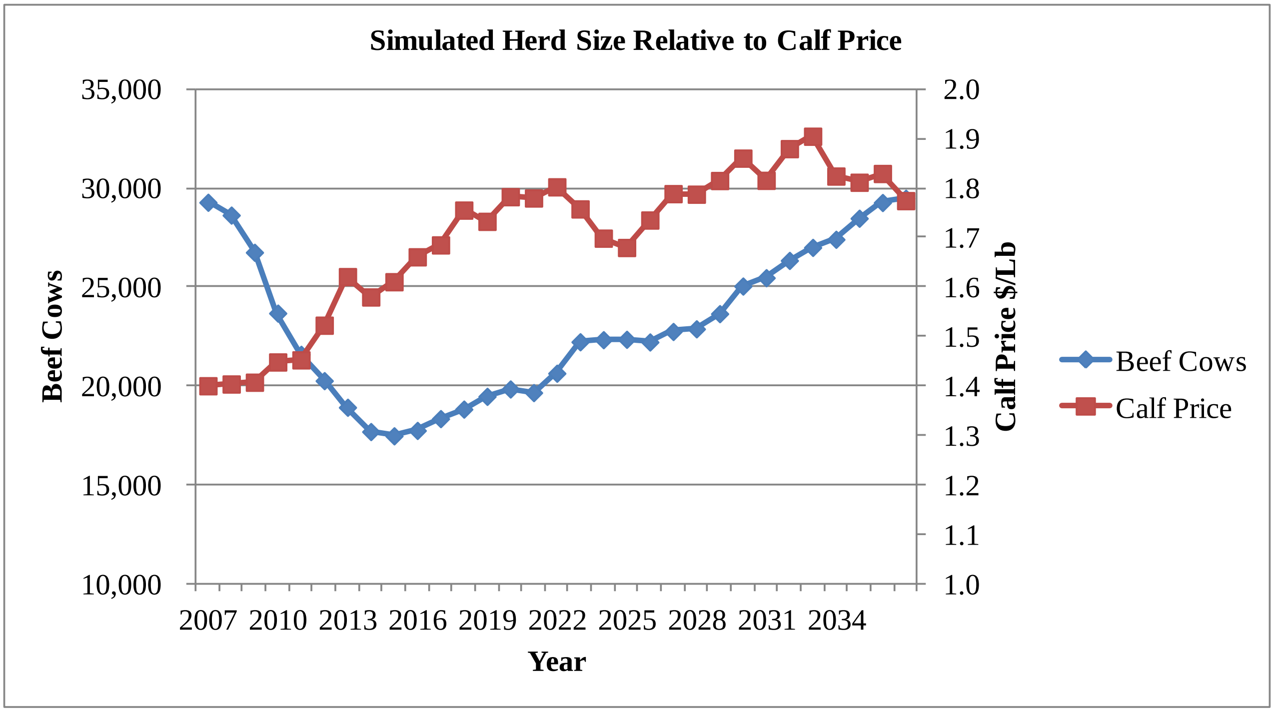

Figure 5.7 Simulated Herd Size Relative to Mean Calf Price

5.3.3.2 Baled Hay and Forage Production

In the base scenario, baled hay acres remain relatively constant throughout the simulation with starting acres of 26,002 and final acres of 29,992, for an average annual change of 0.48% (Table 5.11 and Figure 5.8). Total baled acres initially decrease for the first seven years then increase sharply, followed by a fluctuating but stable period for the next 20 years after which they increase until ending the simulated period slightly higher than initial levels. In the early years of depleted cow numbers, excess hay production is sold or hayland is shifted to pasture, which results in less efficient utilization. When herd numbers recover, hay is no longer sold but used for feed and / or forage efficiency is increased.

With the introduction of the energy crop, hay and forage baled acres shift into energy crop production. Baled acres of hay and forage continue to decline in each energy crop scenario. They fall by -5.12% annually to final baled acres of 5,366 in scenario \$2/GJ, to as low as -12.79% annually in the \$4/GJ scenario with only 428 baled acres.

While hay and calf prices are negatively correlated, hay price is determined exogenously and since there is no feedback from herd numbers in the model, forage land utilization might be different if hay output was rendered endogenous to the model.

Table 5.11 Simulated Total Baled Acres

Year	Base	$2/GJ	$4/GJ
2008	26,002	25,996	25,942
2014	24,038	14,513	10,385
2020	29,695	9,447	3,998
2021	28,303	8,168	3,135
2029	29,838	5,114	571
2037	29,992	5,366	428
Mean Annual Change	0.48%	-5.12%	-12.79%

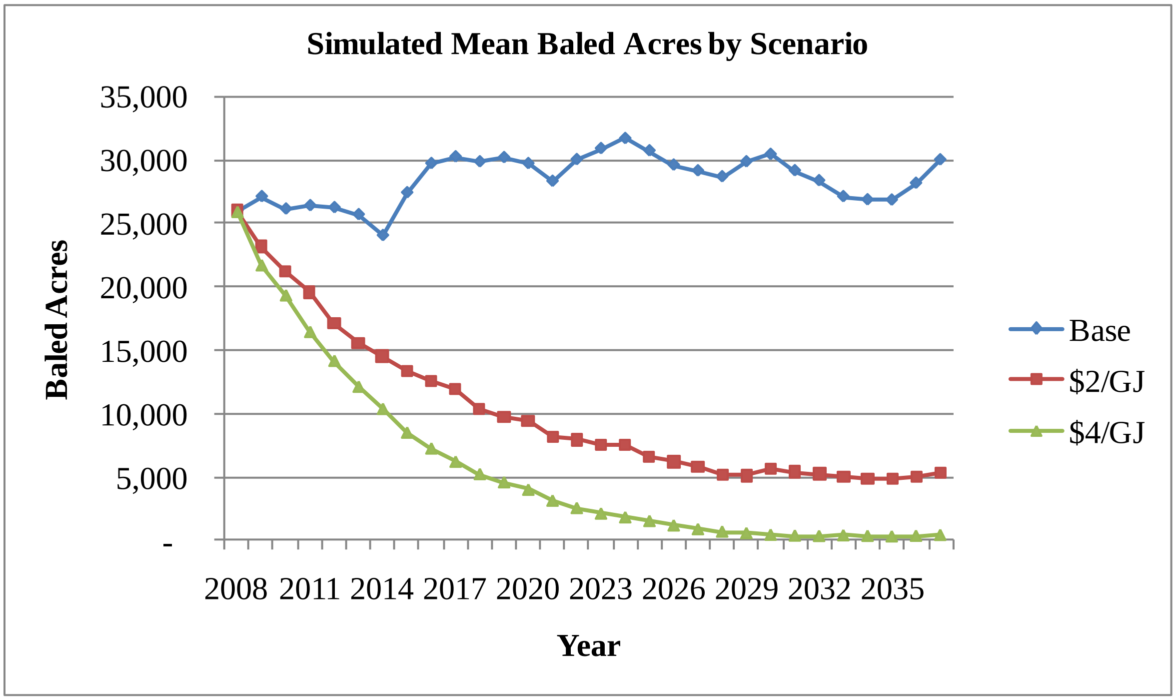

Figure 5.8 Simulated Mean Baled Acres by Scenario

5.3.4 Farm Financial Structure and Performance

Assessing total sector well-being in the standard static economic sense of producer welfare or surplus is necessarily difficult because of the dynamic interplay of factors such as investment decisions, cash flows, off-farm income and income taxes. Accordingly, sectoral well-being and vitality is appraised by comparing simulated to actual farm financial structure. To gauge farm financial viability and long-run growth in net worth, financial characteristics in the model are tracked via a balance sheet approach following Stolniuk (2008). Measures of sector well-being used in this simulation include total sector income, equity and structural change associated with farm numbers, farm transfers, bankruptcies, cash flow exits and retirements. The latter are included in farm financial structure because they are directly related to the overall financial solvency and liquidity of the farm. These elements are reviewed in the following section.

5.3.4.1 Trends in Sector Equity

The base case scenario generates a final farm equity average increase of 3.66% per year over the 30 years, culminating with a final value of just over $2.3 billion (Table 5.12). The first energy crop scenario equity at $2/GJ is only slightly higher than the base scenario at $2.53 billion with an average annual increase of 3.93%, meaning the latter is close to a break-even situation. In fact, total sector equity is the greatest under the $4/GJ energy crop scenario at $3.57 billion, a total generated by an average annual increase of 5.12%.

Table 5.12 Simulated Total Farm Sector Equity CAR 1A

	Year	Base	$2/GJ	$4/GJ
Initialization - Year 0	2007	$ 786,290,901	$ 797,152,874	$ 796,645,874
Year - 30	2037	$ 2,310,123,821	$ 2,531,337,181	$ 3,567,794,003
Average Annual Change		3.66%	3.93%	5.12%

5.3.4.2 Simulated Net Farm Income

Net farm income is an important component in generating farm equity. In order to examine the impact of energy crops, farm income sources are delineated in this section. In the first year of the simulation (2008), save for tall grass Prairie sandreed, energy crops have little effect as their income is delayed - total sector net income from energy crops runs from $118,655 to $366,444 respectively (Table 5.13). The initial energy crop income generates returns of $5.76 and $20.86 per acre for Prairie sandreed in the $2/GJ and $4/GJ scenarios respectively. However, by the end of the 30-year simulation period, mean energy crop net income ranges from $33.4 million to $104.3 million, respectively, for $2/GJ and $4/GJ scenarios. The $2/GJ energy crop net income represents a per acre return of approximately $173 per acre per year or $518 per acre when the estimated majority of the biomass is only harvested every three years. The return in the $4/GJ scenario corresponds to approximately $514 per acre per year or $1,545 per acre over three years when the $104.3 million is averaged amongst the 202,624 acres of energy crops.

Net crop income is minimally affected by the introduction of energy crops because they compete for different land qualities. However, there may be indirect effects on sector health as cash flow is improved, facilitating investments and thus potentially improving sector efficiency.

On beef cow farms most if not all (at least in the later years) hay production is transferred to the beef herd. Since internal transfer credits are not generated, net hay income is accordingly negative.[78] In the case of the base scenario, net hay income eventually becomes positive because of increasing hay sales, although it is still relatively small. Subsequently, net hay income drops over time in the energy crop scenarios compared to the base scenario, while this drop occurs because of the shift in acres to energy crops. By the end of the simulation, mean sector net beef cow income decreases from the base scenario compared to the $2/GJ energy crop scenario by approximately $504,799 from $19.6 million to $19.1 million despite the beef cow herd size being just over 10,000 cows less. In addition, beef cow income also includes hay sales and in the base scenario it is likely that some farmer agents were losing money on their hay sales. As mentioned, the price of hay is determined endogenously and in some years when the hay contribution margin is high, significant hay is grown for resale. Finally, beef cow income decreases to $9.4 million in the $4/GJ price scenario.

Energy income increases with virtually no change in livestock income because beef cow herds are maintained in the simulation through the highest productivity hayland and through purchased feeds. In addition energy crops grown on the lowest productivity rated marginal land plots maintain sufficient biomass yields, allowing for increased income on the lower pasture productivity plots. Energy crop yields, primarily willow yields, improve as the stand becomes more mature (refer to Table 4.10 in Chapter 4). The increase in harvestable yields as willows age directly affects the contribution margin of energy crops to increasing net income per acre.

[78] Net hay income is included as beef cow income for beef cow farmers because the costs associated with growing hay are difficult to separate when a proportion is sold and another is fed.

Table 5.13 Simulated Mean Total Net Income, by Scenario

Scenario	Year	Total Income	Energy Income	Crop Income	Hay Income	Beef Cow Income
Base	2008	$ 65,884,964	$ -	$ 56,492,402	-$ 16,798	$ 9,409,360
	2037	$119,668,633	$ -	$ 99,627,133	$ 428,893	$ 19,612,606
$2/GJ	2008	$ 67,153,155	$ 118,665	$ 57,719,646	-$ 16,793	$ 9,331,637
	2037	$158,987,397	$ 33,421,518	$ 106,431,835	$ 26,236	$ 19,107,807
$4/GJ	2008	$ 67,468,152	$ 366,444	$ 57,804,753	-$ 16,789	$ 9,313,744
	2037	$214,968,470	$ 104,317,938	$ 101,216,065	-$ 6,341	$ 9,440,807

5.3.4.3 Simulated Mean Number of Farmer Agents

The stability of farm population is a concern to rural villages and their associated infrastructure. In fact, all scenarios generate the same long-run average decline in the number of farms, as displayed in Figure 5.9 below. The base scenario has a final mean population of 434, representing an average annual population decline of approximately 1.66% per year. But the introduction of energy crops tends to stabilize the farm population somewhat, as the mean ending farm numbers in the two energy crop scenarios ranged from 469 to 471 farms, respectively, for the $2/GJ and $4/GJ scenario. Thus, the energy crop scenarios lead to an increased population of 8.1% - 8.5% over the base scenario. While this indicates energy crops actually will have a limited impact on structural change, the proximity of the two final population numbers indicates that increasing energy prices more would likely have little effect on farm numbers.

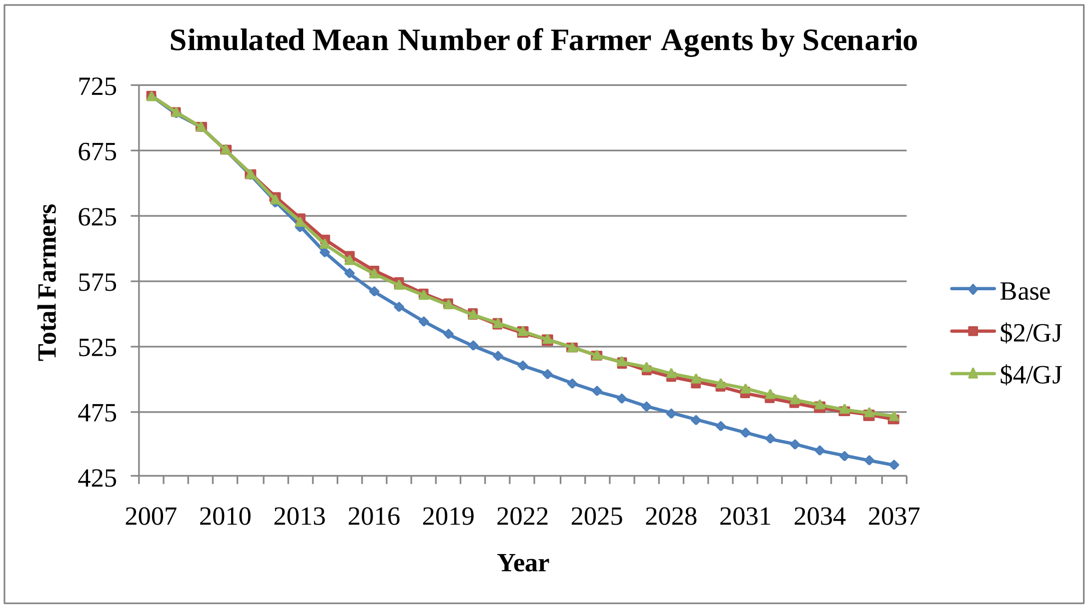

Figure 5.9 Simulated Mean Number of Farmer Agents by Scenario

One of the other benefits associated with the depth and detail of the MIXFARM-ABM model is that farm succession and exits can be examined in order to assess the dynamics of farm transitions (Table 5.14). We find that energy crops help farms survive across generations. as indicated by increased farm transfers over the base scenario. There are some differences between the two energy crops scenarios, as slightly more farmers retired with no subsequent intergenerational transfer under the $4/GJ scenario. In the $4/GJ scenario mean farm transfers totalled 479 over the entire 30 years, as compared to 486 farm transfers associated with the $2/GJ scenario. This reduction in farm transfers is likely due to increased farm equity allowing early exit.

The increased accumulated equity and improved cash flows associated with the $4/GJ scenario also resulted in fewer exits associated with bankruptcies. A total of 34 were generated as compared to 42 bankruptcies found in the base and $2/GJ scenario, meaning a reduction of 19%. More generally, even though the farm business may be technically solvent, premature farm exits can be caused by chronic cash flow deficits (cash flow exits). In these cases, the introduction of energy crops reduced farm forced cash flow exits, averaging 125 farms as compared to the base scenario of 161 farms, an improvement of approximately 22% over the base scenario. In addition, farmer retirement exits increased between 3.7% and 7.5% from the base scenario as compared to the $2/GJ and $4/GJ respectively. Total farmer retirements in each scenario were 83 and 86 individuals respectively in the energy scenarios, as compared to 80 in the base.

Table 5.14 Simulated Mean Structural Change Results at Year 2037

	Base Scenario	Energy Scenario $2/GJ	Energy Scenario $4/GJ
Ending Farm Numbers	434	469	471
Farm Transfers	468	486	479
Bankruptcies	42	42	34
Cash Flow	161	124	125
Retirements	80	83	86

5.3.5 Long-run Impact of Energy Crops on Farm Structure

This section examines the potential impacts on general farm structure stemming from the adoption of energy crops. General farm structure includes mean farm size, mean crop acres, distribution of farm size and changes in farm agent numbers by farmer agent type.

5.3.5.1 Simulated Farm Size

At the end of 30 years, the base case mean farm size sits at 2,524 acres and is the largest of all the scenarios due to of its smaller farm population (Table 5.15 and Figure 5.10). The introduction of energy crops allowed more farm agents to remain, leading to mean farm sizes of 2,340 and 2,327 acres respectively for the $2/GJ and $4/GJ scenarios. The energy scenario most affects farm sizes falling between 1,920 and 2,560 acres. In the energy price scenarios, very few time paths generated mean farm sizes greater than 3,200 acres.

Table 5.15 Simulated Distribution of Farm Size, 2037 by Scenario

	Farm Acres							
Scenario	< 1920	1920-2240	2240-2560	2560-2880	2880-3200	3200-3520	3520-3840	3840-4160
Base	0	5	30	7	5	2	0	1
$2/GJ	0	18	22	8	1	0	1	0
$4/GJ	0	19	22	7	1	1	0	0

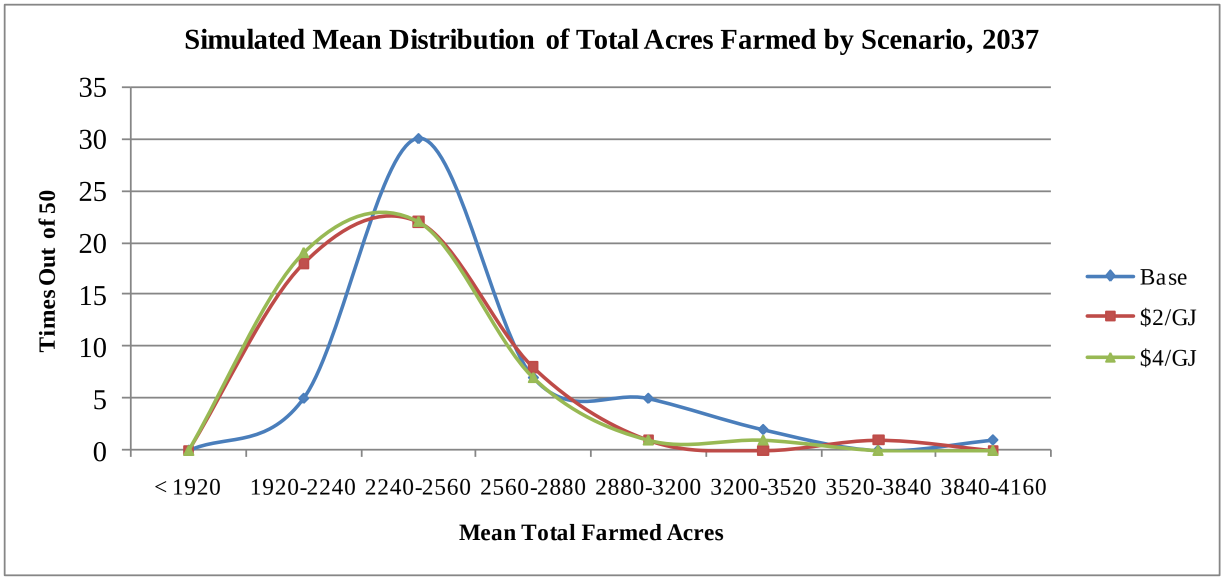

Figure 5.10 Simulated Mean Distributions of Total Acres Farmed by Scenario, 2037

The distribution of mean crop acres follows a similar distribution to that of total mean farm size. The output in Table 5.16 indicates that with an alternative option for investment such as energy crops, more farmers stay in business and this effect in turn reduces average farm size. Crop acres dominate the base scenario, while energy crops stabilize mixed and beef cow farms, and keep farm size and crop acres relatively small.

Table 5.16 Simulated Mean Distribution of Total Crop Acres 2037 by Scenario

	Crop Acres					
Scenario	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880	2880-3200
Base	1	26	15	6	1	1
$2/GJ	4	33	11	1	0	1
$4/GJ	6	34	8	1	1	0

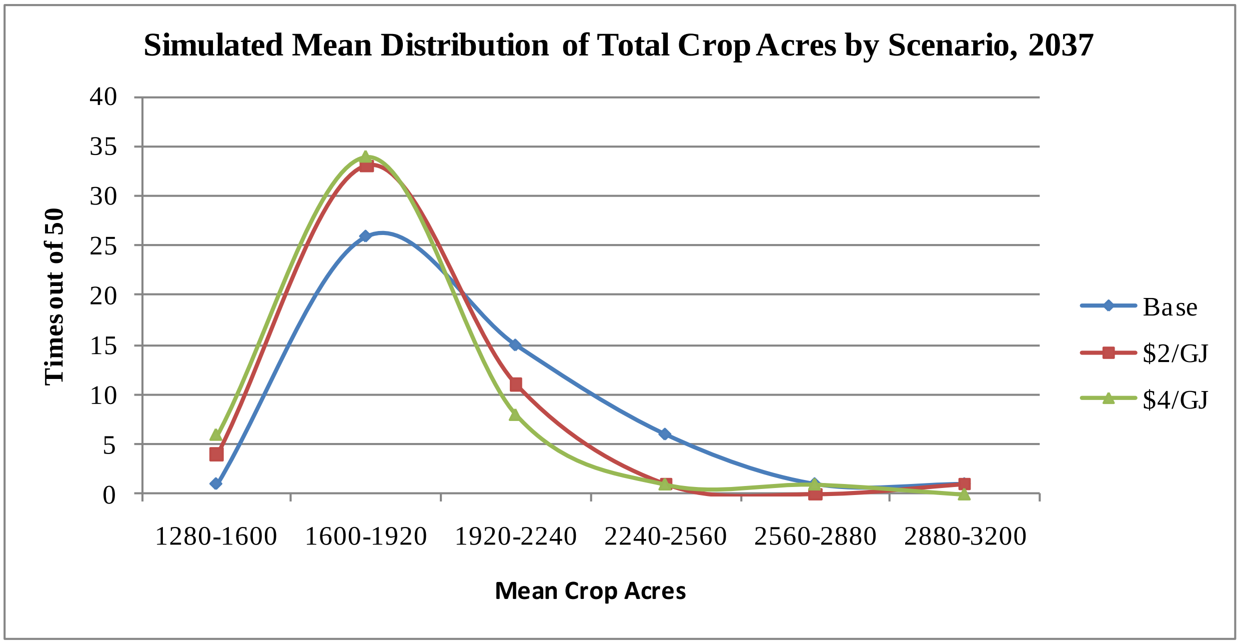

Figure 5.11 Simulated Mean Distributions of Total Crop Acres by Scenario, 2037

Average acres farmed increased by an average annual rate of 1.65% in the base scenario and between 1.38% and 1.40% in the energy crop scenarios (Table 5.17). This pattern is consistent with historical and other simulated trends (refer to Stolniuk 2008, Freeman 2005).

