

## Farmers' Choice of Crops in Canadian Prairies under Climate Change: An Econometric Analysis

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### Abstract

As climate is an uncontrollable yet essential input in the agriculture industry, the impact of climate change may have on crop production in Saskatchewan is of importance. The main objective of this study is to investigate how farmers would adapt to climate change by switching their crop mix under future climate change scenarios. A fractional multinomial logit (FMNL) model was used to assess how total area of cropland has changed over a thirty year time period. The panel data included variables to represent the land characteristics of Saskatchewan, climatic variables, and price and policy variables in order to assess how average seeded area of each crop group changed. The results indicate that crop allocation depends largely on the price of other crop groups and temperatures in the spring (April) and summer (July). Climate plays an important role in the major crop groups, such as wheat, canola and pulses. Cool, dry springs are the ideal conditions when choosing nearly all crops, while hot, wet summers increase the choice to leave land to summerfallow. Policy and the different soil zones also play a significant role in area allocation decisions. Changes in policies such as the removal of the Crow's Nest Pass Agreement, and the removal of oats from the Canadian wheat board (CWB) marketing, had a negative impact on the choice to grow wheat, as expected. The different soil zones in Saskatchewan played an important role in area allocation for a majority of the crops, having a negative effect on the choice of wheat over every other crop group except pulses and summerfallow. Three future climate change scenarios were simulated for each soil zone. Results indicate that under the projected changes in climate area allocated to wheat will continue to decrease into the future by 2.7 to 4.6% in various soil zones. At the same time, the area left to summerfallow is projected to increase under climate change. The choice of wheat is preferred over pulses, feed and forages, while the choice of specialty oilseeds (flaxseed, mustard seed and canary seed) are projected to become preferred over wheat in the future.

**Keywords:** Agricultural crops; Crop choice; Saskatchewan; Future climate

### Introduction

The Intergovernmental Panel on Climate Change [1] has concluded that climate change is being observed all around the globe with increased surface temperatures; mountain glaciers and snow cover shrinking in both hemispheres; rising sea level and increased precipitation. Experts believe global warming<sup>1</sup> is caused by the accumulation of greenhouse gases in the Earth's atmosphere [2,3]. A majority of climate change research predicts a higher level of warming for the northern latitudes resulting in a longer and warmer growing season; however there are predictions of drying and increased evapotranspiration projected for midcontinent regions [4].

Being a major primary industry in Saskatchewan; impacts of climate change on agriculture may be significant. Currently; agriculture in Saskatchewan is challenged by a relatively short growing season (as a result of early frost) as well as from low and unreliable precipitation. If under climate change; the growing season would be longer; there could be beneficial impacts on crop and livestock production. A general consensus is that Saskatchewan will have both positive and negative impacts as a result of climate change and these impacts would vary regionally [5].

Although Saskatchewan is a leader in agriculture production; it has some of the most diverse farmland; such as Palliser's triangle; which is characterized by aridity and an annual water deficit [6]; and transition zones between agriculture and forests in the north. Because weather is one of the most important determinants of agriculture

production; farmers must adopt management practices that are dictated by changing climate. In order to take advantage of opportunities due to predicted longer and warmer growing seasons; crop mix on farms may change. These changes would have major impacts on the welfare of crop producers; but may also have impacts on livestock producers; as well as the provincial and national economies.

Although climate change may impart potential changes; the net impact on crop production will depend on the adaption measures that are undertaken by producers. Altering production practices is included among these sets of measures; which can be accomplished at the farm level by methods such as irrigation; crop diversification and early seeding [8,9]. The latter may involve changing the crop mix in order to adapt to a changing climate. Past studies have suggested that farmers do select their crop choice taking climate into consideration [10]. These crop choice decisions could therefore provide an important adaptation strategy to a changing climate. There is a paucity of studies in this area for Canada; as well as Saskatchewan. This study was developed to shed some light on this aspect of adaptation to climate change for Saskatchewan producers.

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<sup>1</sup>Global warming is one of the contributors to climate change. Although warming has been experienced on the planet in the past, the current trend in increased temperatures has increased at the fastest rate in recorded history [7].

## Methods

The earlier studies related to climate dealt mostly with impact of climate on crop [11-13]. Thompson [12] concluded that the highest yields were observed when weather was near normal or slightly cooler for a majority of crops grown in the northern latitudes; therefore a slight cooling would be beneficial but a warming trend could have detrimental effects on crop yields in Canada and Northern USA crop producing regions. Although this work was seminal in understanding the effects of weather on different crops; it did not account for all the decisions and inputs that went into crop production. This opened up a new area of research that focused on assessing how farmers were adapting to a different climate. These studies have involved several types of methods; including agro-economic models; Ricardian models; and discrete choice model among others.