Table 5.17 Simulated Mean Farm Size by Land Quality by Scenario, 2037

	Year 2007	Ending Acres by Scenario 2037			Average Annual Change		
Land Use	All Scenarios	Base	$2/GJ	$4/GJ	Base	$2/GJ	$4/GJ
Total Acres Farmed	1,533	2,524	2,340	2,327	1.65%	1.40%	1.38%
Total Crop Acres	1,189	1,959	1,816	1,806	1.65%	1.40%	1.38%
Total Hay Land Pasture Acres	136	224	203	207	1.65%	1.33%	1.39%
Total Improved Pasture Acres	88	145	135	134	1.65%	1.41%	1.39%
Total Natural Pasture Acres	119	196	182	181	1.64%	1.40%	1.38%

Mixed farmer agents experience the smallest average annual decline in farm numbers with an average annual change of -0.71%, -0.56% and -0.54% in the base scenario, compared to the $2/GJ and $4/GJ scenarios (Table 5.18). The higher number of remaining mixed farmer agents confirm that these agents possess a competitive advantage in terms of land use alternatives due to their inherent flexibility over grain farms and greater scale over beef cow herds. Grain farmer agents produce the next lowest average annual decline in remaining farmer agents. The remaining grain farmer agents in each scenario do not vary considerably, fluctuating between

-1.45% and -1.54%, while the introduction of energy crop scenarios has the least impact on land use decisions.

Although, beef cow farmers still have the greatest overall average annual change in remaining farmer numbers at -2.8%, -2.06% and -1.91% respectively, beef cow farmer agent numbers are affected most from the introduction of energy crops, with an improvement of approximately 23.8% over the base scenario.

Table 5.18 Simulated Changes in Farm Numbers by Farm Type by Scenario

	Initialized Farmer Agents	Ending Farm Agents By Scenario			Average Annual Change		
Farm Agent Type	All Scenarios	Base	\$2/GJ	\$4/GJ	Base	\$2/GJ	\$4/GJ
Grain Farmer Agents	342	216	222	218	-1.54%	-1.45%	-1.52%
Mixed Farmer Agents	144	117	122	122	-0.71%	-0.56%	-0.54%
Livestock Farmer Agents	231	101	125	131	-2.80%	-2.06%	-1.91%
All Farmer Agents	717	434	469	471	-1.69%	-1.42%	-1.41%

5.3.6 Simulated Land Markets

This section evaluates land prices in both the purchase and lease land markets. Farmland prices are an extremely important component of structural change and sector health. Purchased farmland becomes an important part of farm equity and via the balance sheet feedback loop, affects the ability of an individual to borrow in the future.

In the MIXFARM-ABM model, farmland market prices are unstable and possibly complex. Individual farmland patches come up for purchase because of a farm exit or retirement, or because a non-farming owner is not obtaining their required rate of return. As these land patches become available, they are placed in individual auctions. If surrounding agents have sufficient equity and financial resources they are allowed to bid on the patches. But their bid values are based on a set of heterogeneous individual characteristics like expectations, risk aversion, financial base, age and location. Since there is no single auction for farmland over time but instead a series of auctions, there can be many transacted land prices with no easily discernible single equilibrium price. Likewise, in some years only a few parcels may be transacted and their associated bid prices can appear to be particularly unstable. Hence, while mean prices are reported this represents a tendency not an equilibrium price.

So in order to compare the relative changes, prices and number of transactions are reported separately for the cropland and marginal land auctions. Note that under conditions of extremely low commodity prices, the farmland auctions can fail to file willing buyers so that some productive farmland lies idle until the following season..

5.3.6.1 Cropland Purchase Markets

In Figure 5.1, after the first few years of the simulation (as commodity markets recovered to more historic values) mean cereal, oilseed and pulse prices approach historical averages. However, this does not result in stable farmland prices (Figures 5.12- 5.15), likely due to the simulated farms becoming more efficient as they shift to improved technology and gain economies of size and scale. All three scenarios examined here start at a market price of $453 per acre, but by 2037 the mean prices are $1116, $1053 and $1611 per acre, respectively for the base scenario, $2/GJ and $4/GJ scenario. This results in final land price differentials of -5.0% and 44.4%, respectively, for the $2/GJ and $4/GJ scenarios over the base scenario.

When re-examined as an annual rate of increase, we find that mean cropland purchase prices possessed a 3.2% average annual increase in land values over the simulated period for the base scenario. Paradoxically, I found that while the $2/GJ scenario was somewhat more profitable than the base scenario, conditions of the scenario delayed farm exits, resulting in a slightly lower average annual increase of 3.0% in land prices. Conversely, the increased profitability in the $4/GJ price scenario increased bid prices of both cropland and marginal farmland markets, producing an average annual increase in the mean value of land of 4.5%. This spillover effect to the cropland market occurs because increased available cash leads to more qualified buyers and fewer exits with increased competition.

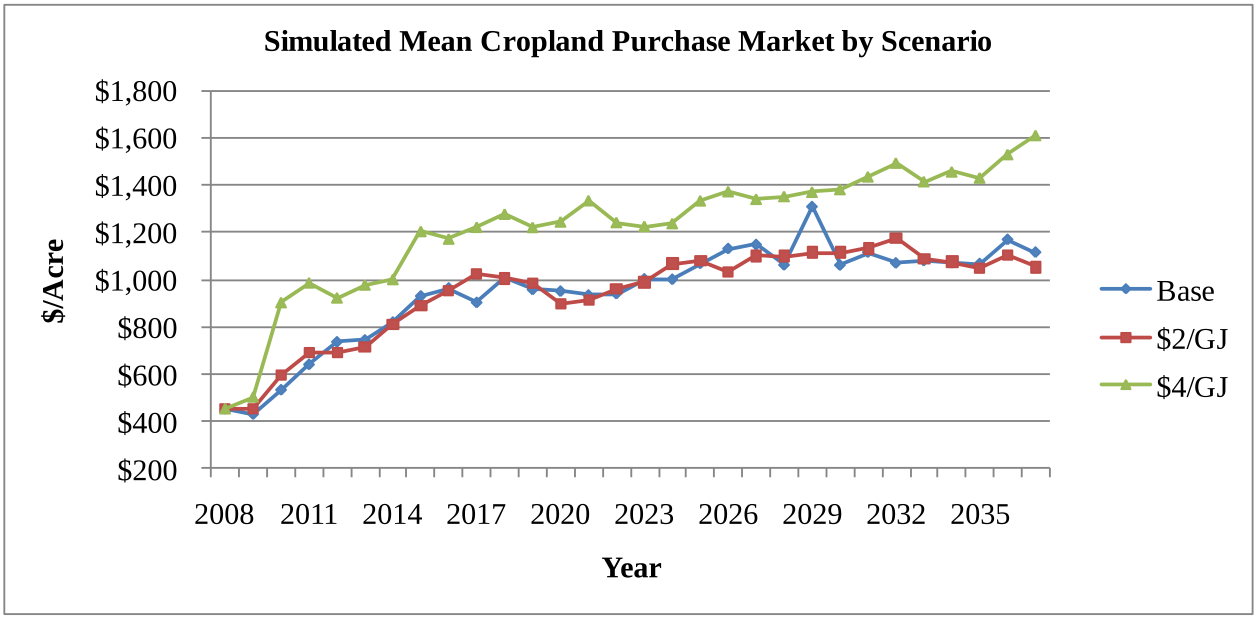

Figure 5.12 Mean Cropland Purchase Prices

5.3.6.2 Marginal Land Purchase Market

Interestingly, even though energy prices are fixed, marginal farmland prices vary because of the beef cycle and their degree of substitutability with cropland (Figure 5.13). The initial mean marginal land prices are $280 per acre, while the base and mean 2037 ending values (annual percentage increase) are $682 (3.1%), $685 (3.1%) and $1043 (4.6%) per acre, respectively, for the base, $2/GJ scenario and $4/GJ scenario. Since a $2/GJ energy price is only slightly more profitable than the base scenario, it should be that the final values should be similar. However, the much greater $4/GJ price clearly indicates that there are high returns being earned from energy crops, a fact also evident in the marginal land market. The $4/GJ marginal land price was significantly higher (approximately 53%) than that generated under the base scenario.

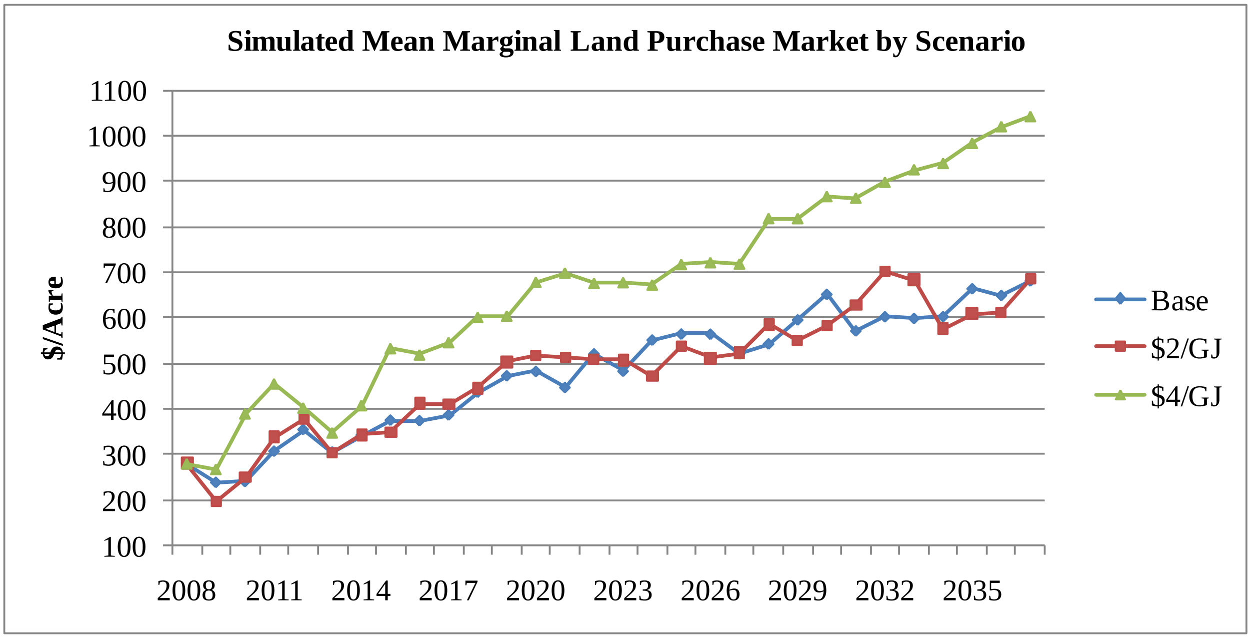

Figure 5.13 Simulated Mean Marginal Land Purchase Market by Scenario

5.3.6.3 Cropland Lease Markets

While the cropland lease market follows a similar trend to that of the cropland purchase market, it generates slightly higher average annual increases than the purchase market (Figure 5.14). Although they vary by parcel quality, mean initial lease values for cropland are $23 per acre. The 2037 ending lease values (annual percentage increase) are $68 (3.8%), $63 (3.6%) and $92 (4.9%) per acre for the base, $2/GJ and $4/GJ simulations. The $4/GJ price scenario generates a cropland lease value increase of about 35% over the base scenario as of the final year, while the $2/GJ price scenario fell 7% in 2037 as compared to the base scenario.

The annual percent increase in lease over purchase prices reflects the increased breadth of leasing markets attributable to increased market turnover and the greater number of potential number of bidders. Leased land is easier to cash flow than purchased farmland.

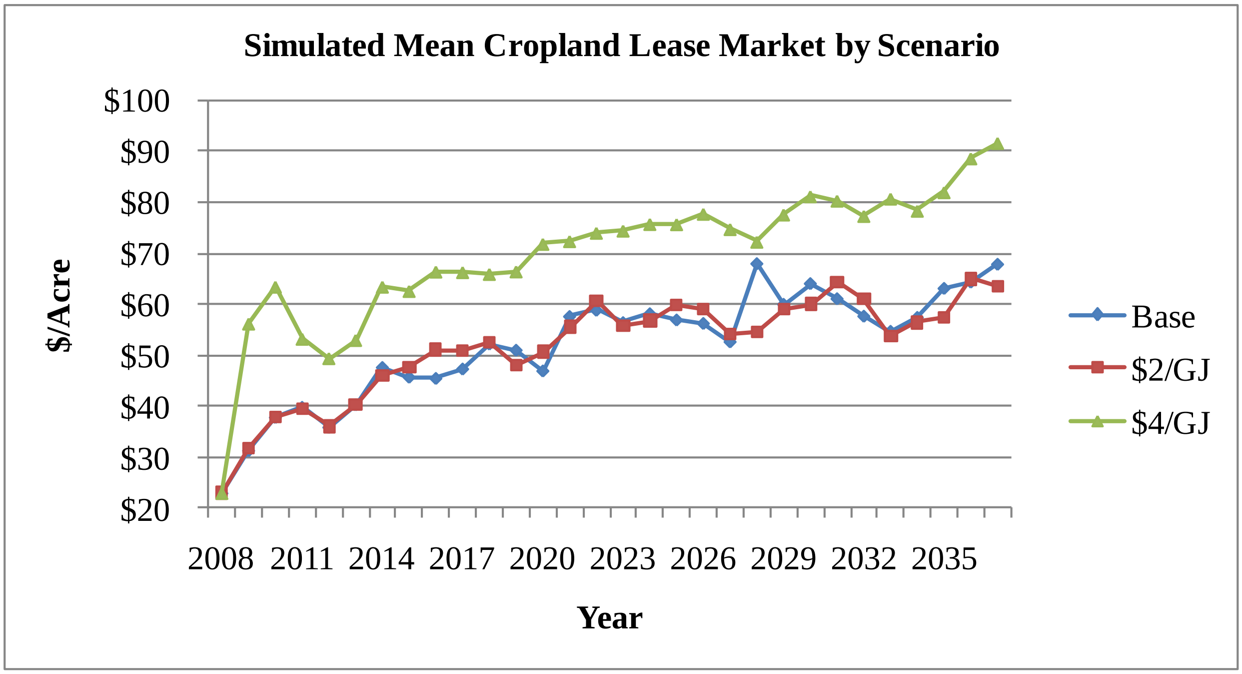

Figure 5.14 Mean Cropland Lease Prices by Scenario

5.3.6.4 Marginal Land Lease Markets

For the most part, marginal land lease rates generated under the two energy crop scenarios are higher than those of the base scenario. The introduction of energy crops ($2/GJ scenario) results in an almost 12% greater ending lease value in the year 2037 than the base scenario, producing a lease rate of $42 per acre compared to $37 per acre. The lease rate is nearly 70% higher in the final value of the $4/GJ scenario over the base scenario (at $63 per acre). The average annual increases in marginal land lease rates for each of the base, $2/GJ and $4/GJ scenarios were 3.7%, 4.1% and 5.6% respectively over the entire simulated period.

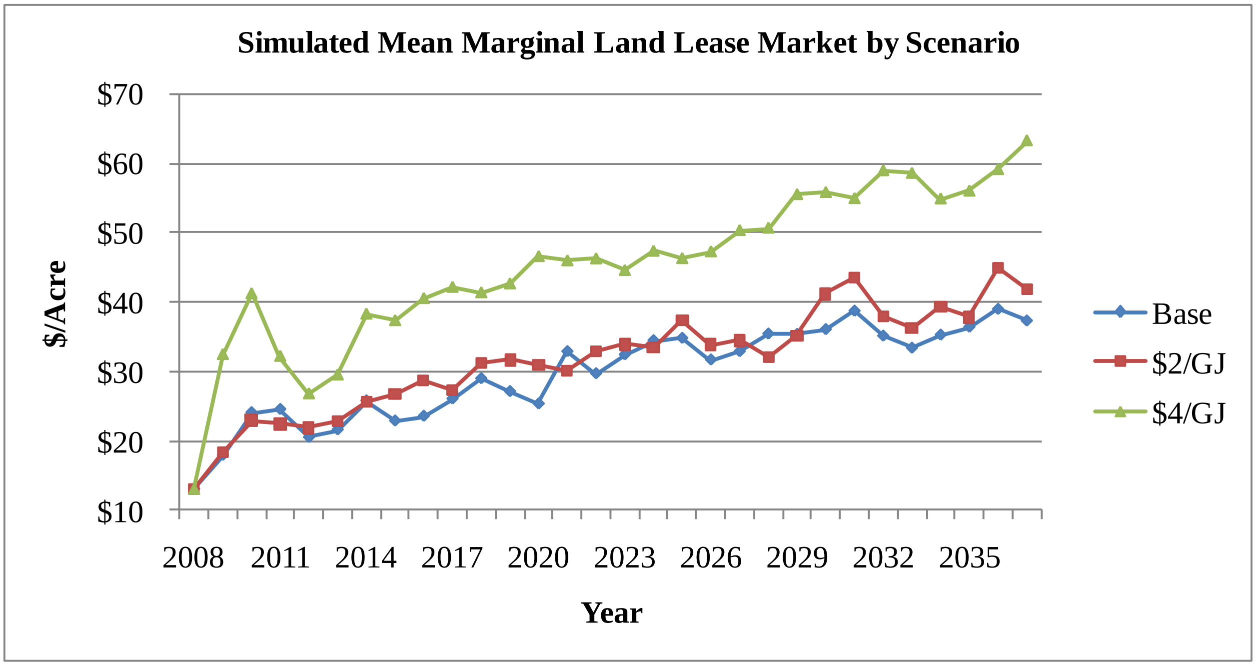

Figure 5.15 Simulated Mean Marginal Land Lease Market by Scenario

5.3.6.5 Land Purchase Transactions

Considering the entire simulation, 221 plots of farmland (9.6%) change ownership in the base scenario, including both farmer agents and investor agent ownership. The energy crop scenarios show similar trends with 167 and 221 plots (8.4% and 11.1% respectively) changing hands over the entire simulated period. The entire 30-year mean total purchase market turnover is shown in Table 5.19[79].

Table 5.19 Thirty-Year Mean Total Purchase Market Turnover

Scenario	Farmer Cropland Plots	Farmer Marginal Plots	Farmer Total Plots	Investor Total Plots	Total Plots	Farmland Market Turnover
Base	29.7	94.1	123.8	67.1	190.9	9.6%
$2/GJ	26.6	85.6	112.1	54.9	167.0	8.4%
$4/GJ	44.1	138.7	182.8	38.0	220.8	11.1%

The average total number of farmland plots sold each year is relatively low, with an overall average turnover of 0.33%, 0.28% and 0.3% per year in the base, $2/GJ and $4/GJ scenarios. The low turnover rates seem to suggest that the purchase land markets experience so few

[79] The land market transaction turnover is relatively low as transactions of land transferred in succession are not included.

transactions that it is difficult to interpret any meaningful results from them. One factor contributing to this low turnover rate stems from the fact that farmland transferred to an heir is not accounted for in the land markets. However, this transfer can only take place if there is a willing heir and there is sufficient equity to make the transfer feasible. Note that a low turnover in the simulated purchase market does not necessarily indicate that there is no a change in operators as the vast majority of the land market transactions occurred in the leasing market. Unfortunately, the latter transactions were not stored due to 1) the large associated data requirements and 2) increased run times associated with more data storage.

The mean annual total purchased farmland market turnover is displayed in Table 5.20.

Table 5.20 Mean Annual Total Purchased Farmland Market Turnover

Scenario	Farmer Cropland Plots	Farmer Marginal Plots	Farmer Total Plots	Investor Total Plots	Total Plots	Farmland Market Turnover
Base	1.0	3.2	4.3	2.3	6.6	0.33%
$2/GJ	0.9	3.0	3.9	1.9	5.8	0.29%
$4/GJ	1.5	4.8	6.3	1.3	7.6	0.38%

5.3.6.6 Idle Farmland Plots

Farmland up for sale that receives no purchase bids remains idle until the succeeding year's auction process. The amount of idle farmland in the simulations is highest in the base case with an average of 2.9 plots of farmland sitting idle each year over 50 replicates. As would be expected, as energy crop prices increase the amount of idle land falls to an average of 1.4 plots in scenario $2/GJ to zero in the $4/GJ scenario. I conclude that the introduction of energy crops is clearly a net benefit for CAR 1A since less farmland remains idle over time.

5.3.6.7 Factors Underlying Farmland Pricing

The simulated land markets clearly display an upward price trend over time. However, there are numerous possible explanations for such increased farmland values. Although commodity prices and yields are detrended to the 2008 base period, this year appears to be the starting point for increased expectations. Expected prices are developed using a weighted average of the last five years of data, leading to a lag in land valuation around this same time horizon. Increases in farming efficiency result from the shift to larger farms, which in turn permits greater economies of size and scale. Both of these factors positively affect farmers' margins as well as their continued ability to bid on farmland.

The generational and transitional shifts may also be affecting land markets in those situations when an heir of the farm takes over. This sometimes results in these land transfers not being included in the land market sales leading to fewer land transactions being reported than would typically occur.

As might be expected, off-farm income plays a significant role in the simulated land markets through its effect on farm cash flows. In all scenarios, 68.8% of farms have off-farm income at initialization and this amount increases to between 80.2% - 80.6% by the end of the simulated period in year 2037 in all three scenarios. Increased cash flow allows farmer agents to pay more for land, with off-farm income being used to support other farm expenses. The balance sheet effect also increased land values since as land prices increase, farmer agents borrow on their increased net worth which could generate a price bubble in the future.

Farmland market outcomes may also be a result of different plots being sold, where productivity rating corresponds to different land values. In addition, each plot for sale attracts very different types of bidders, a process symptomatic of how complex and unstable land markets can be even in an simulation. In addition, farmland rental agreements that are up for renewal are renewed based on the current lease market rate, which is in turn based upon random factors, as discussed in Chapter 3. Taken together, given the relatively low turnover rate of farmland there are likely just too few transactions across the simulated CAR to accurately characterize what is occurring in land markets as energy markets are concurrently created.

5.3.7 Simulated Government Programs

Government programs include policies like *AgriStability*, *AgriInvest* as well as *crop insurance*. Simulated government program payments remain relatively constant in all scenarios for the first 5 – 7 years, after which total payments to producers increase each year. Increased government payments are directly related to higher volatility in prices and yields from the simulated time paths. Note as well that the increased payouts are not visible until year seven due to the lagging effect of the five year price and yield expectations.

5.3.7.1 Simulated *AgriStability* Payments

Even though energy crops are not included in *AgriStability* reference margins, the introduction of energy crops results in increasing payouts to farmers within the energy crop scenarios. *AgriStability* payments increase in the energy crop scenarios, whereby beef cow reference margins begin to decline as farmers decrease herd size, along with a reduction in hay acres and hay sales. Although, Scheffran and BenDor (2009) predict that energy crops might decrease government payments, in fact we find that *AgriStability* payments are higher in the simulations. However, increased *AgriStability* payments in the energy crop scenarios are a function of excluding energy crops as part of the reference margins for *AgriStability* due to the difficulty of incorporating them into the existing program. Obviously, if energy crops were directly included as part of the reference margin, different government payments might occur. However, over the simulation period, the participation rates in *AgriStability* increase to 69.4% (base case) by year 2037, which would also affect the total amount of payments made. As displayed in Table 5.21 average total *AgriStability* payments increase not only by year but also by scenario over time. In all, the AgriStability payments in our scenarios generate an average annual increase of 10.37%, 10.56% and 11.07% respectively, in the base, \$2/GJ and \$4/GJ scenarios.

Table 5.21 Simulated Mean AgriStability Payments – All Scenarios

Year	Base	\$2/GJ	\$4/GJ
2008	\$ 756,588	\$ 691,416	\$ 725,820
2014	\$ 1,767,246	\$ 1,723,153	\$ 1,933,650
2020	\$ 4,805,180	\$ 4,698,327	\$ 5,882,669
2021	\$ 5,289,461	\$ 5,497,369	\$ 6,652,729
2029	\$10,714,793	\$11,002,391	\$12,951,748
2037	\$14,613,491	\$14,042,176	\$16,928,609
Mean Annual Change	10.37%	10.56%	11.07%

5.3.7.2 Simulated *AgriInvest* Account Balances

The average farmer agent account balances of *AgriInvest* also grow over the 30-year simulated period. The average final farmer agent account balance is greatest under the base scenario at $48,977 per farmer agent participating, while the energy price scenarios have final *AgriInves*t account balances of $41,946 and $43,527 respectively. The simulated average *AgriInvest* account balances are shown in Table 5.22.

Table 5.22 Mean Average Farmer Agent Account Balance *AgriInvest*

Scenario	2007	2037
Base	$ 9,495	$ 48,977
$2/GJ	$ 9,736	$ 41,946
$4/GJ	$ 9,706	$ 43,527

In addition, participation in *AgriInvest* increases dramatically over the 30 year period with a 95.7% participation rate in the base scenario by 2037. Of the latter, government matches producer contributions adding to the farmer agent's available cash flow. The participation rates in the energy crop scenarios are slightly lower at 93.6% and 93.5% for the $2/GJ and $4/GJ prices. The mean farmer agent participation rates for *AgriInvest* are displayed in Table 5.23.

Table 5.23 Farmer Agent Participation Rate *AgriInvest*

Scenario	2007	2037
Base	56.2%	95.7%
$2/GJ	55.8%	93.6%
$4/GJ	55.5%	93.5%

5.3.7.3 Simulated *Crop Insurance* Payments

In terms of *crop insurance* payouts, payments remain relatively stable over the entire simulated period and by scenario. Average *crop insurance* payments increase about 5% on an average annual basis over the 30 simulated years with 5.28%, 5.03%, 5.08% increases respectively, in the base, $2/GJ and $4/GJ scenarios. However, the total payments in year 2037 are larger because respectively, 89.5%, 89.5% and 85.2% of farmers are participating in *crop insurance* as compared to 83.6%, 83.9% and 83.9% in the year 2008 for the base, $2/GJ and $4/GJ scenarios in that order[80]. The simulated mean total *crop insurance* payouts for all the scenarios are displayed in Table 5.24.

Table 5.24 Simulated Mean Total *Crop Insurance* Payout – All Scenarios

Year	Base	$2/GJ	$4/GJ
2008	NO CROP INSURANCE PAYOUT		
2009	$ 2,581,359	$ 2,659,544	$ 2,725,014
2014	$ 5,874,810	$ 5,704,558	$ 6,013,080
2020	$ 8,975,060	$ 8,605,920	$ 9,049,934
2021	$ 8,276,671	$ 8,279,579	$ 8,519,038
2029	$ 11,548,625	$ 11,270,825	$ 11,827,737
2037	$ 10,899,462	$ 10,504,049	$ 10,903,146
Mean Annual Change	5.28%	5.03%	5.08%

5.3.7.4 An Assessment of Government Programs on Farm Structure

In the bootstrapped model, there is considerable volatility in yields and prices. This combined with individual agent variation affects the individual farmer agent reference and increase *AgriStability* payments over time[81]. With increased participation rates in government programs and increased volatility in prices and yields, increased payouts occur.

Increased volatility results in a correspondingly higher government contribution and greater farm income than otherwise. Even though they are not part of individual price and yield expectations, *AgriStability* and *crop insurance* generate increased farm cash, effectively relaxing the financial constraints to the bid price formation and increasing bid prices. In addition, government programs slow down the number of farm exits, reducing the amount of available farmland. Hence, program payments are indirectly capitalized into farmland values through their effect on farmland demand and supply.

[80] Percentages based upon the base scenario. The energy crop scenarios had participation rates similar to the base case.
[81] The volatile price swings are based upon the bootstrapped prices and were verified in section 5.

5.4 Chapter Summary

Model verification, validation and overall findings were presented in this chapter. The simulation is initially verified through testing integer and linear programming replications in Microsoft Excel© and by comparing simulated values with calculated values. Model validation is accomplished through confirming that accounts balance, yielding internal consistency and ensuring that the linear and mixed integer programs converge. Model verification is not as easily checked as simulated population is a subset of the total farm population because supply-managed, hog, specialty and hobby farms are excluded from the analysis. Overall, given the set of omitted farms in the simulations, the MIXFARM-ABM model seems to mirror historical regional population statistics reasonably well, given the likely difference between the simulated farm subpopulation and the entire population. Moreover, where there are substantial differences identified (such as wheat acres), in fact these differences will not affect relevant conclusions, so ultimately the MIXFARM-ABM model performance can be accepted as a reasonable representation of reality.

Three different scenarios were each simulated using the same 50 time paths. In each of the scenarios simulated and under most of the time paths, the trend of larger and fewer farms continues into the long run. These results are consistent with prior work of Stolniuk (2008) that mixed farms tend to dominate the results as they make the greatest use of both cropland and marginal land. The introduction of energy crops and prices in my simulation has a smaller effect on grain farmers than it has on mixed and beef cow farms. In the energy crop scenarios, energy crops push out beef cows and hay production and lower average total farm size as well as mean crop acreage. Thus, energy crops introduction into the simulation generates a greater structural change effect on beef cow and mixed farms in the CAR than it does on grain farms.

However with the introduction of energy crops, we find that total sector equity for CAR 1A is improved. The adoption of energy crops offers the potential to somewhat alter farm financial structure by improving cash flows and accumulated equity. We also find that land values remain comparable between the base and $2/GJ price scenario, indicating that the $2/GJ price is near to a break-even price for the energy crops considered here.

CHAPTER 6: SUMMARY, CONCLUSIONS AND LIMITATIONS

6.0 Summary

Building upon the prior work of Stolniuk (2008) and Freeman (2005), an agent based simulation model (ABSM) we call MIXFARM is developed incorporating three stages of farm optimizing models: 1) a long- run strategic optimization based on a mixed integer programming; 2) consideration of annual crop portfolios based on linear programming; and 3) a recourse ration balancing based on a linear program. MIXFARM is then used to assess the effects of introduction of particular energy crops into the farm economy of Census Agricultural Region 1A, an important agricultural area located in the southeast part of the province of Saskatchewan. In turn, sector profitability, the number of beef cows and marginal land use are simulated and tracked over a 30 year period. Three scenarios are considered, including a base scenario (no energy crops), and two energy price scenarios (with prices of $2/GJ and $4/GJ), each scenario using the same bootstrapped crop price and yield time paths.

We find that total farm sector equity and farm income improves in both energy scenarios indicating that energy crop production may be profitable under low energy prices and more profitable at higher energy prices. Total agricultural farm sector equity grows to between $200 million and $1.2 billion, respectively, for the $2/GJ and $4/GJ energy crop scenarios by the 30 year time period. While farm financial structure measured by outstanding debt displayed only marginal improvements over time under the $2/GJ scenario, it improved significantly at the $4/GJ price with reduced bankruptcies and forced exits. And increased farm income translates into an upward trend over time in land values and cash rents. The $2/GJ scenario generates only minor differences in land values compared to the base scenario throughout the entire simulation. However, the $4/GJ land values were substantially higher than both the base and $2/GJ scenario, the final $4/GJ farmland values running between 35% – 70% higher than the base scenario. However, since land purchase markets suffer from low turnover and variability, caution must be used in this interpretation. But farmland lease markets possessed the same upward trend over time, and this coupled with relatively little idle land in the simulations makes this interpretation of the evolution of farmland markets in the model reasonable.

Government programs can have a significant impact on structural change, as evident in the increasing simulated land values in all scenarios. With increased price and yield volatility and higher participation rates in *AgriStability*, larger government payouts to farmer agents are done over time. Because these payments are capitalized into farmland values, this program has unintended consequences. Historically government programs are short-lived, and *AgriStability* is unlikely to be around for the entire simulated period.

In the base scenario, the number of beef cows declines initially because of low returns, followed by the simulated farms rebuilding herds in response to increased calf prices. By 2037, beef cow numbers remain virtually unchanged from the beginning of the simulation. In the case of the two energy crop scenarios, alternative use of forage land is introduced. Even though forages can be purchased, the internal cost of feed is increased. Since feed costs make up a large portion of total costs, higher feed costs combined with depressed calf prices make the beef sector extremely vulnerable to alternative enterprises that can utilize forage lands. In both energy price scenarios, energy crops are widely adapted with a concurrent displacement of forage acres and reduction in beef cow numbers as more marginal land is devoted to energy crop production over time. The dynamics of this adaptation are interesting: the initial decline in beef cow production caused by poor margins gives the adoption of energy crops a considerable boost in adoption, but when beef prices return to more average levels, energy crops are by that time well established and the associated cost of reversal is sufficient to largely prevent shift back to traditional forage use patterns.

6.1 Conclusion

From an economic perspective, we assume in this model that farmers do not adopt energy crops because they are beneficial for the environment but do so because they are profitable. Farmers maximize profit by using the optimal combination of land, machinery, labour, inputs and management in the least costly way available, given their resource endowment and farm size to produce their optimal commodity mix. By using optimal combination of resources in production, farmers free up other scarce resources allowing other farmers to produce commodities that the marketplace deems valuable.

It is well understood that energy crops have the potential to change the structure of agriculture, but we find that this effect will occur primarily above the $2/GJ price threshold. Energy crops emerge in the simulation in both energy price scenarios, while total farm sector equity and total sector net income is improved over the base (i.e. zero energy crop price) scenario. Farmers with significant quantities of marginal land experience the greatest change in their farm structure by adopting energy crops, if they chose to go down this path. However, spillover effects of this adoption would be felt throughout the entire cattle industry as cattle numbers would necessarily be reduced.

These findings indicate that all pure beef cow farmers are better off from the introduction of energy crops as compared to the reference base scenario because energy crops stabilize and maintain farm income as average farm size decreases. Nevertheless, the high land values associated with $4/GJ price scenario could create a barrier for some farm families wishing to pass their farm on to succeeding generations if they fail to meet equity requirements for their heirs to assume the farm.

Agent based simulation models of farming behavior help assess problems associated with structural change as captured by overall farm numbers, farm type and financial status. AGSM's permit assumptions of heterogeneity in the landscape and the farm population, and they also allow dynamic population changes associated with entry, they capture aging and farm succession effects and also individual farmer interaction in farmland purchase and leasing markets. Individual heterogeneity, interaction and the feedback of farm and land prices to the farm decision making process means that farming is a complex economic system, a system that cannot be accurately modeled by static or analytic models of farming.

6.2 Limitations and Suggestions for Further Study

This thesis incorporated the use of three stages for the linear programming/mixed integer programming decision making process. The use of LP/MIP assumes that all farmers are profit maximizers and that each has an objective of growing their farm businesses. Because not all farmers are necessarily profit maximizers, farm behavior by its heterogeneous nature is difficult to model. In future related research, farmer behavioural patterns should be incorporated into farmer agents' decision making. This means developing a more sophisticated approach to both perceived and actual risks associated with adopting energy crops. For example, experience shows that it is highly unlikely that farmers would shift immediately into energy crops but rather that they would test the industry first with limited acres. Another limitation of this model exercise is the exogenously determined price of hay and barley. If local hay and feed barley prices were determined endogenously through local markets via a feedback pricing system, reduced forage acres could further affect the cattle industry through increased feed prices.

Additional limitations include the omission of regional effects associated with potential bio-energy industry since it was assumed that and energy crop custom seeding and harvesting industry and associated plants would emerge to meet farm production. The dynamics of establishing a bio-energy industry include having a critical mass of bio-energy crop acres to start an industry while not over exhausting the capacity of the energy crop custom seeding and harvesting industry. Furthermore as a bio-energy industry emerges, other biomass feedstocks are likely to come on stream, including straw refuge from annual crops. Of particular regional interest for this particular CAR are the possible synergies coming from co-firing biomass with coal in the *Boundary Dam Power Station* located near Estevan, Saskatchewan.

While the benefits associated with using ABSM in this context are extensive, ABSM modeling based on RePast may not have reached its full potential given the steep learning curve associated with Java programming. The programming requirements and required specialized knowledge means programming assistance often needs to be available, and without this further development may be compromised. Finally, I would suggest that the fourth generation of modelling needs to move to a team approach in order to manage time constraints and technical requirements.

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APPENDIX A

THE MIP MODEL

The following model features a much more expanded activity specification taking into account differing machine technology (J); land quality: cropland (associated with J) and marginal land (q) and the lumpy (integer) nature of machine and land plot investment requirements. MIP activities include crop production activities, 2) forage activities, 3) the beef herd, 4) the sales or purchase of excess or deficit feed requirements, 5) machinery operation and purchase, and 6) renting of farmland in or out.

A.1.0 The MIP Objective Criterion

In order to accommodate differing replacement cycles and the integer nature of machines and the long-run, strategic nature of machinery and farm sizing, the problem is annualized. Equation A.1 decision variables include acreages of ten annual crops (X^J) by tillage system J,[82] five uses of the forage (marginal) land (X^F), three purchased feed rations (T^+) in tonnes according to feed type (hay, barley and wheat), two types of forage hay sales in tonnes (T^-) based on land quality (improved or hayland), whole plot acres of land rented out (Q^-)[83], land rented in (Q^+) by basic land type (marginal or cropland), three energy crop enterprises ($W_q, P_q, or\ G_q$) available on three types of marginal land; ten machinery package options (M^J) with associated operating levels (O^J); the beef cow herd enterprise (L), amount of feed fed (T) in four feeding periods and finally optimal borrowing (B). The following MIP is still somewhat stylized; the full matrix is reviewed in the following section:

$$max\ Z = \sum_{j=1}^{10} C_j^J X_j^J + \sum_{q=1}^{5}\left[\left(C_q^F - \vartheta I_q^F\right)X_q^F\right] - \sum_{j=1}^{3} D_j^+ T_j^+ + \sum_{j=1}^{2} D_j^- T_j^- + R_i^- Q_i^- - R_i^+ Q_i^+ +$$

$$\sum_{q=1}^{3}\left[R_q^- Q_q^- - R_q^+ Q_q^+\right] + \sum_{q=1}^{3}\left[\left(C_q W_q - I_q^W\right) + \left(C_q P_q - I_q^P\right) + \left(C_q G_q - I_q^G\right)\right] - \sum_{m=0}^{9}\left(V_m^J O_m^J +\right.$$

$$FmJMmJ+CLL+ \propto -\Delta L-- \propto +\Delta L+-FLKL-f=14CfTf-rBt \qquad (A.1)$$

Where:

[82] The tillage system is a 0/1 choice either conventional or no-tillage.

[83] The model has the capacity to rent out a portion of a plot of land not suitable to the farmer agent but was sub-sequentially turned off during the simulations because further coding is required for fractional plots to be incorporated into the land rental markets.

Annual Crops:

C^J is the contribution margin for annual crops or variable production costs for feed crops
X^J is the number of crop acres of production
J is the tillage system; conventional or no-till
j is the commodity produced or used in the feeding activity[84]
P^C is the average annual crop acres in parcel

Forage and Pasture:

C_q^F is variable production costs of forage, hay or pasture depending on land quality
X_q^{TP} is total marginal acres
X_q^F is forage land quality [85]
$C_f T_f$ is variable feeding period cost of the corresponding ration
ϑ is a zero or a one depending if forage requires breaking[86]
I is the investment required for breaking cost of forage
P^F is the average forage and pasture acres in parcel

Hay and Forage Sales:

D^- is the sale price of forage which includes a transaction fee
T^- represents tonnes of forage[87]

Purchased Hay and Cereal Feed Rations:

D^+ is the purchase price of forage or cereal feed rations which includes a transaction fee
T^+ represents tonnes of forage or cereals

Land in or out:

R^- is rented out in dollars per acre
R^+ is rented land in dollars per plot
Q^- is the actual acres rented out
Q^+ is the number of plots in from rent/purchase (Integer)
$R_i^- Q_i^-$ is crop acres rented out
$R_q^- Q_q^-$ is pasture or forage land rented out
$R_i^+ Q_i^+$ is a cropland plot rented in (Integer)
$R_q^{\mp} Q_q^+$ is a marginal plot rented in (Integer)

Energy Crops:

W is acres of willow
P is acres of popular
G is acres of prairie sandreed (tall grass)
I is the initial investment in energy crops and forage breaking

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[84] Annual crop production activities include feed barley, malting barley, canola, feed wheat, wheat, durum, flax, peas, and lentils.
[85] Includes natural pasture, improved pasture, hayland both improved and hayland having two baling periods.
[86] Natural pasture does not require breaking, while improved pasture and hayland pasture requires breaking every 7 years.
[87] Forage and hay sales can come from either improved pasture baled or hayland pasture baled.

Machine Operation and Ownership:

V variable machine cost per acre

O is the acres operated

F^J is the annualized ownership cost of machines

M^J is the number of machine units (integer)

m refers to the appropriate annual crop machinery package of 0 – 9

The Beef Cow Herd:

α is investment in more cows (+) or cull cows (-) including transaction fee for culling herd[88]

L is the current number of beef cows[89]

Δ represents the change in beef cow herd size:

(+) Invest in more cows

(-) Sell cull cows

F^L fixed costs of the beef cow machinery, handling and labour package

K^L number of units (integer) of beef cow machinery, handling and labour package

Feeding Activity:

C_f cost of feeding

T_f represents tonnes of feed i

Financing:

r is the real cost of capital

B is the amount borrowed

A.1.1 Long-run, Expected Gross Margins

Expected annualized returns over variable costs are calculated for annual crops, energy crops, hay, pasture and livestock. For a tillage system, J (conventional or minimum tillage), the expected returns over variable costs are:

$$E(C_j) = \left[E(P_j)E(Y_j^J) - V_j^J\right] \qquad (A.2)$$

Where: $E\left(Y_j^J\right)$, is expected yield adjusted by the tillage system for annual crops[90]

V_j^J is the per acre variable cost for the appropriate tillage system

It is assumed that output price expectation, $E\left(P_j\right)$ at time *t*, follow an adaptive expectations model:[91]

[88] Assume farmer agents buy all heifers.

[89] This is required as a separate activity because of the cows carried over from the previous period and the associated constraints.

[90] Conventional seeded crops are assigned a yield-multiplier value of 1, while no-till crop yields are increased by 7%, this follows Zentner et al. (2002) where it was found that crops seeded using no-till technology tended to have higher yields than conventional seeded crops.

$$E(P_t) = \sum_{j=1}^{5} w_{t-j} \cdot P_{t-j} \tag{A.3}$$

Where: *W_{t-1}* is the weighted of the previous year's prices
P_{t-1} is the price of commodity j for the give year

Each individual farmer agent then develops their own price expectations using the inverse normal distribution function method. The following equations are used to generate individual price expectations for each commodity based on the inverse normal distribution function.

$$farmer_{optimism_i} = \sqrt{-2 * \ln Rand_1} * \cos(2 * \pi * Rand_2 * E(P_t) * CV_j * \alpha * \gamma \tag{A.4}$$

Where: $Rand_1$ is a (fixed) random number between 0 and 1 for all commodities
$Rand_2$ is a (fixed) random number between 0 and 1for all commodities
CVj is the co-efficient of variation for commodity j
α is 0.25
γ is 0.65
$E(P_t)$ is price expectation from equation A.3

$$Error_{crop_j} = \sqrt{-2 * \ln Rand_1} * \cos(2 * \pi * Rand_2 * E(P_t) * CV_j * \alpha * (1 - \gamma) \tag{A.5}$$

Where: $Rand_1$ is a random number between 0 and 1 for commodity j
$Rand_2$ is a random number between 0 and 1for commodity j
CVj is the co-efficient of variation for commodity j
α is 0.25
γ is 0.65
$E(P_t)$ is price expectation from equation A.4

The farm agent's price expectation then becomes:

$$E(\widehat{P_t}) = E(P_t) + farmer_{optimism_j} + Error_{crop_j} \tag{A.6}$$

In the case of perennial crops such as hay forages and energy crops, annual expected returns are the annualized return, using *r*, the risk-free rate, of net cash flows over the stand life cycle. The annualized return of perennial crops can be found at the intersection of the contribution margin

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[91] For justification of this refer to Fisher and Tanner, 1978 and Spriggs et al. 1982. Price expectations do not allow for an expected price trend, however the prices generated in the model are based on historic detrended prices.

row and columns 10 – 12, 14 – 16, and 18 – 20 in the MIP Tables A.1.0 and A.1.1. In the year *0*, the establishment year, there are only cash out flows associated with the establishment cost, $S_{\mathbf{0}}$. The full establishment cost associated with each perennial crop is found in row 47 and the same columns as listed above. In the following *t* years, expected forage and energy crop net returns over variable cost, $E\left(C_{q,t}^F\right)$ and $E\left(C_q W_{q,t} + C_q P_{q,t} + C_q G_{q,t}\right)$ consists of revenues from hay sales, oven-dried biomass tonnage sales or additional herd income generated. Using forage as an example at the end of the stand, *n*, breaking cost, $E\left(C_{B,n}\right)$, is incurred:

$$E\left(C_{q,t}^F\right) = -S_0 + \frac{r}{1-(1+r)^{-n}}\left[\sum_{t=1}^{n}\left(\frac{E\left(C_{q,t}^F\right)}{(1+r)^t}\right) - \frac{E\left(C_{B,n}\right)}{(1+r)^n}\right] \quad (A.7)$$

The net return from hay is:

$$E\left(C_{q,t}^F\right) = E\left(\hat{P}_q^F\right) - TF * E\left(Y_q^F\right) - \left(V_q^F\right) \quad (A.8)$$

However, it should be noted that hay can generate income through its feed value to the herd. Pasture land has a minor variable cost representing land taxes, fence and dugout maintenance costs and its value is based on cow carrying capacity.