The basis of agro-economic models was to include social variables; in addition to climate related variables; that would determine the nature of adjustments that farmers were making in response to climate [14]. They accomplished this by using a pooled cross-sectional model with climatic variables; economic environment (social conditions that influence management decisions; purchased inputs) and technical/scale variables (size of farms; level of technology; quality of land planted) to explain changes in yield of corn across the U.S Grain Belt. The results proved that yield is determined by both social and climate factors.

The Ricardian model was developed to better represent farmers' and the potential crop switching adaptation strategies that they would be likely to employ. The method uses climatic and non-climatic variables to explain changes in the value of farmland or the income generated by the farm. The benefit of this method is that adaptation methods can be compared and assessed. The model assumes that farmers first take climate as given and then decide what to grow; with what inputs; and in what way; or decide to convert land to other uses entirely [15]. This encompasses various kinds of adaptation methods; without assuming only the 'naïve' farmer [16]. The Ricardian model has been applied exclusively in developing countries (and in the USA); it has had a limited number of applications for Canada [15,17,18]. Climatic and land characteristics were included as explanatory variables and due to the spatial scale latitude; longitude and elevation data were also used. Due to the nature of the rural population; Reinsborough included migration rates; population density and income to make up the socio-economic variables. These studies have suggested that Canada would benefit enormously from increased temperature and precipitation<sup>2</sup>; although like Mendelsohn et al. [10] there are large deviations in the results from land values and farm revenues. Weber and Hauer [17] acknowledged that the Ricardian approach has the potential to overestimate the benefits of climate change on agriculture-that is; the influence of the sum is greater than the individual parts. For example; while crops migrate easily within the same geoclimatic zone; there are barriers; such as different land characteristics and technology; across large regions (such as the Prairies) [19]. The Ricardian model gave researchers the opportunity to include several adaptation measures to climate change in their research. However this method still suffered from weaknesses; most notably not being able to account for price effects [10]. According to Polsky [20]; although the premise of the model is based on perfect competition and therefore postulates that prices have reached equilibrium; Mendelsohn et al. have stated that

<sup>2</sup>Reinsborough assumed that temperatures and precipitation across Canada increased uniformly by 2.8°C and 8%, respectively. However, as mentioned, it is highly unlikely that this change will be uniform across Canada.

the model could be better adapted to include price effects. Another weakness of the Ricardian model is that interpretation of adaptation is based solely on the researcher. Farmers are also assumed to respond seamlessly and without incurring additional cost to climate change using technologies that are presumed to be accessible to all farmers at any given point in time. However; in reality adaptation is an ongoing and potentially costly process [16,21]. These assumptions made it difficult to properly predict how farmers would make their decisions in light of the uncertainty faced by climate change. Therefore there was a need to better understand how adaptation was being undertaken and how it may influence future production decisions. Seo and Mendelsohn [22] were the first to develop a 'structural' Ricardian model that would explicitly model the underlying decisions by farmers. The basic formulation of the 'structural' Ricardian model was a discrete choice problem. This formulation had the advantage of showing exactly how adaptation was taken as the dependent variable showing it as a choice among alternatives.

Discrete choice models are often used in literature where the decision maker is faced with such a problem. A common choice model that is used is the multinomial logit (MNL) model. The MNL model allows a choice between multiple alternatives; such is the case in marketing; transportation and agriculture. This model is important to this area of research; as it can be a predictor of supply response when crop choice is used as the dependent variable. Discrete choice models have been applied in developing countries to assess the role of climate in crop choice made. Seo and Mendelsohn [22] used a discrete choice model to analyze adaptation on farms in South America. Study showed that crop switching is likely to occur under different climate scenarios (as a form of adaptation). Similar applications of the MNL model have been reported by Mendelsohn and Seo [23] Kurukulasuriya and Mendelsohn [24] and Deressa et al. [25].