The net return from oven-dried biomass tonnage is:

$$E\left(C_q W_{q,t} + C_q P_{q,t} + C_q G_{q,t}\right) = \left(\left[\left((P_{gj}) * E(Y_{W,t}) * \ GJ/T\ \right) - V_q W_q\right] + \left[\left((P_{gj}) * E(Y_{P,t}) * \ GJ/T\ \right) - V_q P_q\right] + \left[\left((P_{gj}) * E(Y_{G,t}) * \ GJ/T\ \right) - V_q G_q\right]\right) \quad (A.9)$$

Where: (P_{gj}) is the energy price per gigajoule

$E(Y_{W,t})$ is the expected yield of willows in tonnes for the given harvest period

$E(Y_{P,t})$ is the expected yield of poplar in tonnes for the given harvest period

$E(Y_{G,t})$ is the expected yield of prairie sandreed in tonnes for the given period

GJ/T is the energy content gigajoule per tonne of the corresponding energy crop

A.1.2 Transportation Costs

Transportation costs for annual crops vary for each farmer agent as they are determined by distance from their own farm location to each delivery point in CAR 1A[92]. The distance is calculated using the Euclidean distance method following the farm agents x, y co-ordinate and each delivery points x, y co-ordinate and is as follows:

$$TruckingDistance_i = \sqrt{\left(x_i^d - x_j^f\right)^2 + \left(y_i^d - y_j^f\right)^2} \qquad (A.10)$$

Where: *TruckingDistance$_i$* is the trucking distance from delivery point *i* to the agent *j*'s farm

x_i^d is the x co-ordinate of delivery point *i*

x_j^f is the x co-ordinate of the agent's farm

y_i^d is the y co-ordinate of delivery point *i*

y_j^f is the y co-ordinate of the agent's farm

For model simplicity it is assumed that each delivery point offers the same price, thus the farm agent then chooses the delivery point that minimizes trucking distance for the least-cost transportation expense. The transportation expense for each farm agent then becomes:

$$Trans_{Exp} = VC_t * T_j * TruckingDistance_i \qquad (A.11)$$

Where: $Trans_{Exp}$ is the total transportation expenditure

VC_t is the variable cost per tonne per trucking distance

T_j is the total tonnes of commodity j being transported

In terms of transportation costs for energy crops only one delivery point (Estevan) is assumed in the model and the transportation expense is based upon the farm distance to that one delivery point.

[92] Seven delivery points are available in CAR 1A (Alameda, Carievale, Carnduff, Estevan, Northgate, Redvers and Stoughton) for annual crops at representative co-ordinates that closely resemble their respective locations in the region. However, given that the grid in the model is 40 x 50 rectangle, the respective locations are only an approximation.

A.1.3 Perennial Crop Establishment and Breaking Costs

Perennial crops such as forage and energy crops are a long-run investment and require farmland to be broken and prepared for perennial seeding. The cost of establishing perennial crops is as follows:

$$PE_C = Acres_f * EVC_f + Acres_{ec} * EVC_{ec} \qquad (A.12)$$

Where: PE_C is the total perennial establishment cost of the farmer
$Acres_f$ is the total forage acres established
$Acres_{ec}$ is the total energy crop acres established
EVC_f is the variable cost per acre to establish forage
EVC_{ec} is the variable cost per acre to establish energy crops

When the perennial crop comes to the end of its life-cycle breaking of the land is required to prepare it for its next use. The breaking cost is calculated as:

$$PB_C = Acres_f * BVC_f + Acres_{ec} * BVC_{ec} \qquad (A.13)$$

Where: PB_C is the total perennial breaking cost of the farmer
$Acres_f$ is the total forage acres broken
$Acres_{ec}$ is the total energy crop acres broken
BVC_f is the variable cost per acre to break forage
BVC_{ec} is the variable cost per acre to break energy crops

The breaking cost of energy crops and forage is found in rows 39, and 42 – 44 which is the hay and forage breaking constraint, along with willow, poplar and prairie sandreed transfer constraints associated with the initial investment costs. These are represented by columns 13, 17, 21 and 35 in Tables 3.1.0 and 3.1.1[93].

A.1.4 The MIP Constraints

The above objective function is subject to cash flow, credit and a series of accounting and financial constraints. These are discussed below.

[93] Note: At the intersection of forage breaking constraint row 39 and breaking cost column 35 the value is zero. However, if it is a breaking year for forage this value will be a negative one indicating a transfer of acres for breaking. In this example the farmer agent does not have any forage acres requiring re-breaking.

A.1.4.1 Land Constraints

Total acres farmed must be less than or equal to the total of all rented and owned land. In the example MIP the total acres farmed constraint is the 6,258 acres on the right hand side (RHS) of the inequality in row 1 in Table A.1.3. This constraint becomes:

$$X - Q^{+} \leq Owned \qquad (A.14)$$

Where: X is the total acres farmed
Q^{+} is the total number of plots rented/purchased

Annual crops are also subject to upper limits for pulses, cereals and oilseeds. We assume that annual crop rotations have both upper and lower limits. Annual crop limits vary by both conventional and no-till farms due to different technologies being employed. For conventional farms, cereals are a major part of their annual rotation and are assumed to have an annual limit of 70% of total crop land acres, X_j^J, while oilseeds and pulses have a constraint of 40% and 30% respectively. No-till farms have the following constraints, 65% cereals, 40% oilseeds and 30% pulse crops[94]. For specific cereal, pulse and oilseed commodities the constraints are the same for both conventional and no-till farms. Within the cereal limit, additional limits are placed on barley, wheat and durum acres at 25%, 90% and 25% respectively of the cereal upper limit. This is done to prevent one particular commodity from not entering into the solution for any farm agent[95]. These upper limits force the other upper limit to become a lower limit for the other cereal. The oilseed limits of canola and flax both are 75% of the oilseed constraint while lentils and peas have upper limits of 30% and 100% of the pulse constraint respectively. However, the following exceptions apply - lentils are not available in the conventional crop rotation and as such the conventional peas limit becomes the conventional pulse limit of 30%, and durum is not available to beef cow farmer agents. As well, wheat and barley limits are constrained further for beef cow producers as they are more likely to grow feed barley and feed wheat. The upper limit of feed barley and feed wheat become the cereal limit.

A.1.4.2 The Simplified Annual Crop Acres Constraint

$$\sum_{t=1}^{n} (X_j^J + Q_j^- - P^C Q_j^+) \leq Crop\ Acres \qquad (A.15)$$

[94] The percentage of annual crop limits are based upon historical crop rotations and producer interviews through the Agribenchmark® network.
[95] Wheat refers to hard red spring wheat (HRSW).

To understand the individual commodity constraint limits, please refer to rows 3 – 14 in Tables A.1.0 – A.1.3, where the RHS shows the appropriate acres allowed. In addition, for farm expansion, the corresponding acre limits for each commodity are found in column 72 on Table A.1.3.

In terms of pasture land, higher quality hayland pasture X_q^{HP} can be used in hay, improved pasture or natural pasture acreage quality, as it can fall back to a lower quality. Improved pasture can be used as either improved or natural pasture but cannot be used in a higher use like hay land. Therefore land going into improved pasture can be of improved pasture quality or higher (hay land quality). Hence the right hand side of the equation (A.18) is total marginal land, subtracting off the natural pasture as follows: $X_q^{TP} - X_q^{NP}$. Natural pasture ,X_q^{NP} can be used only in pasture. The pasture constraints are contained in rows 25 – 27 and the corresponding acreage to pasture quality is found on the RHS of the inequality in Table A.1.3.

A.1.4.3 Total Marginal Land

$$X_q^{NP} + X_q^{IP} + X_q^{HP} \leq X_q^{TP} \qquad (A.16)$$

Where:

$$X_q^{NP} + X_q^{IP} + X_q^{HP} \leq X_q^{TP} \qquad (A.17)$$

$$X_q^{IP} + X_q^{HP} \leq X_q^{TP} - X_q^{NP} \qquad (A.18)$$

$$X_q^{HP} \leq X_q^{TP} - X_q^{IP} - X_q^{NP} \qquad (A.19)$$

$$C_q X_q^{TP} - Q_q^{-} + P^F Q_q^{+} \leq X_q^{TP} \qquad (A.20)$$

A.1.4.4 Acres of Machine Capacity Required Transfer

The amount of annual crop acres sowed (represented by X_j^J) must have the appropriate acres of machine capacity required, represented by $-X_j^{Jm}$. The following equation transfers the machine capacity in acres of the farmer agent to match corresponding acres in annual crops:

$$\sum_{j=1}^{n} (X_j^J - X_j^{Jm}) \leq 0 \qquad (A.21)$$

A.1.4.5 Machine Capacity Requirements to Amount Available

Farm machinery has upper limits on the total acreage capacity it can cover annually. This is particularly true in annual cropping. Although partial machine hours can be rented or hired through custom work in the short-run, in the long-run the likelihood of machines being available when a farmer needs them complicates the decision making process. Thus, machinery can only be purchased in discrete units and results in an integer value. For the machinery limit constraints in the MIP example, refer to rows 15 – 24 and columns 1-9, and 54 – 70 in Tables A.10 and Table A.1.3. In terms of the whole annual cropping machinery package used, the equation becomes:

$$\sum_{j=1}^{n} (X_j^{Jm} - \beta^m M_j^{Jm}) \leq 0 \qquad (A.22)$$

Where: β is the maximum acres per unit of *m* machinery package
M_j^{Jm} is the number of units of the particular package the famer has
X_j^{Jm} is total annual crop acres farmed by the farmer

A.1.4.6 Beef Cow Labour, Machinery and Handling System Constraint

Machinery, equipment and labour associated with beef cow farming follows a similar constraint to that in equation (A.22), except instead of capacity in acres the capacity becomes per herd limit. An additional cow labourer, machinery and handling system are required per 300 cows. The initial endowment of cow labourer, machinery and handling systems for each mixed and livestock farm is set at 300, which indicates these farms currently have handling facilities for the first 300 cows. The herd size, cow labour limit, cow equipment handling constraint and cow machinery constraint are found in rows 28, 29, 40 and 41 and correspond to columns 48 through 53 as indicated in MIP matrix in Table A.1.2

$$L - 300K^L \leq 300 \qquad (A.23)$$ [96]

A.1.4.7 Acres per Cow Required

Beef cow acreage requirements limit the herd size to a certain number of acres that can support the herd, depending on the productivity of the land. Higher quality land can support more beef

[96] Initial endowment assumes the farm has cow labourer, machinery and handling systems for the first 300 cows.

cows per acre. Overall, the limit falls at approximately four acres required per cow. This constraint is as follows:

$$\sum_{t=1}^{4}(-\tfrac{1}{2}X_q^F - X_q^F - 2\,X_q^F + \;4L \;- 640\,Q_q^+) \leq 0 \qquad (A.24)$$

Where: ½ X_q^F corresponds to ½ acre of natural pasture (NP)
1 X_q^F correpsonds to one acre of improved pasture (IP)
2 X_q^F correpsonds to two acres of hayland pasture (HP)
4 acres required per cow
640 acres (1 integer plot) for herd expansion of marginal land

The above constraint is found in row 45, columns 22 – 24 and column 49 in the example MIP in Tables A.1.1 and A.1.2.

A.1.4.8 Herd Size Constraint

The herd size constraint is represented by L, and the optimal herd size of the farmer agent with ΔL^+ , indicating the additional number of cows purchased, while $-\Delta L^-$ is the number of cows culled from the heard. The herd size constraint becomes:

$$L - \;\Delta L^+ + \Delta L^- \leq Current\ Herd\ Size \qquad (A.25)$$

A.1.4.9 Cereal Feeds and Forage Rations

The nutritional and energy requirements of beef cows must be met for each period. The weighted average Mcals produced are estimated based on the actual plot. Beef cows require some roughage in their diet (represented by α) and can be found in Row 46 in the example MIP Tableaux. Therefore, the following constraint prevents the feed from being entirely based on cereals:

$$+\sum_{j=1}^{2} Mcal_j FD_{jt} \leq \propto (\sum_{j=1}^{2} Mcal_j FD_{jt}^J + \;\sum_{f=1}^{3} Mcal_f FD_{ft}) - (1{-}\propto)\sum_{j=1}^{2}\; Mcal_j FD_{jt} {+}\propto \sum_{f=1}^{3} Mcal_f FD_{ft} \qquad (A.26)$$

Where*: $Mcal_j FD_{jt}^J$ is the Mcals fed from feed barley or feed wheat*
$Mcal_f FD_{ft}$is the Mcals from winter hay, barley straw or wheat straw

A.1.4.10 Cow-Calf Feeding and Nutrient Requirements

In the MIP example, the weighted average Mcals can be found where rows 35 – 38 intersect with columns 22 – 24 on Table A.1.1. The cereal Mcals are based upon the yield in tonnes as found at row 31 column 1 and row 32 column 4 for feed barley and feed wheat respectively. The required Mcal constraints are as follows:

$$\sum_{t=1}^{4}(Mcal_{it}^{J} - Mcal^{J}FD_{t}^{J} + Mcal_{t}^{L}L) \leq 0 \quad (A.27)$$

$$\sum_{t=1}^{4}(Mcal_{it}^{F} - Mcal^{F}FD_{t}^{F} + Mcal_{t}^{L}L) \leq 0 \quad (A.28)$$

Where*:* $Mcal_{it}^{J}$ *is the Mcals produced from the corresponding cereal in time t*
$Mcal_{it}^{F}$*is the Mcals produced from the corresponding pasture quality*
$Mcal_{t}^{L}$*is the Mcals required per cow*
$Mcal_{it}^{f}FD_{t}^{J}$*is the Mcals fed from the corresponding feed*

A.1.4.11 Concentrate Transfer and Hay and Forage Transfer

All feed ration concentrates, whether farm grown or purchased, that are fed to livestock is transferred (represented by $-Mcal_jX_j$ for feed cereals or $-Mcal_qT_q$ for baled forages) to the appropriate feeding period (represented by FDj for cereals and FDt for hay). The concentrate transfer and hay and forage transfer equations become:

$$\sum_{j=1}^{2}(-Mcal_jX_j + FD_j) \leq 0 \quad (A.29)$$

For j =1, 2 feed barley or feed wheat during the winter period

$$\sum_{q=1}^{3}(-Mcal_qT_q + \sum_{t=1}^{4}FD_t) \leq 0 \quad (A.30)$$

For q =1, 2, 3 types of pasture and hay
For t = 1, 2, 3, 4 periods of feeding hay

A.1.4.12 Borrowing/Cash Flow Constraint

The operating capital required to cash flow the daily operations of the farm is an important constraint in farm viability. Equation A.31 includes ten annual crops ($\sum_{J=1}^{10}$), five uses of the forage (marginal) land ($\sum_{q=1}^{5}$), three purchased feed rations (hay, barley and wheat, ,$\sum_{J=1}^{3}$) two types of forage sales (improved or hayland forage ($\sum_{j=1}^{2}$)), land rented out ($R^{-}Q^{-}$) [97], land plot expansion (marginal or cropland) ($R^{+}Q^{+}$), three energy crop enterprises $W_q, P_q, or\ G_q$) (available on three types of marginal land ($\sum_{q=1}^{3}$), ten machinery package options ($\sum_{m=0}^{9}$), livestock enterprise (L), four feeding periods ($\sum_{f=1}^{4}$)and finally optimal borrowing (B). Thus, every farm must maintain positive cash flows, including borrowing against equity (note that crop inventory values have been dropped):

$$\sum_{j=1}^{10} V_j^J X_j^J + \sum_{q=2}^{5}(V_i^q + \vartheta I_i^q)X_q + \sum_{j=1}^{3} VD_j^+ T_j^+ + \sum_{j=1}^{2} VD_j^- T_j^- + VR_i^- Q_i^- + \sum_{q=1}^{3} VR_q^- Q_q^- +$$

$$R_i^+ Q_i^+ + R_q^+ Q_q^+ + \sum_{q=1}^{3} V_q W_q + I_q^W + \sum_{q=1}^{3} V_q P_q + I_q^P + \sum_{q=1}^{3} V_q G_q + I_q^G + \sum_{m=0}^{9}\big(V_m^J O_m^J +$$

$$F_m^J M_m^J\big) + (V^L L + \propto^- \Delta L^- + \propto^+ \Delta L^+ + F^L K^L) + \sum_{f=1}^{4}(VC^f T^f) - B \leq Cash \qquad (A.31)$$

A.1.4.13 Debt to Asset Ratio Constraint

It is assumed that credit and hence the ability to borrow is limited by the farm debt asset ratio and that all assets are valued at their fair market value. Assuming that the maximum debt to asset ratio is δ (represents a ratio of 0.35)[98], this generates the following constraint:

$$-\delta\big(\sum_{q=1}^{3} I_q^W + \sum_{q=1}^{3} I_q^P + \sum_{q=1}^{3} I_q^G + R_q^+ Q_q^+ + R_i^+ Q_i^+ + \sum_{m=0}^{9}\big(F_m^J M_m^J\big) + \propto^- \Delta L^- + \propto^+ \Delta L^+ +$$

$$FLKL + B \leq \delta Equity \qquad (A.32)$$

The cash flow and credit constraints are represented by the borrowing and debt asset ratio rows (47 and 48) in the MIP example in Tables A.10 – A.1.3.

A.1.4.14 MIP Model Structure—An Example Tableaux

As described above and in Chapter 3, the strategic MIP optimizes the long-run farm size and corresponding land-use. A gross margin is calculated for each activity based on the farmer's

[97] The model has the capacity to rent out a portion of a plot of land not suitable to the farmer agent but was sub-sequentially turned off during the simulations because further coding is required for fractional plots to be incorporated into the land rental markets.

[98] Anonymous financial institutions were contacted regarding maximum debt to asset ratio limits on their agricultural portfolios.

expectations. Variable and fixed costs of machinery for all enterprises as well as beef cow handling facilities are incorporated into the model. Land and machinery can only be purchased in discrete units and thus are only available as integer values. Increases in farmland values affect a farmer's decision for purchasing land, and the appreciation value in this model can be either above or below the overall inflation rate in farm earnings. To illustrate the MIP as used in the simulation, a 48 by 73 matrix is developed using a pure grain farm consisting of 6,258 initial farm acres is shown in Tables A.1.0 – A.1.3 on pages 151 – 154. The constraints explained in this Chapter/Appendix will refer back to this illustrated example by referring to the appropriate column or row number and its corresponding Table. The 6,258 acres of this grain farm includes 5,865 crop acres with the remaining 393 acres being pasture (natural, improved and hayland pasture) as shown in Table A.1.0 – A.1.3. on pages 151 - 154. The objective function or the farms net present value (NPV) (Table A.1.3) of this farm example is $313,867, which includes seeding 952 acres of barley, 2,144 acres of canola, 1,161 acres of durum, and 2,144 acres of peas. The farmer agent in this example is a mixed grain and beef cow farmer and initially has 152 cows, but invests in an additional 41 heifers for a total herd size of 193 beef cows. This can be found in columns 48 and 49 in the activity level on page 153 in the MIP tableau.

Table A.1.0 Stage-One Mixed Integer Programming 48 X 73 Tableau (Variables 1 - 17)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
	MIP Tableau 1 - 17	Feed Barley Acres NoTill	Barley Acres NoTill	Canola Acres NoTill	Feed Wheat Acres NoTill	Wheat Acres NoTill	Durum Acres NoTill	Flax Acres NoTill	Peas Acres NoTill	Lentils Acres NoTill	Willows Natural Pasture	Willows Improved Pasture	Willows Hayland Pasture	Willows Initial Investment	Poplar Natural Pasture	Poplar Improved Pasture	Poplar Hayland Pasture	Poplar Initial Investment	<=	RHS
	Xj Activity Level	0	952	2144	0	0	1161	0	2144	0	0	0	0	0	0	0	0	0	Objective Function	
	Cj Contribution Margin	-$ 189.17	$ 96.55	$ 102.29	-$ 236.92	$ 79.38	$ 112.89	$ 71.21	$ 140.55	$ 64.82	$ 140.30	$ 144.16	$ 135.49	-$ 99.23	$ 26.55	$ 28.58	$ 24.01	-$ 70.71	$ 313,867	
1	Total Acres Farmed	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	<=	6258
2	Total Crop Acres	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	<=	5865
3	Cereal Limit	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	<=	3812
4	Feed Wheat Limit	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	3812
5	Feed Barley Limit	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	3812
6	Wheat Limit	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	<=	3,431
7	Barley Limit	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	953
8	Durum Limit	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	<=	953
9	Oilseed Limit	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	<=	2,346
10	Canola Limit	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1,760
11	Flax Limit	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	<=	1,760
12	Pulse Limit	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	<=	1,760
13	Peas Limit	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	<=	1,760
14	Lentils Limit	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	<=	528
15	Crop Custom Hire Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	500
16	Machine Operate 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
17	Machine Operate 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
18	Machine Operate 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
19	Machine Operate 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
20	Machine Operate 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
21	Machine Operate 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
22	Machine Operate 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
23	Machine Operate 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
24	Machine Acres Required	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	<=	0
25	Natural Pasture	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	0	<=	393
26	Improved Pasture	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0	<=	313
27	Hayland Pasture	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	<=	135
28	Cows Labour Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	300
29	Herd Size	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	152
30	Hay Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
31	Barley Transfer	-1.12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
32	Wheat Transfer	0	0	0	-0.82	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
33	Barley Straw Transfer	-1.12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
34	Wheat Straw Transfer	0	0	0	-0.82	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
35	Early Pasture Mcals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
36	Late Pasture Mcals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
37	Fall Pasture Mcals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
38	Winter Mcals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
39	Forage Breaking Constraint	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
40	Cow Handling Constraint	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	300
41	Cow Machine Constraint	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	300
42	Willow Transfer	0	0	0	0	0	0	0	0	0	1	1	1	-1	0	0	0	0	<=	0
43	Poplar Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	-1	<=	0
44	Prairie Sandreed Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
45	Acres/Cow Required	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
46	Max Cereal Mcals Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
47	Borrowing	$ 74.88	$ 78.50	$ 107.86	$ 77.60	$ 79.95	$ 78.88	$ 80.38	$ 77.35	$ 115.90	$ 181.31	$ 185.99	$ 175.46	$ 1,541.91	$ 42.29	$ 44.70	$ 39.27	$ 1,098.76	<=	$ 291,902
48	D/A Ratio	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 539.67	$ -	$ -	$ -	-$ 384.57	<=	$ 2,014,720

Source: (Authors Calculation and Verification)

Table A.1.1 Stage-One Mixed Integer Programming 48 X 73 Tableau (Variables 18 - 35)

	MIP Tableau 18 - 35	18 Prairie Sandreed Natural Pasture	19 Prairie Sandreed Improved Pasture	20 Prairie Sandreed Hayland Pasture	21 Prairie Sandreed Initial Investment	22 Natural Pasture	23 Improved Pasture	24 Hayland Pasture	25 Rent Out Cropland	26 Rent Out Natural Pasture	27 Rent Out Improved Pasture	28 Rent Out Hayland Pasture	29 Pasture Carryover One	30 Pasture Carryover Two	31 Improved Bale First Cut	32 Improved Bale Second Cut	33 Hay Production One Cut	34 Hay Production Two Cuts	35 Breaking Cost	<=	RHS
	Xj Activity Level	0	0	0	0	1033	0	0	0	0	0	0	619430	471203	0	0	0	0	0	Objective Function	
	Cj Contribution Margin	$ 11.04	$ 15.07	$ 5.99	-$ 6.23	$ -	-$ 1.40	-$ 6.20	-$ 40.00	-$ 15.00	-$ 20.00	-$ 35.00	$ -	$ -	-$ 11.89	-$ 17.84	-$ 20.81	-$ 26.75	-$ 12.71	$ 313,867	
1	Total Acres Farmed	1	1	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1	0	<=	6258
2	Total Crop Acres	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	5865
3	Cereal Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	3812
4	Feed Wheat Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	3812
5	Feed Barley Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	3812
6	Wheat Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	3,431
7	Barley Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	953
8	Durum Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	953
9	Oilseed Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	2,346
10	Canola Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1,760
11	Flax Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1,760
12	Pulse Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1,760
13	Peas Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1,760
14	Lentils Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	528
15	Crop Custom Hire Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	500
16	Machine Operate 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
17	Machine Operate 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
18	Machine Operate 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
19	Machine Operate 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
20	Machine Operate 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
21	Machine Operate 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
22	Machine Operate 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
23	Machine Operate 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
24	Machine Acres Required	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
25	Natural Pasture	1	1	1	0	1	1	1	0	1	1	1	0	0	1	1	1	1	0	<=	393
26	Improved Pasture	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	1	1	0	<=	313
27	Hayland Pasture	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	1	0	<=	135
28	Cows Labour Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	300
29	Herd Size	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	152
30	Hay Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.26	-0.41	-1.29	-2.07	0	<=	0
31	Barley Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
32	Wheat Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
33	Barley Straw Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
34	Wheat Straw Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
35	Early Pasture Mcals	0	0	0	0	-967	-1098	-1340	0	0	0	0	1	0	0	0	0	0	0	<=	0
36	Late Pasture Mcals	0	0	0	0	-387	-439	-536	0	0	0	0	-0.5	1	-1098	0	-1340	0	0	<=	0
37	Fall Pasture Mcals	0	0	0	0	-77	-88	-107	0	0	0	0	0	-0.5	-659	-659	-804	-804	0	<=	0
38	Winter Mcals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
39	Forage Breaking Constraint	0	0	0	0	0	0.5	1	0	0	0	0	0	0	0.5	0.5	1	1	0	<=	0
40	Cow Handling Constraint	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	300
41	Cow Machine Constraint	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	300
42	Willow Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
43	Poplar Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
44	Prairie Sandreed Transfer	1	1	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
45	Acres/Cow Required	0	0	0	0	-0.5	-1	-2	0	0.5	1	2	0	0	0	0	0	0	0	<=	0
46	Max Cereal Mcals Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
47	Borrowing	$ 9.11	$ 12.44	$ 4.94	$ 96.80	$ -	$ 1.40	$ 6.20	$ 6.00	$ 3.39	$ 3.59	$ 3.78	$ -	$ -	$ 11.89	$ 17.84	$ 20.81	$ 26.75	$ 67.98	<=	$ 291,902
48	D/A Ratio	$ -	$ -	$ -	-$ 33.88	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 23.79	<=	$ 2,014,720

Source: (Authors Calculation and Verification)

Table A.1.2 Stage-One Mixed Integer Programming 48 X 73 Tableau (Variables 36 - 53)

		36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53		
	MIP Tableau 36 - 53	Buy Hay	Buy Feed Wheat	Buy Feed Barley	Feed Early Summer Hay	Feed Late Summer Hay	Feed Fall Hay	Feed Winter Hay	Feed Wheat	Feed Barley	Feed Wheat Straw	Feed Barley Straw	Sell Hay	Invest Cows	Cows Head	Cows Labour	Cows FC Handling System	Cows FC Machinery	Sell Cull Cows	<=	RHS
	Xj Activity Level	682	0	43	0	0	0	682	0	43	0	0	0	41	193	0.0	0.0	0	0	Objective Function	
	Cj Contribution Margin	-$ 112.04	-$ 208.69	-$ 173.10	-$ 9.96	-$ 9.96	-$ 9.96	-$ 9.96	-$ 9.69	-$ 9.69	-$ 11.89	-$ 11.89	$ 59.62	-$ 99.96	$ 754	-$ 9,000	-$ 2,368	-$ 12,469	$ 50	$ 313,867	
1	Total Acres Farmed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6258
2	Total Crop Acres	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	5865
3	Cereal Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	3812
4	Feed Wheat Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	3812
5	Feed Barley Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	3812
6	Wheat Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	3,431
7	Barley Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	953
8	Durum Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	953
9	Oilseed Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	2,346
10	Canola Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1,760
11	Flax Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1,760
12	Pulse Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1,760
13	Peas Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1,760
14	Lentils Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	528
15	Crop Custom Hire Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	500
16	Machine Operate 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
17	Machine Operate 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
18	Machine Operate 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
19	Machine Operate 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
20	Machine Operate 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
21	Machine Operate 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
22	Machine Operate 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
23	Machine Operate 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
24	Machine Acres Required	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
25	Natural Pasture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	393
26	Improved Pasture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	313
27	Hayland Pasture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	135
28	Cows Labour Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-300	0	0	0	<=	300
29	Herd Size	0	0	0	0	0	0	0	0	0	0	0	0	-1	1	0	0	0	1	<=	152
30	Hay Transfer	-1	0	0	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	<=	0
31	Barley Transfer	0	0	-1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	<=	0
32	Wheat Transfer	0	-1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	<=	0
33	Barley Straw Transfer	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	<=	0
34	Wheat Straw Transfer	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	<=	0
35	Early Pasture Mcals	0	0	0	-1219	0	0	0	0	0	0	0	0	0	1970	0	0	0	0	<=	0
36	Late Pasture Mcals	0	0	0	0	-1219	0	0	0	0	0	0	0	0	1237	0	0	0	0	<=	0
37	Fall Pasture Mcals	0	0	0	0	0	-1219	0	0	0	0	0	0	0	1636	0	0	0	0	<=	0
38	Winter Mcals	0	0	0	0	0	0	-1219	-3724	-3394	-664	-823	0	0	5075	0	0	0	0	<=	0
39	Forage Breaking Constraint	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
40	Cow Handling Constraint	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-300	0	0	<=	300
41	Cow Machine Constraint	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-300	0	<=	300
42	Willow Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
43	Poplar Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
44	Prairie Sandreed Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
45	Acres/Cow Required	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	<=	0
46	Max Cereal Mcals Limit	0	0	0	0	0	0	-182.85	3165.4	2884.9	-99.6	-123.45	0	0	0	0	0	0	0	<=	0
47	Borrowing	$ 112.04	$ 208.69	$ 173.10	$ 9.96	$ 9.96	$ 9.96	$ 9.96	$ 9.69	$ 9.69	$ 11.89	$ 11.89	$ 25.00	$ 837.95	$ 127.69	$ 9,000	$ 30,800	$ 161,085	$ 228.01	<=	$ 291,902
48	D/A Ratio	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 293.28	$ -	$ -	-$ 10,780	-$ 56,380	0	<=	$ 2,014,720

Source: (Authors Example and Verification)

Table A.1.3 Stage-One Mixed Integer Programming 48 X 73 Tableau (Variables 54 - 73)

		54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73		
	MIP Tableau 54 - 73	Crop Custom Hire	Option 2 Acres	Option 3 Acres	Option 4 Acres	Option 5 Acres	Option 6 Acres	Option 7 Acres	Option 8 Acres	Option 9 Acres	Option 2 Number Machines	Option 3 Number Machines	Option 4 Number Machines	Option 5 Number Machines	Option 6 Number Machines	Option 7 Number Machines	Option 8 Number Machines	Option 9 Number Machines	Expand Pasture Land	Expand Cropland	Amount Borrow	<=	RHS
	Xj Activity Level	0	0	6400	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	2	$ 2,570,489	Objective Function	
	Cj Contribution Margin	-$ 82.70	-$ 11.52	-$ 10.48	-$ 9.18	-$ 10.21	-$ 10.80	-$ 9.95	-$ 10.18	-$ 9.91	-$ 94,122	-$ 147,509	-$ 185,424	-$ 348,594	-$ 448,433	-$ 633,614	-$ 791,012	-$ 961,308	-$ 8,320	-$ 16,118	-3%	$	313,867
1	Total Acres Farmed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-640	-640	0	<=	6258
2	Total Crop Acres	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-640	0	<=	5865
3	Cereal Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-416	0	<=	3812
4	Feed Wheat Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-416	0	<=	3812
5	Feed Barley Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-416	0	<=	3812
6	Wheat Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-374	0	<=	3,431
7	Barley Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-104	0	<=	953
8	Durum Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-104	0	<=	953
9	Oilseed Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-256	0	<=	2,346
10	Canola Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-192	0	<=	1,760
11	Flax Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-192	0	<=	1,760
12	Pulse Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-192	0	<=	1,760
13	Peas Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-192	0	<=	1,760
14	Lentils Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-58	0	<=	528
15	Crop Custom Hire Limit	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	500
16	Machine Operate 2	0	1	0	0	0	0	0	0	0	-2000	0	0	0	0	0	0	0	0	0	0	<=	0
17	Machine Operate 3	0	0	1	0	0	0	0	0	0	0	-3200	0	0	0	0	0	0	0	0	0	<=	0
18	Machine Operate 4	0	0	0	1	0	0	0	0	0	0	0	-4300	0	0	0	0	0	0	0	0	<=	0
19	Machine Operate 5	0	0	0	0	1	0	0	0	0	0	0	0	-9000	0	0	0	0	0	0	0	<=	0
20	Machine Operate 6	0	0	0	0	0	1	0	0	0	0	0	0	0	-12300	0	0	0	0	0	0	<=	0
21	Machine Operate 7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	-18000	0	0	0	0	0	<=	0
22	Machine Operate 8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	-23500	0	0	0	0	<=	0
23	Machine Operate 9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	-28000	0	0	0	<=	0
24	Machine Acres Required	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	<=	0
25	Natural Pasture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-640	0	0	<=	393
26	Improved Pasture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-640	0	0	<=	313
27	Hayland Pasture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-640	0	0	<=	135
28	Cows Labour Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	300
29	Herd Size	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	152
30	Hay Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
31	Barley Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
32	Wheat Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
33	Barley Straw Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
34	Wheat Straw Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
35	Early Pasture Mcals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
36	Late Pasture Mcals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
37	Fall Pasture Mcals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
38	Winter Mcals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
39	Forage Breaking Constraint	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
40	Cow Handling Constraint	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	300
41	Cow Machine Constraint	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	300
42	Willow Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
43	Poplar Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
44	Prairie Sandreed Transfer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
45	Acres/Cow Required	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-640	0	0	<=	0
46	Max Cereal Mcals Limit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0
47	Borrowing	$ 82.70	$ 11.52	$ 10.48	$ 9.18	$ 10.21	$ 10.80	$ 9.95	$ 10.18	$ 9.91	$ 683,596	$ 1,020,870	$ 1,323,110	$ 2,645,330	$ 3,575,300	$ 4,959,830	$ 6,464,990	$ 7,704,090	$ 8,320	$ 16,118	-1	<=	$ 291,902
48	D/A Ratio	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 239,259	-$ 357,306	-$ 463,090	-$ 925,864	-$ 1,251,360	-$ 1,735,940	-$ 2,262,750	-$ 2,696,430	-$ 2,912	-$ 5,641	1	<=	$ 2,014,720

Source: (Authors Calculation and Verification)

A.2.0 Second-Stage (Tactical LP)

The second-stage decision model is a tactical decision process in the sense that it supports the higher level strategic investment decisions of the farm enterprise by striving to maximize short-run profits.

Table A.2 Stage-Two Linear Programming 11 X 7 Tableau

		1	2	3	4	5	6	7		
	Tactical LP Tableau	Barley Acres No-Till	Canola Acres No-Till	Wheat Acres No-Till	Durum Acres No-Till	Flax Acres No-Till	Peas Acres No-Till	Lentils Acres No-Till	<=	RHS
	Xj Activity Level	975	1800	450	975	0	1800	0	Objective Function	
	Cj Contribution Margin	$ 96.55	$102.29	$ 79.38	$112.89	$ 71.21	$140.55	$ 64.82	$	677,037
1	Crop Land Acres	1	1	1	1	1	1	1	=	6000
2	Cereal Limit	1	0	1	1	0	0	0	≤	3900
3	Max Wheat Limit	0	0	1	0	0	0	0	≤	3510
4	Max Durum Limit	0	0	0	1	0	0	0	≤	975
5	Max Barley Limit	1	0	0	0	0	0	0	≤	975
6	Oilseed Limit	0	1	0	0	1	0	0	≤	2400
7	Max Canola Limit	0	1	0	0	0	0	0	≤	1800
8	Max Flax Limit	0	0	0	0	1	0	0	≤	1800
9	Pulse Limit	0	0	0	0	0	1	1	≤	1800
10	Max Peas Limit	0	0	0	0	0	1	0	≤	1800
11	Max Lentils Limit	0	0	0	0	0	0	1	≤	540

Source: (Authors Example and Verification)

A.3.0 Stage Three Recourse Objective Function

In Stage Three, the farm agents expected feeding preferences are adjusted to actual prices and yields by optimizing herd related recourse decisions, such as rotation formulations and forage buying/selling activities. The recourse linear program minimizes costs in feed rations while maintaining the minimum energy (Mcal) content required, maintaining beef cows, as well as growing and finishing calves to desired specifications for the finished beef cattle slaughter market. However, the recourse LP is a maximization problem in the sense that it sells the higher valued feeds in the market place and minimizes feeding costs by feeding the low valued feeds.

$$Max\ Z = -\sum_{j=1}^{2} D_j^+ T_j^+ - \sum_{f=1}^{4}\left(C_f T_f\right) + \sum_{j=1}^{3} D_j^- T_j^- \qquad (A.33)$$

A.3.1 Herd Nutrient Requirement Constraints

The herd nutrient requirement constraints used in the recourse LP include hay, barley, and a straw refuse limit all in tonnes. The Mcal energy content constraint is as follows:

$$\sum_{t=1}^{4}\left[-Mcal_{it}^F - Mcal_{jt}^J + \sum_{f=1}^{2} Mcal_{it}^F FD_t^F + \sum_{j=1}^{2} Mcal_{jt}^J FD_t^J \geq Mcal_t^L\right] \qquad (A.34)$$

A.3.2 Feed Limit Constraints

The hay limit is a lower limit constraint and is set at 5% of the annual tons hay needed, A_H. The barley and wheat straw refuse limit both are required to be greater than or equal to zero. These constraints are as follows:

$$Feed\ Barley\ Limit\ (Tonnes)\ X_B\ \geq 0 \tag{A.35}$$

$$Feed\ Wheat\ Limit\ (Tonnes)\ X_w\ \geq 0 \tag{A.36}$$

$$Barley\ Straw\ Refuse\ Limit\ (Tonnes)\ X_B\ \geq 0 \tag{A.37}$$

$$Wheat\ Straw\ Refuse\ Limit\ (Tonnes)\ X_w\ \geq 0 \tag{A.38}$$

Table A.3 Stage-Three Recourse Linear Programming 12 X 13 Tableau

		1	2	3	4	5	6	7	8	9	10	11	12	13		
	Recourse LP Tableau	Buy Hay	Buy Barley	Feed Early Summer Hay	Feed Late Summer Hay	Feed Fall Hay	Feed Winter Hay	Feed Winter Barley	Feed Winter Wheat	Feed Winter Barley Straw	Feed Wheat Straw	Sell Hay	Sell Barley	Sell Wheat	≤ or ≥	RHS
	Xj Activity Level	60	0	66	42	60	60	0	0	80	123	0	93	123	Objective Function	
	Cj Contribution Margin	-$ 72.47	-$ 128.99	-$ 9.96	-$ 9.96	-$ 9.96	-$ 9.96	-$ 9.69	-$ 9.69	-$ 9.96	-$ 9.96	$ 47.47	$ 128.98	$ 154.81	$	22,397
1	Early Mcal Energy Content	0	0	1340	0	0	0	0	0	0	0	0	0	0	≥	88650
2	Late Mcal Energy Content	0	0	0	1340	0	0	0	0	0	0	0	0	0	≥	55665
3	Fall Mcal Energy Content	0	0	0	0	1219	0	0	0	0	0	0	0	0	≥	73620
4	Winter Mcal Energy Content	0	0	0	0	0	1219	3394	3724	664	823	0	0	0	≥	228375
5	Wheat	0	0	0	0	0	0	0	1	0	0	0	0	1	≤	123
6	Barley	0	-1	0	0	0	0	1	0	0	0	0	1	0	≤	93
7	Feed Early Hay	-1	0	1	0	0	0	0	0	0	0	1	0	0	≤	171
8	Feed Late Hay	-1	0	0	1	0	0	0	0	0	0	1	0	0	≤	171
9	Feed Fall Hay	-1	0	0	0	1	0	0	0	0	0	1	0	0	≤	0
10	Feed Winter Hay	-1	0	0	0	0	1	0	0	0	0	1	0	0	≤	0
11	Wheat Straw	0	0	0	0	0	0	0	0	0	1	0	0	0	≤	123
12	Barley Straw	0	0	0	0	0	0	0	0	1	0	0	0	0	≤	93

Source: (Authors Example and Verification)

APPENDIX B

FIFTY BOOTSTRAPPED WHEAT YIELDS

Fifty Bootstrapped Wheat Yields

	Year																													
Run	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
1	28.54	31.10	35.07	21.34	35.07	27.10	26.12	22.46	25.55	34.63	14.96	25.55	27.10	26.79	31.21	27.10	29.24	23.42	26.79	35.07	21.34	28.86	27.36	31.45	33.86	26.12	30.43	31.21	25.49	30.50
2	28.54	34.63	39.15	30.73	30.73	24.24	39.15	17.48	17.48	31.10	28.54	30.73	31.10	27.10	21.34	26.79	26.57	31.10	31.10	17.48	35.07	31.21	25.19	28.83	30.73	23.94	28.86	30.73	27.36	24.24
3	28.54	31.45	31.21	27.36	30.61	23.94	21.34	31.10	27.36	33.86	25.77	31.45	25.19	28.25	23.42	30.73	21.34	23.42	31.45	34.63	25.19	35.07	17.48	31.10	25.55	23.35	25.49	21.34	17.48	35.07
4	28.54	31.21	30.43	31.10	30.50	32.25	33.86	21.34	39.15	17.48	25.77	39.15	22.46	26.12	22.46	14.96	25.49	28.86	27.10	25.77	28.86	32.25	32.25	31.21	31.21	26.12	25.49	28.25	21.34	23.35
5	28.54	22.46	25.19	25.77	31.10	22.46	29.24	26.57	39.15	17.48	24.24	28.83	25.49	23.94	21.34	29.24	27.36	23.94	24.24	37.44	35.07	24.24	23.94	26.79	31.21	28.25	26.12	35.07	22.46	28.86
6	28.54	27.36	26.57	31.21	25.55	31.45	30.50	21.34	34.63	25.55	37.44	28.83	14.96	26.57	29.24	31.21	25.55	31.21	37.44	29.24	30.43	25.55	39.15	28.25	30.50	28.25	30.69	35.07	26.12	30.50
7	28.54	17.48	23.35	17.48	31.10	37.44	26.12	30.69	17.48	30.61	29.24	30.43	35.07	37.44	28.54	30.61	23.94	31.10	29.24	25.77	27.10	28.25	17.48	30.61	30.69	26.79	30.50	29.24	27.10	30.43
8	28.54	31.21	25.77	35.07	30.61	24.24	23.35	33.86	25.55	17.48	35.07	26.57	34.63	37.44	25.55	31.21	23.94	23.94	31.10	30.61	30.43	28.83	29.24	14.96	28.25	39.15	22.46	25.55	35.07	31.45
9	28.54	23.42	14.96	23.35	33.86	25.77	28.86	39.15	26.12	31.21	35.07	33.86	26.57	32.25	31.10	34.63	30.61	25.19	28.25	30.69	26.79	22.46	34.63	31.10	23.94	25.77	28.86	31.21	14.96	26.12
10	28.54	27.36	27.10	34.63	28.86	27.36	30.61	27.10	23.35	23.42	22.46	35.07	22.46	28.25	25.77	28.54	24.24	30.50	33.86	27.36	39.15	26.79	33.86	31.21	25.19	24.24	28.86	31.21	21.34	28.25
11	28.54	32.25	27.10	34.63	25.49	25.49	29.24	32.25	39.15	31.21	28.25	28.86	30.43	28.86	22.46	37.44	33.86	30.50	39.15	33.86	25.77	17.48	24.24	21.34	28.86	30.61	25.55	28.54	25.55	31.45
12	28.54	28.83	33.86	31.10	32.25	30.50	23.35	23.94	30.43	23.42	25.77	34.63	26.57	21.34	27.10	31.45	37.44	26.57	26.12	30.73	28.54	31.10	30.69	33.86	25.77	31.10	27.36	27.10	14.96	29.24
13	28.54	27.36	30.73	25.19	30.69	27.10	25.77	25.55	26.79	31.10	22.46	26.12	26.12	28.54	26.12	26.12	28.54	39.15	25.55	23.42	28.54	27.36	30.61	26.57	31.45	23.94	23.94	26.79	22.46	25.77
14	28.54	22.46	30.50	30.73	17.48	26.12	17.48	26.57	25.19	29.24	14.96	30.43	21.34	30.73	33.86	27.10	34.63	30.43	34.63	30.73	26.79	30.73	17.48	23.42	17.48	17.48	31.21	32.25	35.07	30.73
15	28.54	30.43	33.86	30.69	21.34	25.77	27.36	22.46	25.55	25.55	27.10	30.73	34.63	25.55	23.42	31.21	32.25	29.24	24.24	31.21	26.79	27.10	17.48	24.24	31.10	33.86	30.50	21.34	35.07	29.24
16	28.54	25.19	14.96	21.34	25.77	25.55	31.45	26.79	26.12	31.45	31.45	31.45	25.55	35.07	28.25	22.46	31.21	27.36	27.36	30.69	28.83	23.42	39.15	26.79	23.35	26.12	30.50	17.48	30.69	35.07
17	28.54	25.49	30.61	31.45	30.73	24.24	31.10	25.55	30.69	29.24	30.73	39.15	30.61	23.35	26.12	25.55	28.54	30.43	31.10	22.46	27.10	21.34	28.54	23.42	26.79	39.15	23.42	14.96	33.86	31.45
18	28.54	14.96	37.44	31.10	31.21	31.21	30.50	23.42	31.21	28.25	27.36	30.73	30.73	27.36	30.50	35.07	27.36	30.69	28.86	35.07	34.63	22.46	23.94	23.94	25.55	26.12	26.12	29.24	30.61	33.86
19	28.54	25.19	39.15	37.44	23.35	30.43	30.73	23.94	30.50	28.86	25.77	21.34	28.54	21.34	23.42	25.49	28.86	35.07	26.57	22.46	30.69	33.86	22.46	14.96	33.86	31.10	28.83	25.77	31.10	21.34
20	28.54	26.79	33.86	32.25	30.73	23.42	31.21	17.48	22.46	24.24	25.77	28.54	23.42	33.86	27.36	26.12	27.36	26.57	35.07	30.73	30.69	33.86	31.10	25.55	27.10	33.86	26.79	28.83	21.34	22.46
21	28.54	33.86	31.21	17.48	25.19	31.10	28.86	31.45	31.10	25.77	30.69	32.25	23.94	28.86	27.10	29.24	30.69	23.35	28.25	22.46	25.77	30.50	28.25	25.77	31.21	26.79	32.25	17.48	24.24	27.36
22	28.54	31.10	23.94	23.94	28.25	22.46	23.35	22.46	22.46	30.69	27.10	28.86	23.94	26.57	34.63	27.10	28.86	23.35	30.69	35.07	25.55	25.55	34.63	25.49	26.12	22.46	23.35	24.24	17.48	23.35
23	28.54	30.73	25.55	28.54	27.10	21.34	23.42	27.36	21.34	22.46	30.69	30.61	34.63	25.19	23.35	28.54	28.54	37.44	27.36	26.57	25.55	31.21	17.48	34.63	27.10	22.46	25.19	35.07	39.15	33.86
24	28.54	35.07	28.83	28.86	31.45	35.07	14.96	37.44	22.46	31.45	28.86	35.07	31.45	27.10	21.34	23.94	27.36	28.86	30.73	23.42	33.86	29.24	30.43	34.63	30.61	30.73	31.45	28.25	29.24	30.50
25	28.54	26.12	30.69	30.43	14.96	23.42	23.35	31.21	28.54	30.43	34.63	33.86	32.25	31.45	23.42	21.34	30.50	33.86	30.50	26.12	31.10	25.55	33.86	29.24	25.19	26.12	37.44	27.10	14.96	17.48
26	28.54	23.94	25.77	30.73	31.21	30.43	25.19	17.48	26.12	21.34	25.19	28.25	21.34	21.34	30.69	26.79	27.10	21.34	31.21	28.25	31.10	23.42	28.86	29.24	30.69	22.46	37.44	35.07	33.86	28.83
27	28.54	28.86	31.45	21.34	31.21	29.24	28.54	26.79	25.19	25.77	31.10	23.35	31.10	37.44	30.50	34.63	31.10	35.07	35.07	35.07	30.73	22.46	22.46	24.24	17.48	31.21	30.43	31.10	25.77	21.34
28	28.54	25.19	34.63	31.45	22.46	33.86	25.77	26.57	25.49	27.10	28.54	33.86	35.07	28.83	26.57	23.42	28.25	14.96	28.54	17.48	27.10	22.46	33.86	31.21	32.25	22.46	17.48	28.86	30.69	30.50
29	28.54	14.96	31.10	30.50	17.48	22.46	31.45	28.25	31.10	24.24	25.49	26.12	31.10	26.12	30.50	28.54	25.77	30.69	23.42	25.19	33.86	17.48	28.83	27.10	33.86	23.94	27.36	28.25	34.63	32.25
30	28.54	34.63	14.96	25.49	25.77	17.48	28.83	28.25	23.94	25.19	31.10	27.36	30.61	21.34	30.43	23.42	22.46	25.55	30.73	23.94	31.45	26.57	29.24	31.10	30.69	24.24	21.34	31.10	35.07	28.54
31	28.54	28.86	26.12	31.21	30.73	31.21	21.34	30.73	30.61	25.77	35.07	22.46	27.10	29.24	22.46	26.79	31.10	22.46	25.77	31.10	28.25	30.73	17.48	26.12	30.43	23.94	25.49	32.25	17.48	31.10
32	28.54	25.19	28.54	26.57	31.45	30.43	28.54	23.42	30.73	31.45	23.42	34.63	23.35	21.34	31.10	25.55	25.77	33.86	25.49	35.07	30.43	31.10	22.46	26.57	22.46	28.86	35.07	34.63	31.21	33.86
33	28.54	30.69	29.24	25.19	22.46	27.10	28.86	28.86	25.55	28.25	27.36	33.86	37.44	34.63	23.94	22.46	26.57	27.10	17.48	27.36	21.34	26.57	22.46	29.24	30.73	30.73	34.63	30.61	30.43	29.24
34	28.54	29.24	39.15	30.69	31.10	30.61	31.21	33.86	25.55	31.10	23.35	30.50	33.86	31.10	26.57	35.07	23.42	25.19	30.61	23.94	31.45	23.42	31.21	26.57	31.21	24.24	35.07	31.10	33.86	28.25
35	28.54	22.46	31.21	28.83	25.19	37.44	39.15	30.43	30.43	25.77	21.34	23.94	14.96	27.36	22.46	33.86	31.45	14.96	34.63	21.34	28.86	25.19	39.15	30.50	28.86	28.83	25.55	25.55	34.63	28.54
36	28.54	31.10	31.45	17.48	22.46	30.50	23.94	28.25	25.77	28.54	21.34	26.12	23.35	30.73	28.54	26.57	39.15	21.34	31.10	25.19	30.43	17.48	22.46	30.61	30.43	23.35	23.35	24.24	28.86	22.46
37	28.54	25.55	26.12	23.35	30.73	31.45	22.46	31.45	25.19	30.43	30.73	28.83	23.42	29.24	24.24	35.07	30.50	30.43	23.42	30.50	25.77	17.48	35.07	35.07	26.12	26.57	26.57	28.54	25.77	30.43
38	28.54	31.10	30.61	26.57	34.63	34.63	25.55	28.54	28.54	25.55	37.44	30.73	28.25	34.63	30.43	17.48	25.49	30.73	23.42	26.79	24.24	30.61	31.45	31.45	21.34	27.36	28.25	34.63	34.63	28.54
39	28.54	31.45	39.15	26.79	27.10	39.15	25.77	26.57	26.12	25.55	24.24	25.19	23.42	34.63	28.54	30.61	27.36	28.54	30.73	23.35	23.42	30.69	14.96	30.69	28.25	30.73	23.94	30.73	30.43	25.49
40	28.54	23.94	23.35	28.86	34.63	37.44	31.45	32.25	30.61	26.79	30.50	39.15	30.73	28.86	28.86	30.73	26.12	27.36	33.86	17.48	35.07	17.48	28.25	26.12	31.45	14.96	29.24	26.79	22.46	30.73
41	28.54	29.24	30.73	31.21	17.48	30.43	25.19	28.25	30.61	25.55	31.21	25.49	31.45	25.77	25.49	39.15	31.45	30.43	28.25	31.45	26.12	26.57	23.35	28.86	23.42	28.86	30.43	23.35	37.44	37.44
42	28.54	26.79	37.44	24.24	21.34	23.94	26.79	17.48	14.96	23.42	30.61	26.57	25.55	26.12	31.45	28.25	39.15	31.21	21.34	31.45	30.50	27.10	28.86	27.36	24.24	30.50	23.94	21.34	34.63	39.15
43	28.54	30.73	23.94	17.48	23.42	24.24	30.61	27.36	29.24	25.77	26.79	28.86	30.43	26.57	26.57	29.24	31.10	30.73	33.86	26.12	24.24	28.83	22.46	31.10	27.10	27.10	14.96	25.49	30.73	31.45
44	28.54	26.57	28.54	24.24	31.21	26.57	30.73	30.73	33.86	28.86	24.24	23.94	35.07	31.21	25.55	25.77	30.69	23.94	30.61	26.79	35.07	28.86	35.07	27.10	22.46	21.34	27.36	17.48	35.07	24.24
45	28.54	25.77	22.46	25.19	23.42	27.36	28.54	33.86	14.96	25.49	24.24	28.83	30.50	28.25	34.63	31.45	28.54	30.43	25.19	17.48	30.61	22.46	31.45	23.94	39.15	28.25	26.12	29.24	26.12	29.24
46	28.54	28.25	28.86	31.21	28.25	26.57	27.10	31.10	25.19	34.63	23.42	28.25	29.24	25.77	31.10	26.12	33.86	26.79	31.45	25.77	30.43	31.45	23.35	35.07	30.73	39.15	31.45	22.46	24.24	17.48
47	28.54	23.94	17.48	28.25	27.10	26.79	14.96	17.48	25.19	39.15	23.35	25.77	31.21	30.69	39.15	34.63	26.12	25.55	31.10	28.86	30.73	21.34	32.25	28.54	30.43	21.34	30.43	30.69	25.49	39.15
48	28.54	25.49	31.45	30.43	30.73	34.63	30.43	22.46	28.86	29.24	37.44	26.79	31.10	23.42	30.43	27.10	17.48	30.50	31.10	28.25	14.96	29.24	31.45	22.46	27.10	31.45	25.19	31.45	21.34	28.54
49	28.54	14.96	24.24	23.35	33.86	30.43	35.07	28.83	21.34	34.63	22.46	25.49	28.54	30.50	25.19	31.21	28.25	23.35	31.45	30.69	25.77	25.55	31.21	27.36	37.44	31.10	28.25	31.21	30.73	31.45
50	28.54	24.24	14.96	29.24	37.44	28.86	31.21	28.54	25.19	39.15	28.54	25.49	25.77	25.55	31.21	23.35	25.49	37.44	25.19	22.46	21.34	33.86	28.86	33.86	30.43	25.49	30.61	30.69	30.73	30.61

APPENDIX C

HISTORICAL YIELDS 1968 - 2008

Year	Historical Yields							
	Canola	Spring Wheat	Durum	Lentils	Peas	Barley	Flax	Hay
	bu/ac	bu/ac	bu/ac	lbs/ac	lbs/ac	bu/ac	bu/ac	bu/ac
1968	16.57	19.23				38.51	4.61	1.18
1969	29.84	38.247				74.91	10.41	1.39
1970	25.22	26.57	12.52			66.97	10.1	1.75
1971	28.66	33.86	15.53			77.46	9.54	1.52
1972	26.28	25.19	12.97			55.54	9.57	1.39
1973	23.59	32.25	14.61			66.96	9.65	1.53
1974	23.62	25.49	12.34			50.33	8.01	1.6
1975	20.64	29.24	14.69			51.96	8.98	1.7
1976	24.29	28.86	15.44			57.03	9.68	1.55
1977	27.44	31.45	16.13			62.05	10.17	1.4
1978	28.83	37.44	19.43			71.32	12.38	1.81
1979	18.09	24.24	12.75			43.82	8.13	1.5
1980	20.05	23.35	13.07			48.89	8.56	0.74
1981	23.29	28.83	14.94			48.74	9.27	1.24
1982	24.67	31.21	16.59			58.15	12.75	1.71
1983	19.49	25.55	14.86			44.52	10.54	1.66
1984	13.19	21.34	11.13			32.78	6.15	0.95
1985	19.15	25.47	14.85			46.09	8.15	1
1986	31.67	39.15	23.9			77.81	16.37	2.15
1987	27.85	31.1	19.32			58.91	13.87	1.13
1988	18.49	14.96	8.96			29.19	7.7	0.56
1989	7.9	17.48	11.1			28.88	5.89	0.63
1990	25.52	34.63	24.35			61.22	16.49	1.31
1991	28.5	27.1	20.86			49.87	14.11	1.05
1992	30.69	35.07	26.2	1446.75	1503.27	67.65	14.9	0.9
1993	32.67	30.61	24.76	1093.3	1663.67	66.11	16.73	1.08
1994	24.3	28.25	22.51	1183.85	1820.77	59.44	16.52	1.44
1995	20.7	27.36	21.11	1295.76	1974.03	50.63	17.05	1.44
1996	26.22	30.5	24.14	1501.68	1880.58	59.52	19.47	1.37
1997	19.72	22.46	18.76	1227.38	1697.8	49.08	14.31	1.17
1998	23.7	26.12	22.54	1211.25	1884.46	55.16	16.64	1.1
1999	23.8	23.42	22.43	1476.47	2020.92	46.29	16.15	1.5
2000	28.62	30.473	27.71	971.77	2227.6	55.75	17.21	1.2
2001	23.07	26.57	22.63	1005.11	2050.51	50.75	16.87	0.8
2002	21.44	26.79	23.44	833.64	1730.6	43.3	15.13	0.7
2003	17.03	23.94	20.22	851.38	1395.84	40.17	11.6	0.8
2004	25.1	28.54	24.57	1035.56	2218.1	54.6	12.59	1.2
2005	27.14	30.69	30.1	1150.53	1432.81	51.01	19.35	1.4
2006	22.24	30.43	29.34	695.06	1728.44	51.14	15.85	1.4
2007	23.27	28.69	28.94	937.23	2068.5	51.83	17.84	1.4
2008	25.87	32.59	27.61	1100.54	1796.5	51.71	18.6	1.1
Average	23.62	28.18	19.42	1118.66	1829.08	53.81	12.63	1.28

Source: Saskatchewan Ministry of Agriculture (2008)

HISTORICAL PRICES 1968 - 2008

Year	Historical Prices								
	Canola	Spring Wheat	Durum	Lentils	Peas	Barley	Flax	Hay	Calf
	$/bu	$/bu	$/bu	¢/lb	$/lb	$/bu	$/bu	$/t	$/cwt
1968	4.17	2.7			4.05	1.92	5.82	59.88	117.97
1969	4.99	2.54			4.01	1.61	5.06	56.89	143.36
1970	5.18	2.89	2.75		4.28	1.88	4.29	53.59	147.37
1971	4.72	2.67	2.45	7.46	4.43	1.56	4.3	55.7	146.45
1972	6.9	3.28	4.99	7.74	5.59	2.84	7.64	53.92	162.3
1973	11.59	7.97	11.72	10.02	9.67	5.52	16.75	75.62	192.581
1974	13.25	6.89	9.67	27.63	8.45	4.4	16.11	89.58	125.03
1975	8.72	5.44	6.91	21.31	8.68	4.32	10.34	84.04	80.29
1976	10.14	4.28	5.27	9.58	8.4	3.46	10.29	84.7	83.43
1977	10.21	4.05	4.52	41.67	10.89	2.86	7.86	75.8	91.2
1978	9.48	5.26	5	16.95	6.6	2.84	9.72	76.11	165.62
1979	8.44	6.11	6.6	23.27	5.88	3.6	9.71	90.73	225.09
1980	8.27	6.67	7.29	26.83	7.75	4.38	10.32	97.63	175.01
1981	7.58	5.57	5.54	18.3	7.75	3.55	8.96	90.9	129.98
1982	6.66	4.69	4.67	12.79	6.89	2.69	6.39	73.37	119.05
1983	9.07	4.71	5.03	12.49	6	3.02	7.99	71.75	132.11
1984	8.2	4.57	4.83	15.26	6.79	2.96	7.65	82.86	133.79
1985	6	0.48	4.02	24.61	6.33	2.51	6.21	84.35	130.29
1986	4.52	2.67	3.1	17.51	6.54	1.9	4.01	68.29	150.36
1987	5.79	2.92	3.6	9.69	5.89	1.83	4.63	67.65	170.47
1988	6.5	4.54	4.53	13.3	6.62	2.86	8.38	79.02	156.68
1989	5.65	3.68	3.36	14.81	5.74	2.55	7.7	63.41	144.67
1990	5.25	2.73	2.47	15.5	5.69	1.81	4.14	57.97	142.4
1991	4.75	2.61	2.61	10.77	5.33	1.94	3.21	42.63	135.22
1992	5.2	2.78	3.01	9.32	6.04	1.83	4.49	46.39	134.8
1993	7	2.8	4.29	10.2	5.59	1.71	4.77	58	160.86
1994	7.33	4.04	5.73	12.85	6.21	2.42	5.98	50.87	147.39
1995	7.73	5.2	5.76	15.89	7.04	3.54	6.6	57.06	118.28
1996	8.25	3.91	4.82	12.4	7.85	2.67	7.44	81.86	97.72
1997	8.13	3.7	5.81	11.21	6.76	2.64	7.72	82.95	132.77
1998	7.53	3.79	4.02	13.92	5.74	2.22	6.89	79.11	143.33
1999	5.39	3.22	3.98	16.1	5.46	2.34	4.76	58.05	168.76
2000	5.33	3.57	4.93	12.74	5.06	2.5	5.46	60.36	192.59
2001	6.97	4.25	5.5	13.13	7.48	2.98	7.31	78.19	181.77
2002	8.23	4.6	5.22	16.43	8.39	3.26	8.83	112.37	146.3
2003	7.65	4.08	4.65	12.6	4.84	2.58	8.15	79.96	134.65
2004	6.05	2.93	3.63	15.42	5.71	2.04	10.69	64.73	110.51
2005	5.49	2.89	3.13	10.51	5.05	1.87	6.27	85	140.15
2006	7.26	3.91	4.46	12.25	6.88	2.69	6.35	80	132.93
2007	10.42	7.94	11.93	21.25	6.57	4.46	13.45	90	109.71
2008	10.01	6.25	8.03	33.05	6.58	4.6	12.36	70	100.99
Average	7.32	4.21	5.12	15.97	6.48	2.81	7.68	72.47	140.35

Source: Saskatchewan Ministry of Agriculture (2008)

APPENDIX D

CEREAL STRAW MCALS CALCULATION

The cereal straw Mcals are based upon straw production per tonne of cereal crop yield per acre. Each farm agent generates different yields per acre based upon the soil productivity of their plot. Therefore, the energy content per acre of cereal straw is based upon barley and wheat straw having an energy content of 992 Mcal per tonne. However, the ratios of straw per tonne of grain for wheat and barley vary and so are based upon barley straw having 0.80 tonnes of straw per tonne of barley seed yield while wheat straw has 0.79 tonnes of straw per tonne of wheat seed yield. To generate an average Mcal of straw per acre the following assumptions were used - barley possesses an average yield of 1.2 tonnes per acre, while wheat has an average of 0.95 tonnes per acre. Therefore:

Average tonne of barley straw per acre becomes:

$$\frac{0.80}{1.2} = 0.83$$

Average tonne of wheat straw per acre becomes:

$$\frac{0.79}{0.95} = 0.67$$

Finally, the average Mcal of straw per acre for wheat and barley become:

$$Mcal_{BS} = 0.83 * 992 = 664$$

$$Mcal_{WS} = 0.67 * 992 = 823$$

APPENDIX E

ANNUAL CROP MACHINERY PACKAGE OPTIONS

Machinery Option 0 - Max 500 Acres

Number	Machine	CAT	HP	Date Made	New Cost (Replacement)	Current Value	Ending Value	Annualized Repairs	Actual Annual Usage	Use to Date	Use to End of Warranty	Repairs to End of Warranty	Replacement Age	Width/ Rate	Current Age	Years of Life Remaining	CRC
1	2WD	3	90	1995	$ 75,000	$ 25,796	$ 8,077	$ 1,916	300	4200	300	274	30	0	14	16	$ 2,039
1	Tandem	5	370	1982	$ 115,000	$ 15,560	$ 6,057	$ 1,052	150	4050	150	185	40	0	27	13	$ 1,314
1	Grain Truck	5	275	1981	$ 87,000	$ 10,947	$ 4,583	$ 454	100	2800	100	79	40	0	28	12	$ 947
1	Auger 7"	24		1999	$ 5,300	$ 724	$ 112	$ 53	75	750	75	1	20	0	10	10	$ 85
1	2WD Yard-Tractor	3	50	1995	$ 30,000	$ 10,318	$ 4,644	$ 195	125	1750	125	29	25	0	14	11	$ 915
1	Rock Picker	21		1999	$ 8,600	$ 2,729	$ 562	$ 3	10	100	10	1	25	0	10	15	$ 237
1	1/2 Ton -Truck	6		1999	$ 25,000	$ 11,616	$ 8,081	$ 889	150	1500	150		15	0	10	5	$ 1,220
1	1/2 Ton -Truck	6		1995	$ 25,000	$ 8,689	$ 5,622	$ 889	150	2100	150		20	0	14	6	$ 885
		Total Investment			$ 370,900	$ 86,379	$ 37,738	$ 5,451								**Total CRC**	$ 7,643
		Investment or C			$ 741.80	$ 172.76	$ 75.5	$ 10.90								**CRC/Acre**	$ 15.29

Labour	$ -
Total Fixed Cost	$ 7,643
Average Fixed Cost/Acre	$ 15.29
Variable Cost/Acre	$ 56.51
Total Machinery Cost/Acre	$ 71.79

Machinery Option 1 - Max 1300 Acres

Number	Machine	CAT	HP	Date Made	New Cost (Replacement)	Current Value	Ending Value	Annualized Repairs	Actual Annual Usage	Use to Date	Use to End of Warranty	Repairs to End of Warranty	Replacement Age	Width/ Rate	Current Age	Years of Life Remaining	CRC
1	2WD	3	170	1999	$ 117,900	$ 54,208	$ 26,236	$ 3,286	361	3610	361	568	20	0	10	10	$ 4,934
1	2WD	3	90	1995	$ 75,000	$ 25,796	$ 8,077	$ 1,774	285	3990	285	254	30	0	14	16	$ 2,039
1	AirSeeder	14		1999	$ 92,400	$ 29,318	$ 17,312	$ 428	43	433	43	155	15	30	10	5	$ 3,639
1	Combine	4	300	1999	$ 215,500	$ 58,216	$ 30,723	$ 2,401	135	1350	135	454	15		10	5	$ 7,887
1	Draper Header	11		1999	$ 35,800	$ 11,359	$ 6,708	$ 799	101	1010	101	208	15	20	10	5	$ 1,410
1	Pick-up Header	11		1999	$ 20,900	$ 6,632	$ 3,916	$ 102	34	340	34	26	15	14	10	5	$ 823
1	Sprayer - Pull Type	13		1999	$ 37,200	$ 12,711	$ 4,432	$ 1,305	161	1613	161	317	20	60	10	10	$ 1,294
1	Tandem	5	370	1985	$ 115,000	$ 19,345	$ 12,516	$ 966	150	3600	150	185	30		24	6	$ 1,971
1	Grain Truck	5	275	1984	$ 87,000	$ 13,610	$ 9,468	$ 736	150	3750	150	140	30		25	5	$ 1,430
1	Auger 7"	24		2004	$ 5,300	$ 1,837	$ 112	$ 53	75	750	75	1	20		5	15	$ 172
2	Auger 8"	24		2004	$ 12,400	$ 4,298	$ 263	$ 124	75	750	75	1	20		5	15	$ 402
1	2WD Yard-Tractor	3	50	1995	$ 30,000	$ 10,318	$ 4,644	$ 256	150	2100	150	39	25		14	11	$ 915
1	Swather Roller	18		1999	$ 1,400	$ 444	$ 91	$ 16	65	650	65	5	25		10	15	$ 39
1	Swather SP	22	50	1999	$ 94,900	$ 25,637	$ 7,140	$ 83	15	148	15	20	20	22	10	10	$ 2,752
1	Harrow Standard	18		1999	$ 8,700	$ 2,760	$ 568	$ 98	65	650	65	32	25	40	10	15	$ 240
1	Field Cultivator	20		1999	$ 26,900	$ 8,535	$ 5,040	$ 15	5	52	5	5	15	25	10	5	$ 1,059
1	HD Cultivator -w/NH3 Tank	20		1999	$ 51,600	$ 16,373	$ 9,668	$ 574	52	520	52	207	15	25	10	5	$ 2,032
1	Land Roller	18		1999	$ 28,900	$ 9,170	$ 1,888	$ 22	8	81	8	7	25	40	10	15	$ 796
1	Rock Picker	21		1999	$ 8,600	$ 2,729	$ 562	$ 13	26	260	26	2	25		10	15	$ 237
1	3/4 Ton -Diesel	5		2000	$ 38,200	$ 19,085	$ 12,347	$ 1,185					15		9	6	$ 1,945
1	1/2 Ton -Truck	6		1999	$ 25,000	$ 11,616	$ 8,081	$ 889					15		10	5	$ 1,220
1	1/2 Ton -Truck	6		1995	$ 25,000	$ 8,689	$ 5,622	$ 889					20		14	6	$ 885
	Total Investment Required				$ 1,153,600	$ 352,686	$ 175,414	$ 16,014								**Total CRC**	$ 38,121
	Investment or Cost/Acre				$ 887.38	$ 271.30	$ 134.93	$ 12.32								**CRC/Acre**	$ 29.32

Labour	$ -
Total Fixed Cost	$ 38,121
Average Fixed Cost/Acre	$ 29.32
Variable Cost/Acre	$ 15.60
Total Machinery Cost/Acre	$ 44.92

Machinery Option 2 - Max 2000 Acres

Number	Machine	CAT	HP	Date Made	New Cost (Replacement)	Current Value	Ending Value	Annualized Repairs	Actual Annual Usage	Use to Date	Use to End of Warranty	Repairs to End of Warranty	Replacement Age	Width/ Rate	Current Age	Years of Life Remaining	CRC
1	4WD	2	275	2004	$ 165,100	$ 109,115	$ 52,810	$ 1,032	173	865	173	220	15		5	10	$ 9,932
1	2WD	3	170	1999	$ 117,900	$ 54,208	$ 26,236	$ 1,225	187	1870	187	212	20	0	10	10	$ 4,934
1	2WD	3	90	1995	$ 75,000	$ 25,796	$ 8,077	$ 677	150	2100	150	97	30	0	14	16	$ 2,039
1	AirDrill	14		2004	$ 112,800	$ 60,613	$ 21,134	$ 584	50	250	50	227	15	40	5	10	$ 6,169
1	Combine	4	300	2004	$ 215,500	$ 58,216	$ 30,723	$ 4,010	206	2060	206	855	15		5	10	$ 11,844
1	Draper Header	11		2004	$ 35,800	$ 11,359	$ 6,708	$ 527	75	750	75	137	15	20	5	10	$ 1,958
1	Pick-up Header	11		2004	$ 20,900	$ 6,632	$ 3,916	$ 109	36	357	36	28	15	14	5	10	$ 1,143
1	Sprayer -Pull Type	13		2009	$ 49,200	$ 49,200	$ 9,927	$ 1,752	161	806	161	419	15	80	0	15	$ 4,280
2	Auger 8"	24		2009	$ 12,400	$ 12,400	$ 667	$ 124	75	375	75	1	15		0	15	$ 1,164
1	Auger 10"	24		2009	$ 10,000	$ 10,000	$ 538	$ 100	75	375	75	1	15		0	15	$ 938
1	Tandem	5	370	1985	$ 115,000	$ 19,345	$ 12,516	$ 966	150	3600	150	185	30		24	6	$ 1,971
2	Grain Truck	5	275	1984	$ 174,000	$ 27,220	$ 18,937	$ 1,472	150	3750	150	140	30		25	5	$ 2,860
1	2WD Yard-Tractor	3	50	1995	$ 30,000	$ 10,318	$ 4,644	$ 256	150	2100	150	39	25		14	11	$ 915
1	1/2 Ton Truck	6		2004	$ 25,000	$ 16,697	$ 8,081	$ 889	150	1500	150		15		5	10	$ 1,520
1	Swather Roller	18		1999	$ 1,400	$ 444	$ 91	$ 28	100	1000	100	9	25		10	15	$ 39
1	Swather SP	22	70	2009	$ 97,300	$ 97,300	$ 13,872	$ 86	19	96	19	30	15	26	0	15	$ 8,731
1	Rock Picker	21		2004	$ 8,600	$ 4,621	$ 951	$ 21	40	200	40	4	20		5	15	$ 401
1	Liquid Fertilizer Tank	38		2004	$ 15,000	$ 10,446	$ 6,254	$ 64	0	0	0	2	15		5	10	$ 856
1	Land Roller	18		2004	$ 28,900	$ 15,529	$ 3,197	$ 34	13	63	13	13	20	40	5	15	$ 1,348
1	3/4 Ton -Diesel	5		2000	$ 38,200	$ 19,085	$ 12,347	$ 1,185					15		9	6	$ 1,945
1	1/2 Ton Truck	6		1995	$ 25,000	$ 8,689	$ 5,622	$ 889					20	0	14	6	$ 885
1	Grain Dryer - 300 BU/Hr	27		1999	$ 46,700	$ 26,563	$ 15,904	$ 117					20		10	10	$ 2,176
1	Harrow Heavy	18		2009	$ 29,800	$ 29,800	$ 1,947	$ 151	40	0	40	59	25	50	0	25	$ 2,074
	Total Investment Required				$ 1,449,500	$ 683,596	$ 265,099	$ 16,298								**Total CRC**	$ 70,122
	Investment or Cost/Acre				$ 724.75	$ 341.80	$ 132.55	$ 8.15								**CRC/Acre**	$ 35.06

Labour	$ 24,000
Total Fixed Cost	$ 94,122
Average Fixed Cost/Acre	$ 47.06
Variable Cost/Acre	$ 11.52
Total Machinery Cost/Acre	$ 58.58

Machinery Option 3 - Max 3200 Acres

Number	Machine	CAT	HP	Date Made	New Cost (Replacement)	Current Value	Ending Value	Annualized Repairs	Actual Annual Usage	Use to Date	Use to End of Warranty	Repairs to End of Warranty	Replacement Age	Width/ Rate	Current Age	Years of Life Remaining	CRC
1	4WD	2	350	2009	$ 201,365	$ 201,365	$ 92,584	$ 1,428	250	0	250	466	10		0	10	$ 18,717
1	AirDrill	14		2009	$ 124,175	$ 124,175	$ 54,047	$ 569	64	0	64	345	7	50	0	7	$ 14,822
1	Combine	4	300	2004	$ 235,000	$ 120,296	$ 63,484	$ 4,206	220	1100	220	1029	10		5	5	$ 16,296
1	Draper Header	11		2004	$ 43,900	$ 23,589	$ 13,929	$ 575	80	400	80	184	10	30	5	5	$ 2,928
1	Pick-up Header	11		2004	$ 20,900	$ 11,231	$ 6,632	$ 171	57	286	57	55	10		5	5	$ 1,394
1	Sprayer - Pull Type	13		2009	$ 49,200	$ 49,200	$ 16,812	$ 1,011	161		161	419	10	100	0	10	$ 5,035
1	2WD	3	170	1999	$ 117,900	$ 54,208	$ 26,236	$ 1,215	186	1860	186	210	20	0	10	10	$ 4,934
1	2WD	3	90	1995	$ 75,000	$ 25,796	$ 8,077	$ 515	125	1750	125	74	30	0	14	16	$ 2,039
1	Auger 10"	24		2009	$ 10,000	$ 10,000	$ 1,365	$ 100	75		75	1	10		0	10	$ 1,186
1	Auger 13"	24		2009	$ 15,000	$ 15,000	$ 2,048	$ 150	75		75	2	10		0	10	$ 1,780
1	Tandem	5	370	1993	$ 112,000	$ 33,668	$ 12,189	$ 879	150	2400	150	180	30		16	14	$ 2,779
1	Grain Truck	5	275	1988	$ 87,000	$ 18,194	$ 9,468	$ 553	125	2625	125	108	30		21	9	$ 1,701
1	Grain Cart -750 BU	11		2004	$ 32,300	$ 17,356	$ 6,052	$ 244	57		57	85	15		5	10	$ 1,767
1	Semi-Tractor	5	450	1995	$ 150,000	$ 52,134	$ 16,325	$ 1,155	150	2100	150	241	30		14	16	$ 4,120
1	Semi-Trailer	24		1995	$ 150,000	$ 12,000	$ 714	$ 1,500					30	40	14	16	$ 876
1	2WD Yard-Tractor	3	50	1995	$ 30,000	$ 10,318	$ 4,644	$ 195	125	1750	125	29	25		14	11	$ 915
1	Swather Roller	18		1999	$ 1,400	$ 444	$ 91	$ 21	80	800	80	7	25	10	10	15	$ 39
1	Swather SP	22	100	2009	$ 99,500	$ 99,500	$ 50,934	$ 82	27		27	48	5	30	0	5	$ 13,764
1	Harrow Heavy	18		2009	$ 29,800	$ 29,800	$ 1,947	$ 279	64		64	5	25	50	0	25	$ 2,074
1	1/2 Ton Truck	6		2004	$ 25,000	$ 16,697	$ 8,081	$ 889	150	750	150	40	15		5	10	$ 1,520
1	3/4 Truck Diesel	5		2004	$ 45,000	$ 30,054	$ 20,908	$ 1,185	150	750	150	72	10		5	5	$ 3,158
1	Liquid Fertilizer Tank	38		2004	$ 15,000	$ 10,446	$ 6,254	$ 64				2	15		5	10	$ 856
1	Land Roller	18		2004	$ 28,900	$ 15,529	$ 3,197	$ 63	20	100	20	23	20	40	5	15	$ 1,348
1	1/2 Ton Truck	6		1995	$ 25,000	$ 8,689	$ 5,622	$ 889	150	2100	150	40	20	0	14	6	$ 885
1	Grain Dryer - 300 BU/Hr	27		1999	$ 46,700	$ 26,563	$ 15,904	$ 117					20		10	10	$ 2,176
1	Rock Picker - Fork Type	21		2004	$ 8,600	$ 4,621	$ 951	$ 21					20		5	15	$ 401
	Total Investment Required				$ 1,778,640	$ 1,020,873	$ 448,495	$ 18,076								**Total CRC**	$ 107,509
	Investment or Cost/Acre				$ 555.83	$ 319.02	$ 140.15	$ 5.65								**CRC/Acre**	$ 33.60

1 at $40,000	**Labour**	$ 40,000
	Total Fixed Cost	$ 147,509
	Average Fixed Cost/Acre	$ 46.10
	Variable Cost/Acre	$ 10.48
	Total Machinery Cost/Acre	$ 56.57

Machinery Option 4 - Max 4300 Acres

Number	Machine	CAT	HP	Date Made	New Cost (Replacement)	Current Value	Ending Value	Annualized Repairs	Actual Annual Usage	Use to Date	Use to End of Warranty	Repairs to End of Warranty	Replacement Age	Width/ Rate	Current Age	Years of Life Remaining	CRC
1	4WD	2	425	2009	$ 220,254	$ 220,254	$ 101,269	$ 2,053	300		300	679	10			10	$ 20,473
1	AirDrill	14		2009	$ 152,558	$ 152,558	$ 66,401	$ 810	72		72	491	7	60		7	$ 18,210
1	Combine	4	350	2009	$ 272,417	$ 272,417	$ 139,450	$ 2,871	246		246	1410	5			5	$ 37,684
1	Draper Header	11		2009	$ 42,766	$ 42,766	$ 22,980	$ 358	90		90	210	5	36		5	$ 5,719
1	Pick-up Header	11		2009	$ 24,900	$ 24,900	$ 7,901	$ 197	67		67	82	10	16		10	$ 2,597
1	HC Sprayer	13	110	2004	$ 104,700	$ 60,588	$ 35,777	$ 2,784	161	806	161	892	10	80	5	5	$ 7,520
1	2WD	3	170	1999	$ 117,900	$ 54,208	$ 26,236	$ 670	125	1250	125	116	20		10	10	$ 4,934
1	2WD	3	90	1995	$ 75,000	$ 25,796	$ 8,077	$ 515	125	1750	125	74	30		14	16	$ 2,039
1	Auger 10"	24		2009	$ 10,000	$ 10,000	$ 1,365	$ 100	75		75	1	10			10	$ 1,186
2	Auger 13"	24		2009	$ 30,000	$ 30,000	$ 4,096	$ 300	75		75	3	10			10	$ 3,559
1	Tandem	5	370	1993	$ 112,000	$ 33,668	$ 12,189	$ 879	150	2400	150	180	30		16	14	$ 2,779
1	Grain Truck	5	275	1988	$ 87,000	$ 18,194	$ 9,468	$ 714	150	3150	150	140	30		21	9	$ 1,701
1	Grain Cart -750 BU	11		2009	$ 32,300	$ 32,300	$ 6,052	$ 307	67		67	106	15			15	$ 2,831
1	Semi-Tractor	5	450	1995	$ 150,000	$ 52,134	$ 16,325	$ 1,155	150	2100	150	241	30		14	16	$ 4,120
1	Semi-Trailer	24		1995	$ 150,000	$ 12,000	$ 714	$ 1,500	75	1050	75	15	30	40	14	16	$ 876
1	2WD Yard-Tractor	3	50	1995	$ 30,000	$ 10,318	$ 4,644	$ 195	125	1750	125	29	25		14	11	$ 915
1	Swather Roller	18		1999	$ 1,400	$ 444	$ 91	$ 30	108	1075	108	10	25	10	10	15	$ 39
1	Swather SP	22	100	2009	$ 99,500	$ 99,500	$ 50,934	$ 124	150	750	150	72	5	30		5	$ 13,764
1	Harrow Heavy	18		2009	$ 29,800	$ 29,800	$ 1,947	$ 409	86	860	86	7	25	50		25	$ 2,074
1	3/4 Truck Diesel	5		2004	$ 45,000	$ 30,054	$ 20,908	$ 1,185	150	750	150	72	10		5	5	$ 3,158
1	Liquid Fertilizer Tank	14		2009	$ 15,000	$ 15,000	$ 4,759	$ 91	72		72	48	10			10	$ 1,564
1	Land Roller	18		2004	$ 28,900	$ 15,529	$ 3,197	$ 93	27	134	27	34	20	40	5	15	$ 1,348
1	1/2 Ton - Truck	6		2004	$ 25,000	$ 16,697	$ 8,081	$ 889	150				15		5	10	$ 1,520
1	1/2 Ton - Truck	6		1995	$ 25,000	$ 8,689	$ 5,622	$ 889	150				20		14	6	$ 885
1	Grain Dryer - 300 BU/Hr	27		2009	$ 46,700	$ 46,700	$ 15,904	$ 117					20			20	$ 3,266
1	Rock Picker - Fork Type	21		2009	$ 8,600	$ 8,600	$ 951	$ 18					20			20	$ 661
	Total Investment Required				$ 1,936,695	$ 1,323,114	$ 575,338	$ 19,253								**Total CRC**	$ 145,424
	Investment or Cost/Acre				$ 450.39	$ 307.70	$ 133.80	$ 4.48								**CRC/Acre**	$ 33.82

1 at $40,000/Season	**Labour**	$ 40,000
	Total Fixed Cost	$ 185,424
	Average Fixed Cost/Acre	$ 43.12
	Total Variable Cost/Acre	$ 9.18
	Total Machinery Cost/Acre	$ 52.30

Machinery Option 5 - Max Acres 9000

Number	Machine	CAT	HP	Date Made	New Cost (Replacement)	Current Value	Ending Value	Annualized Repairs	Actual Annual Usage	Use to Date	Use to End of Warranty	Repairs to End of Warranty	Replacement Age	Width/ Rate	Current Age	Years of Life Remaining	CRC
2	4WD	2	425	2009	$ 440,508	$ 440,508	$ 202,538	$ 3,447	267		267	1126	10			10	$ 36,667
2	AirDrill	14		2009	$ 305,116	$ 305,116	$ 132,802	$ 4,232	75		75	1042	7	60		7	$ 32,465
2	Combine	4	350	2009	$ 544,834	$ 544,834	$ 278,901	$ 6,168	258		258	3029	5			5	$ 65,931
2	Draper Header	11		2009	$ 85,532	$ 85,532	$ 45,960	$ 763	94		94	448	5	36		5	$ 9,956
2	Pick-up Header	11		2009	$ 49,800	$ 49,800	$ 15,801	$ 421	70		70	174	10	16		10	$ 4,709
1	HC Sprayer	13	200	2009	$ 216,100	$ 216,100	$ 125,053	$ 6,456	270		270	3790	5	100		5	$ 23,539
1	2WD	3	225	2004	$ 154,100	$ 101,845	$ 34,291	$ 790	125	625	125	151	20		5	15	$ 8,223
1	2WD	3	170	1999	$ 117,900	$ 54,208	$ 26,236	$ 670	125	1250	125	116	20		10	10	$ 4,934
1	2WD Yard-Tractor	3	50	1995	$ 30,000	$ 10,318	$ 4,644	$ 195	125	1750	125	29	25		14	11	$ 915
2	Auger 10"	24		2009	$ 20,000	$ 20,000	$ 2,731	$ 200	75		75	2	10			10	$ 2,373
2	Auger 13"	24		2009	$ 30,000	$ 30,000	$ 4,096	$ 300	75		75	3	10			10	$ 3,559
1	Tandem	5	430	2004	$ 125,000	$ 83,483	$ 58,078	$ 626	150	750	150	201	10		5	5	$ 8,772
1	Grain Cart -1100 BU	11		2009	$ 53,400	$ 53,400	$ 10,005	$ 540	70		70	187	15			15	$ 4,295
2	Semi-Tractor	5	450	2004	$ 300,000	$ 200,358	$ 96,970	$ 1,676	150	750	150	482	15		5	10	$ 18,238
2	Semi-Trailer	24		2004	$ 300,000	$ 103,991	$ 16,135	$ 3,000	75	375	75	30	15	40	5	10	$ 12,184
2	1/2 Ton Truck	6		2004	$ 50,000	$ 33,393	$ 16,162	$ 1,778	150	750	150	80	15		5	10	$ 3,040
1	Swather Roller	18		1999	$ 1,700	$ 539	$ 111	$ 96	225	2250	225	32	25	10	10	15	$ 47
1	Swather SP	22	140	2009	$ 120,000	$ 120,000	$ 61,428	$ 326	63		63	191	5	36		5	$ 14,521
1	Harrow Heavy	18		2009	$ 39,500	$ 39,500	$ 2,580	$ 770	113		113	298	25	80		25	$ 2,538
1	3/4 Truck Diesel	5		2009	$ 38,200	$ 38,200	$ 17,749	$ 1,185	150		150	61	10			10	$ 3,536
2	Liquid Fertilizer Tank	14		2009	$ 30,000	$ 30,000	$ 9,519	$ 194	75		75	102	10			10	$ 2,837
1	Land Roller	18		2009	$ 28,900	$ 28,900	$ 3,197	$ 213	56		56	88	20	40		20	$ 2,048
1	Grain Dryer - 300 BU/Hr	27		2009	$ 46,700	$ 46,700	$ 15,904	$ 117					20			20	$ 3,266
1	Rock Picker - Fork Type	21		2009	$ 8,600	$ 8,600	$ 951	$ 47					20			20	$ 638
	Total Investment Required				$ 3,135,890	$ 2,645,325	$ 1,181,842	$ 34,210								**Total CRC**	$ 269,233
	Investment or Cost/Acre				$ 348.43	$ 293.93	$ 131.32	$ 3.80								**CRC/Acre**	$ 29.91

2 at $40,000/Season	**Labour**	$ 80,000
	Total Fixed Cost	$ 349,233
	Average Fixed Cost/Acre	$ 38.80
	Total Variable Cost/Acre	$ 10.21
	Total Machinery Cost/Acre	$ 49.02

Machine Option 6 - Max Acres 12300

Number	Machine	CAT	HP	Date Made	New Cost (Replacement)	Current Value	Ending Value	Annualized Repairs	Actual Annual Usage	Use to Date	Use to End of Warranty	Repairs to End of Warranty	Replacement Age	Width/ Rate	Current Age	Years of Life Remaining	CRC
3	4WD	2	425	2009	$ 660,762	$ 660,762	$ 303,807	$ 5,762	287		287	1882	10		0	10	$ 55,000
3	AirDrill	14		2009	$ 457,674	$ 457,674	$ 199,203	$ 2,284	68		68	1384	7	60	0	7	$ 48,697
3	Combine	4	350	2009	$ 817,251	$ 817,251	$ 418,351	$ 8,042	235		235	3950	5		0	5	$ 98,896
3	Draper Header	11		2009	$ 128,298	$ 128,298	$ 68,940	$ 1,005	85		85	590	5	36	0	5	$ 14,935
3	Pick-up Header	11		2009	$ 74,700	$ 74,700	$ 23,702	$ 554	64		64	394	10	16	0	10	$ 7,064
1	HC Sprayer	13	250	2009	$ 270,000	$ 270,000	$ 156,244	$ 8,192	273		273	4809	5	100	0	5	$ 29,410
1	Pull-Type Sprayer	19		2009	$ 49,200	$ 49,200	$ 26,437	$ 859	96		96	504	5	100	0	5	$ 5,727
1	2WD	3	225	2004	$ 154,100	$ 101,845	$ 34,291	$ 790	125	625	125	151	20	0	5	15	$ 8,223
1	2WD	3	170	1999	$ 117,900	$ 54,208	$ 26,236	$ 670	125	1250	125	116	20	0	10	10	$ 4,934
1	2WD Yard-Tractor	3	50	1995	$ 30,000	$ 10,318	$ 4,644	$ 195	125	1750	125	29	25		14	11	$ 915
2	Auger 13"	24		2009	$ 30,000	$ 30,000	$ 10,399	$ 300	75		75	3	5		0	5	$ 5,047
1	Conveyor	24		2009	$ 20,000	$ 20,000	$ 6,933	$ 200	75		75	2	5		0	5	$ 3,365
2	Tandem	5	430	2004	$ 250,000	$ 166,965	$ 116,156	$ 1,253	150	750	150	402	10		5	5	$ 17,543
1	Grain Cart -1100 BU	11		2009	$ 53,400	$ 53,400	$ 10,005	$ 709	85		85	246	15		0	15	$ 4,295
2	Semi-Tractor	5	450	2004	$ 300,000	$ 200,358	$ 96,970	$ 1,676	150	750	150	482	15		5	10	$ 18,238
2	Semi-Trailer	24		2004	$ 300,000	$ 103,991	$ 16,135	$ 3,000	75	375	75	30	15	40	5	10	$ 12,184
2	1/2 Ton Truck	6		2004	$ 50,000	$ 33,393	$ 16,162	$ 889	150	750	150	80	15		5	10	$ 3,040
1	Swather Roller	18		1999	$ 1,700	$ 539	$ 111	$ 27	85	854	85	9	25	10	10	15	$ 47
1	Swather SP	22	140	2009	$ 120,000	$ 120,000	$ 61,428	$ 505	85		85	297	5	36	0	5	$ 14,521
1	Harrow Heavy	18		2009	$ 39,500	$ 39,500	$ 2,580	$ 1,155	154		154	447	25	80	0	25	$ 2,538
1	3/4 Truck Diesel	5		2009	$ 38,200	$ 38,200	$ 17,749	$ 1,185	150		150	447	10		0	10	$ 3,536
3	Liquid Fertilizer Tank	14		2009	$ 45,000	$ 45,000	$ 14,278	$ 258	68		68	136	10		0	10	$ 4,255
1	Land Roller	18		2009	$ 35,000	$ 35,000	$ 6,558	$ 1,594	246		246	729	15	50	0	15	$ 2,815
1	Grain Dryer - 300 BU/Hr	27		2009	$ 46,700	$ 46,700	$ 15,904	$ 117					20		0	20	$ 3,266
1	Rock Picker - 3 Paddle Hydrau	21		2009	$ 18,000	$ 18,000	$ 1,991	$ 157					20		0	20	$ 1,276
	Total Investment Required				$ 4,107,385	$ 3,575,302	$ 1,655,214	$ 41,378								**Total CRC**	$ 369,769
	Investment or Cost/Acre				$ 333.93	$ 290.67	$ 134.57	$ 3.36								**CRC/Acre**	$ 30.06

2 at $40,000/Season	**Labour**	$ 80,000
	Total Fixed Cost	$ 449,769
	Average Fixed Cost	$ 36.57
	Total Variable Cost/Acre	$ 10.80
	Total Machinery Cost/Acre	$ 47.37

Machine Option 7 - Max 18000 Acres

Number	Machine	CAT	HP	Date Made	New Cost (Replacement)	Current Value	Ending Value	Annualized Repairs	Actual Annual Usage	Use to Date	Use to End of Warranty	Repairs to End of Warranty	Replacement Age	Width/ Rate	Current Age	Years of Life Remaining	CRC
3	4WD	2	500	2009	$ 825,000	$ 825,000	$ 379,321	$ 9,730	351		351	3510	10			10	$ 68,670
3	AirDrill	14		2009	$ 600,000	$ 600,000	$ 261,150	$ 3,380	75		75	2048	7	80		7	$ 63,841
4	Combine	4	350	2009	$ 1,089,668	$ 1,089,668	$ 557,801	$ 12,696	263		263	6235	5			5	$ 131,861
4	Draper Header	11		2009	$ 171,064	$ 171,064	$ 91,921	$ 1,527	94		94	896	5	36		5	$ 19,913
3	Pick-up Header	11		2009	$ 56,025	$ 56,025	$ 17,777	$ 708	94		94	294	10	16		10	$ 5,298
2	HC Sprayer	13	250	2009	$ 540,000	$ 540,000	$ 312,487	$ 16,133	270		270	9469	5	100		5	$ 58,820
2	2WD	3	225	2004	$ 308,200	$ 203,691	$ 68,583	$ 1,579	125	625	125	303	20		5	15	$ 16,446
1	2WD	3	170	1999	$ 117,900	$ 54,208	$ 26,236	$ 670	125	1250	125	116	20		10	10	$ 4,934
1	2WD Yard-Tractor	3	50	1995	$ 30,000	$ 10,318	$ 4,644	$ 195	125	1750	125	29	25		14	11	$ 915
4	Auger 13"	24		2009	$ 60,000	$ 60,000	$ 20,798	$ 600	75		75	6	5			5	$ 10,095
1	Conveyor	24		2009	$ 20,000	$ 20,000	$ 6,933	$ 200	75		75	2	5			5	$ 3,365
2	Tandem	5	430	2004	$ 250,000	$ 166,965	$ 116,156	$ 1,253	150	750	150	402	10		5	5	$ 17,543
2	Grain Cart -1100 BU	11		2009	$ 106,800	$ 106,800	$ 20,010	$ 1,080	70		70	374	15			15	$ 8,590
3	Semi-Tractor	5	450	2004	$ 450,000	$ 300,537	$ 145,455	$ 2,515	150	750	150	723	15		5	10	$ 27,357
3	Semi-Trailer	24		2004	$ 450,000	$ 155,986	$ 24,203	$ 4,500	75	375	75	45	15	40	5	10	$ 18,277
2	1/2 Ton Truck	6	145	2004	$ 50,000	$ 33,393	$ 16,162	$ 1,778	150	750	150	80	15		5	10	$ 3,040
2	Swather Roller	18		1999	$ 3,400	$ 1,079	$ 222	$ 36	500	5000	500	178	25	10	10	15	$ 94
2	Swather SP	22	140	2009	$ 240,000	$ 240,000	$ 122,856	$ 652	63		63	383	5	36		5	$ 29,043
2	Harrow Heavy	18		2009	$ 79,000	$ 79,000	$ 5,161	$ 1,539	113		113	595	25	80		25	$ 5,077
2	3/4 Truck Diesel	5	210	2009	$ 76,400	$ 76,400	$ 35,497	$ 2,370	150		150	123	10			10	$ 7,072
3	Liquid Fertilizer Tank	14		2009	$ 45,000	$ 45,000	$ 14,278	$ 291	75		75	154	10			10	$ 4,255
1	Land Rollers	18		2009	$ 35,000	$ 35,000	$ 6,558	$ 431	90		90	197	15	50		15	$ 2,815
1	Grain Dryer 600 BU/Hr	27		2009	$ 68,000	$ 68,000	$ 23,158	$ 170					20			20	$ 4,756
1	Rock Picker - Extra Large	21		2009	$ 21,700	$ 21,700	$ 2,401	$ 335					20			20	$ 1,538
	Total Investment Required				$ 5,693,157	$ 4,959,834	$ 2,279,768	$ 64,368								**Total CRC**	$ 513,614
	Investment or Cost/Acre				$ 316.29	$ 275.55	$ 126.65	$ 3.58								**CRC/Acre**	$ 28.53

2 at $40,000/Season	**Labour**	$ 120,000
	Total Fixed Cost	$ 633,614
	Average Fixed Cost/Acre	$ 35.20
	Total Variable Cost/Acre	$ 9.95
	Total Machinery Cost/Acre	$ 45.15

Machine Option 8 - Max 23500 Acres

Number	Machine	CAT	HP	Date Made	New Cost (Replacement)	Current Value	Ending Value	Annualized Repairs	Actual Annual Usage	Use to Date	Use to End of Warranty	Repairs to End of Warranty	Replacement Age	Width/ Rate	Current Age	Years of Life Remaining	CRC
4	4WD	2	500	2009	$ 1,100,000	$ 1,100,000	$ 505,762	$ 11,826	330		330	3862	10			10	$ 91,561
4	AirDrill	14		2009	$ 800,000	$ 800,000	$ 348,200	$ 4,385	73		73	2657	7	80		7	$ 85,121
5	Combine	4	350	2009	$ 1,362,085	$ 1,362,085	$ 697,251	$ 16,507	270		270	8107	5			5	$ 164,827
5	Draper Header	11		2009	$ 197,500	$ 197,500	$ 106,126	$ 1,874	98		98	1100	5	36		5	$ 22,990
3	Pick-up Header	11		2009	$ 74,700	$ 74,700	$ 23,702	$ 1,371	122		122	568	10	16		10	$ 7,064
3	HC Sprayer	13	250	2009	$ 810,000	$ 810,000	$ 468,731	$ 19,924	235		235	11695	5	100		5	$ 88,229
2	2WD	3	225	2004	$ 308,200	$ 203,691	$ 68,583	$ 1,579	125	625	125	303	20		5	15	$ 16,446
2	2WD	3	170	1999	$ 235,800	$ 108,417	$ 52,472	$ 1,339	125	1250	125	232	20		10	10	$ 9,869
1	2WD Yard-Tractor	3	50	1995	$ 30,000	$ 10,318	$ 4,644	$ 256	125	1750	125	29	25		14	11	$ 915
5	Auger 13"	24		2009	$ 75,000	$ 75,000	$ 25,998	$ 750	75		75	8	5			5	$ 12,618
2	Conveyor	24		2009	$ 40,000	$ 40,000	$ 13,865	$ 400	75		75	4	5			5	$ 6,730
3	Tandem	5	430	2004	$ 375,000	$ 250,448	$ 174,234	$ 1,879	150	750	150	602	10		5	5	$ 26,315
2	Grain Cart -1100 BU	11		2009	$ 106,800	$ 106,800	$ 20,010	$ 1,616	94		94	560	15			15	$ 8,590
3	Semi-Tractor	5	450	2004	$ 450,000	$ 300,537	$ 145,455	$ 2,515	150	750	150	723	15		5	10	$ 27,357
3	Semi-Trailer	24		2004	$ 450,000	$ 155,986	$ 24,203	$ 4,500	75	375	75	45	15	40	5	10	$ 18,277
2	1/2 Ton Truck	6		2004	$ 50,000	$ 33,393	$ 16,162	$ 1,778	150	750	150	80	15		5	10	$ 3,040
3	Swather Roller	18		1999	$ 5,100	$ 1,618	$ 333	$ 46	82	816	82	25	25	10	10	15	$ 140
3	Swather SP	22	140	2009	$ 360,000	$ 360,000	$ 184,284	$ 806	82		82	834	5	36		5	$ 43,564
3	Harrow Heavy	18		2009	$ 118,500	$ 118,500	$ 7,741	$ 1,927	98		98	745	25	80		25	$ 7,615
3	3/4 Truck Diesel	5		2009	$ 114,600	$ 114,600	$ 53,246	$ 3,555	150		150	184	10			10	$ 10,608
4	Liquid Fertilizer Tank	14		2009	$ 60,000	$ 60,000	$ 19,038	$ 378	73		73	199	10			10	$ 5,674
2	Land Rollers	18		2009	$ 70,000	$ 70,000	$ 13,115	$ 495	59		59	227	15	50		15	$ 5,630
1	Grain Dryer 600 BU/Hr	27		2009	$ 68,000	$ 68,000	$ 23,158	$ 170					20			20	$ 4,756
2	Rock Picker - Extra Large	21		2009	$ 43,400	$ 43,400	$ 4,802	$ 870					20			20	$ 3,076
	Total Investment Required				$ 7,304,685	$ 6,464,993	$ 3,001,115	$ 80,746								**Total CRC**	$ 671,012
	Investment or Cost/Acre				$ 311.00	$ 275.11	$ 127.71	$ 3.44								**CRC/Acre**	$ 28.55

3 at $40,000/Season	**Labour**	$ 120,000
	Total Fixed Cost	$ 791,012
	Average Fixed Cost/Acre	$ 33.66
	Total Variable Cost/Acre	$ 10.18
	Total Machinery Cost/Acre	$ 43.84

Machine Option 9 - Max Acres 28000

Number	Machine	CAT	HP	Date Made	New Cost (Replacement)	Current Value	Ending Value	Annualized Repairs	Actual Annual Usage	Use to Date	Use to End of Warranty	Repairs to End of Warranty	Replacement Age	Width/ Rate	Current Age	Years of Life Remaining	CRC
5	4WD	2	500	2009	$ 1,375,000	$ 1,375,000	$ 632,202	$ 12,814	300		300	4184	10			10	$ 114,451
5	AirDrill	14		2009	$ 1,000,000	$ 1,000,000	$ 435,250	$ 5,150	70		70	3121	7	80		7	$ 106,401
6	Combine	4	350	2009	$ 1,634,502	$ 1,634,502	$ 836,702	$ 19,589	268		268	9621	5			5	$ 197,792
6	Draper Header	11		2009	$ 237,000	$ 237,000	$ 127,351	$ 2,226	97		97	1307	5	36		5	$ 27,588
3	Pick-up Header	11		2009	$ 74,700	$ 74,700	$ 23,702	$ 1,752	109		109	648	10	16		10	$ 7,064
4	HC Sprayer	13	250	2009	$ 1,080,000	$ 1,080,000	$ 624,975	$ 22,695	210		210	13321	5	100		5	$ 117,639
2	2WD	3	225	2004	$ 308,200	$ 203,691	$ 68,583	$ 1,579	125	625	125	303	20		5	15	$ 16,446
2	2WD	3	170	1999	$ 235,800	$ 108,417	$ 52,472	$ 1,339	125	1250	125	232	20		10	10	$ 9,869
1	2WD Yard-Tractor	3	50	1995	$ 30,000	$ 10,318	$ 4,644	$ 256	125	1750	125	29	25		14	11	$ 915
6	Auger 13"	24		2009	$ 90,000	$ 90,000	$ 31,197	$ 900	75		75	9	5			5	$ 15,142
2	Conveyor	24		2009	$ 40,000	$ 40,000	$ 13,865	$ 400	75		75	4	5			5	$ 6,730
3	Tandem	5	430	2004	$ 375,000	$ 250,448	$ 174,234	$ 1,879	150	750	150	589	10		5	5	$ 26,315
2	Grain Cart -1100 BU	11		2009	$ 106,800	$ 106,800	$ 20,010	$ 1,700	97		97	883	15			15	$ 8,590
4	Semi-Tractor	5	450	2004	$ 600,000	$ 400,717	$ 193,940	$ 3,353	150	750	150	964	15		5	10	$ 36,476
4	Semi-Trailer	24		2004	$ 600,000	$ 207,981	$ 32,270	$ 6,000	75	375	75	60	15	40	5	10	$ 24,369
2	1/2 Ton Truck	6		2004	$ 50,000	$ 33,393	$ 16,162	$ 1,778	150	750	150	80	15		5	10	$ 3,040
3	Swather Roller	18		1999	$ 5,100	$ 1,618	$ 333	$ 57	65	648	65	19	25	10	10	15	$ 140
3	Swather SP	22	140	2009	$ 360,000	$ 360,000	$ 184,284	$ 1,030	65		65	604	5	36		5	$ 43,564
3	Harrow Heavy	18		2009	$ 118,500	$ 118,500	$ 7,741	$ 2,420	117		117	936	25	80		25	$ 7,615
3	3/4 Truck Diesel	5		2009	$ 114,600	$ 114,600	$ 53,246	$ 3,555	150		150	184	10			10	$ 10,608
5	Liquid Fertilizer Tank	14		2009	$ 75,000	$ 75,000	$ 23,797	$ 444	70		70	234	10			10	$ 7,092
2	Land Roller	18		2009	$ 70,000	$ 70,000	$ 13,115	$ 622	70		70	285	15	50		15	$ 5,630
1	Grain Dryer 600 BU/Hr	27		2009	$ 68,000	$ 68,000	$ 23,158	$ 170					20			20	$ 4,756
2	Rock Picker -Extra Large	21		2009	$ 43,400	$ 43,400	$ 4,802	$ 870					20			20	$ 3,076
	Total Investment Required				$ 8,691,602	$ 7,704,085	$ 3,598,035	$ 92,578								**Total CRC**	$ 801,308
	Investment or Cost/Acre				$ 310.41	$ 275.15	$ 128.50	$ 3.31								**CRC/Acre**	$ 28.62

4 at $40,000/Season	**Labour**	$ 160,000
	Total Fixed Cost	$ 961,308
	Average Fixed Cost/Acre	$ 34.33
	Total Variable Cost/Acre	$ 9.91
	Total Machinery Cost/Acre	$ 44.24

APPENDIX F

VARIABLE COSTS ANNUAL CROP MACHINERY

Option 0 - Custom Rate 500 Acres Max	
Machine	Custom Rate
Airseeder	$ 12.52
Combine	$ 23.40
Sprayer	$ 4.60
Swather	$ 3.96
Harrows	$ 2.97
Field Cultivator	$ 9.06
Total VC	$ 56.51

Option 1 - 1300 Acres Max

Number	Machine	HP	HP Efficiency	Fuel Consumption ($/hr)	Operating Cost/hr	Width	field Efficiency	speed (mph)	Acres or BU/hour	Hrs/Acre	Operating Cost
1	2WD	170	0.75	$ 33.12	$ 33.12						
1	2WD	90	0.6	$ 14.03	$ 14.03						
1	AirSeeder			$ -		30	0.77	4.50	12.60	0.0794	$ 2.63
1	Combine	300	0.6	$ 46.76	$ 46.76				9.70	0.1031	$ 4.82
1	Sprayer			$ -		60	0.85	4.00	24.73	0.0404	$ 1.70
1	Swather SP	50	0.6	$ 7.79	$ 7.79	22	0.83	4.25	9.41	0.0266	$ 0.21
1	Harrow - Standard					40	0.83	5.00	20.12	0.0994	$ 1.39
1	Field Cultivator					25	0.77	5.00	11.67	0.0857	$ 0.28
1	HD Cultivator - NH3					25	0.77	5.00	11.67	0.0857	$ 2.84
1	Land Roller					40	0.83	5.00	20.12	0.0124	$ 0.17
										Labour VC	$ 1.55
										Total VC	$ 15.60

Option 2 - 2000 Acres Max

Number	Machine	HP	HP Efficiency	Fuel Consumption ($/hr)	Operating Cost/hr	Width	field Efficiency	speed (mph)	Acres or BU/hour	Hrs/Acre	Operating Cost
1	4WD	275	0.75	$ 53.57	$ 53.57						
1	2WD	90	0.6	$ 14.03	$ 14.03						
1	2WD	170	0.6	$ 26.49	$ 26.49						
1	AirDrill			$ -		40	0.77	3.50	13.07	0.0765	$ 4.10
1	Combine	300	0.6	$ 46.76	$ 46.76				9.70	0.1031	$ 4.82
1	Sprayer			$ -		80	0.85	4.50	37.09	0.0809	$ 1.13
1	Swather SP	70	0.6	$ 10.91	$ 10.91	26	0.83	4.35	11.38	0.0220	$ 0.24
1	Harrow - Standard					50	0.83	5.00	25.15	0.0398	$ 1.05
1	Land Roller					40	0.83	5.00	20.12	0.0124	$ 0.17
										Labour VC	$ -
										Total VC	$ 11.52

Option 3 - 3200 Acres Max

Number	Machine	HP	HP Efficiency	Fuel Consumption ($/hr)	Operating Cost/hr	Width	field Efficiency	speed (mph)	Acres or BU/hour	Hrs/Acre	Operating Cost
1	4WD	350	0.75	$ 66.82	$ 66.82						
1	AirDrill					50	0.85	3.50	18.03	0.0555	$ 3.71
1	Combine	350	0.6	$ 53.46	$ 53.46				14.55	0.0687	$ 3.67
1	2WD	170	0.6	$ 25.97	$ 25.97						
1	Sprayer					100	0.85	5.00	51.52	0.0582	$ 1.51
1	2WD	90	0.6	$ 13.75	$ 13.75						
1	Swather -SP	100	0.6	$ 15.27	$ 15.27	30	0.85	4.60	14.22	0.0176	$ 0.27
1	Land Roller					40	0.85	5.00	20.61	0.0121	$ 0.81
1	Harrow - Heavy					50	0.85	10.00	51.52	0.0194	$ 0.50
										Labour VC	$ -
										Total VC	$ 10.48

Option 4 - 4300 Acres Max

Number	Machine	HP	HP Efficiency	Fuel Consumption ($/hr)	Operating Cost/hr	Width	field Efficiency	speed (mph)	Acres or BU/hour	Hrs/Acre	Operating Cost
1	4WD	425	0.75	$ 80.31	$ 80.31						
1	2WD	170	0.6	$ 25.70	$ 25.70						
1	AirDrill			$ -		60	0.85	3.50	21.64	0.0462	$ 3.71
1	Combine	375	0.6	$ 56.69	$ 56.69				17.45	0.0573	$ 3.25
1	HC Sprayer	110	0.6	$ 16.63	$ 16.63	80	0.85	9.00	74.18	0.0404	$ 0.67
1	Swather -SP	100	0.6	$ 15.12	$ 15.12	36	0.85	4.80	17.80	0.0140	$ 0.21
1	Harrow -Heavy					70	0.85	10.00	72.12	0.0139	$ 0.36
1	Land Roller					40	0.85	5.00	20.61	0.0121	$ 0.97
										Labour VC	$ -
										Total VC	$ 9.18

Option 5 - 9000 Acres Max

Number	Machine	HP	HP Efficiency	Fuel Consumption ($/hr)	Operating Cost/hr	Width	field Efficiency	speed (mph)	Acres or BU/hour	Hrs/Acre	Operating Cost
2	4WD	425	0.75	$ 79.48	$ 79.48						
2	AirDrill			$ -		60	0.86	3.50	21.89	0.0457	$ 3.63
1	2WD	225	0.6	$ 33.66	$ 33.66						
2	Combine	375	0.6	$ 56.11	$ 56.11				17.45	0.0573	$ 3.22
2	HC Sprayer	200	0.6	$ 29.92	$ 29.92	100	0.86	8.00	83.39	0.0360	$ 1.08
1	Swather - SP	140	0.6	$ 20.95	$ 20.95	36	0.86	4.80	18.01	0.0139	$ 0.29
1	Heavy - Harrow					80	0.86	10.00	83.39	0.0120	$ 0.40
1	Land Roller					40	0.86	5.00	20.85	0.0120	$ 0.95
										Labour VC	$ 0.64
										Total VC	$ 10.21

Option 6 - 12300 Acres Max

Number	Machine	HP	HP Efficiency	Fuel Consumption ($/hr)	Operating Cost/hr	Width	field Efficiency	speed (mph)	Acres or BU/hour	Hrs/Acre	Operating Cost
3	4WD	425	0.75	$ 78.66	$ 78.66						
1	2WD	225	0.6	$ 33.31	$ 33.31						
3	AirDrill			$ -		60	0.87	3.50	22.15	0.0452	$ 3.55
3	Combine	375	0.6	$ 55.52	$ 55.52				17.45	0.0573	$ 3.18
1	HC Sprayers	250	0.6	$ 37.01	$ 37.01	100	0.87	10.00	105.45	0.0284	$ 0.78
1	Sprayer			$ -		100	0.87	5.00	52.73	0.0569	$ 0.49
2	Swathers	140	0.6	$ 20.73	$ 20.73	36	0.87	4.80	18.22	0.0137	$ 0.28
1	Heavy - Harrow					80	0.87	10.00	84.36	0.0119	$ 0.39
1	Land Roller					50	0.87	5.00	26.36	0.0095	$ 0.75
										Labour VC	$ 1.37
										Total VC	$ 10.80

Option 7 - 18000 Acres Max

Number	Machine	HP	HP Efficiency	Fuel Consumption ($/hr)	Operating Cost/hr	Width	field Efficiency	speed (mph)	Acres or BU/hour	Hrs/Acre	Operating Cost
4	4WD	500	0.75	$ 91.56	$ 91.56						
2	2WD	225	0.6	$ 32.96	$ 32.96						
4	AirDrill			$ -		80	0.88	3.50	29.87	0.0335	$ 3.07
4	Combine	375	0.6	$ 54.94	$ 54.94				17.45	0.0573	$ 3.15
3	HC Sprayers	250	0.6	$ 36.63	$ 36.63	100	0.88	10.00	106.67	0.0281	$ 1.03
2	Swathers	140	0.6	$ 20.51	$ 20.51	36	0.88	4.80	18.43	0.0136	$ 0.28
2	Heavy - Harrows					80	0.88	10.00	85.33	0.0117	$ 0.39
1	Land Roller					50	0.88	5.00	26.67	0.0094	$ 0.86
										Labour VC	$ 1.18
										Total VC	$ 9.95

Option 8 - 23500 Acres Max

Number	Machine	HP	HP Efficiency	Fuel Consumption ($/hr)	Operating Cost/hr	Width	field Efficiency	speed (mph)	Acres or BU/hour	Hrs/Acre	Operating Cost
5	4WD	500	0.75	$ 90.59	$ 90.59						
2	2WD	225	0.6	$ 32.61	$ 32.61						
5	AirDrill			$ -		80	0.9	3.50	30.55	0.0327	$ 2.97
5	Combine	375	0.6	$ 54.35	$ 54.35				17.45	0.0573	$ 3.11
4	HC Sprayers	250	0.6	$ 36.24	$ 36.24	100	0.9	10.00	109.09	0.0275	$ 1.00
3	Swathers	140	0.6	$ 20.29	$ 20.29	36	0.9	4.80	18.85	0.0133	$ 0.27
3	Heavy - Harrows					80	0.9	10.00	87.27	0.0115	$ 0.37
2	Land Rollers					50	0.9	5.00	27.27	0.0092	$ 0.83
										Labour VC	$ 1.63
										Total VC	$ 10.18

Option 9 - 28000 Acres Max

Number	Machine	HP	HP Efficiency	Fuel Consumption ($/hr)	Operating Cost/hr	Width	field Efficiency	speed (mph)	Acres or BU/hour	Hrs/Acre	Operating Cost
6	4WD	500	0.75	$ 89.62	$ 89.62						
2	2WD	225	0.6	$ 32.26	$ 32.26						
6	AirDrill			$ -		80	0.93	3.50	31.56	0.0317	$ 2.84
6	Combine	375	0.6	$ 53.77	$ 53.77				17.45	0.0573	$ 3.08
5	HC Sprayers	250	0.6	$ 35.85	$ 35.85	100	0.93	10.00	112.73	0.0266	$ 0.95
3	Swathers	140	0.6	$ 20.07	$ 20.07	36	0.93	4.80	19.48	0.0128	$ 0.26
3	Heavy - Harrows					80	0.93	10.00	90.18	0.0111	$ 0.36
2	Land Rollers					50	0.93	5.00	28.18	0.0089	$ 0.79
										Labour VC	$ 1.62
										Total VC	$ 9.91

APPENDIX G

PERENNIAL CROP YIELDS

Perennial crop yields follow the Stolniuk (2008) forage yield formulation, increasing linearly based upon the soil productivity rating up to a maximum where yields peak and plateau. In the case of energy crops, maximum and minimum yields also vary by year depending on the stage of its life-cycle. The yield formulation of each perennial crop becomes:

$$Y_i = \frac{PR}{PR^{Max}} \cdot (Y_i^{Max} - Y_i^{Min}) + Y_i^{Min}$$

Where:

Y_i = yield of perennial crop i in $year_t$
PR = productivity rating of the soil on the plot
PR^{Max} = productivity rating where the maximum yield occurs
Y_i^{Max} = maximum yield of perennial crop i in $year_t$
Y_i^{Min} = minimum yield of perennial crop i in $year_t$