There are various forms of adaptation that could be made by a farmer; including changing crop mix and/or cultivars or even changing the use of the land altogether [17,26,27]. These effects can be captured through the discrete choice model; particularly that of crop switching; that was available to farmers. Although the discrete choice model has been used primarily in developing countries; it has been reported for Canada by Krakar and Paddock [28]. However; climate related variables were not included in this study. One of the major impacts of climate change is increased climate variability and frequency of extreme events. Such events may have a dampening effect on the farm economy (including land value) not only for the current period but also for subsequent periods. The discrete choice method has also not yet been applied to the Prairies Provinces. Due to the random utility theory underlying discrete choice models; such as the multinomial logit model; cannot be used with aggregate data or in a context where the dependent variable is measured as share or percent; which limits its application.

## Conceptual model

A recent variant of discrete allows for aggregate data and a dependent variable that is represented by a share or percentage. These types of observations are common in financial; agricultural and transportation literature. Papke and Wooldridge [29] initially used this model using cross-sectional data to analyze participation rates in a 401(k) plan<sup>3</sup>; as well as to assess middle school test score by using panel data. This model is referred to as the fractional multinomial logit

<sup>3</sup>A 401 (k) plan is a 'tax-deferred' savings account set up by employers where eligible employees can defer salary or wages to saving for retirement in the U.S. Employers may also match this deferral [34].

(FMNL) model. Recently the method has been used in a variety of situations; including applications to agriculture [30-33]. Ding et al. [30] proposed that the ability to adapt to a changing climate could be done by choosing amongst alternative tillage practices (such as conventional till and zero till). This adaptation choice would depend on factors such as precipitation shocks; such as floods and drought; insurance and fuel prices; and land characteristics. Mu and McCarl examined how farmers' adapt to climate change with a given set of options between livestock and crops. They determined using the FMNL model; how land allocation has changed over time. Various climate measures were used including 30 year monthly precipitation and temperature averages as well the Palmer Drought Severity Index and a precipitation intensity index. The results from this study showed that as winter and spring precipitation and temperature increase; more land is allocated for pastureland. Yin et al. [32] examined change in land use in the Upper Yangtze Basin; China. Total area was segmented into four categories-cropland; forestland; pastureland and other. Results showed that land use decisions were initially made to capture immediate profits; but they were not significantly influenced by the long-term price signal (these prices being mostly distorted).

To date; there has been little focus specifically on Saskatchewan; as most studies have analyzed Canada as a whole [15,17]; or the Prairie Provinces [18]. The FMNL is an extension of choice modeling; and has the advantage over the Ricardian model in being able to model adaptation explicitly using aggregate data and a fractional dependent variable. Fractional values; or shares; are common in many industries such as agriculture. For this reason; the FMNL was selected as the most appropriate model to use to address the specific research question.

### Empirical model

Under the assumption that farmers are profit maximizers and will therefore allocate land to the highest valued crops profit ( $\Pi$ ); according to Seo and Mendelsohn can be shown mathematically as<sup>4</sup>:

$$\Pi_{it} = V_{it}(K_{it}; S_{it}) + \varepsilon_{it}(K_{it}; S_{it}) \quad (1)$$

Where K are characteristics that are exogenous to the farm (such as climate; land characteristics and prices); and S represent the characteristics of the farmer; such as age; education; credit etc. The subscripts  $i$  and  $t$  represent the cross-sectional and time series components; respectively.  $V$  represents the coefficient vector and  $\varepsilon$  is the error term.

Farmers' will choose the crop (or crop group if the choices are too abundant) that maximizes this objective function. Thus one can define  $Z=(K;S)$ ; and the farmer will choose crop  $j$  over all other crops;  $k$  if:

$$\Pi_{ij}^*(Z_i) > \Pi_{ik}^*(Z_i) \quad (2)$$

More simply; crop  $j$  will be chosen over all other crops;  $k$  if the expected profit of crop  $j$  is greater than all other crops over the time period.

In the FMNL model framework;  $Y_{it}$  represents the fraction or share of the desired dependent variable that is used where  $i$  ( $i=1;2;3...J$ ) represents the cross-sectional variables in the equations and  $t$  ( $t=1;2;3...T$ ) is the time component. For the level of aggregation it must hold that:

$$0 \leq Y_{it} \leq 1$$

$$\sum_i Y_{it} = 1 \quad (3)$$

<sup>4</sup>Adjusted to fit panel data.

For all  $t$ 's.

Because  $Y_{it}$  is bounded between zero and one; if one uses a linear method; there is a possibility that fitted values may fall outside this unit interval. However; to avoid this result; this problem can be modeled using a logistic function.

$$E(Y_{it}|X_{it}) = p_{it} = \frac{\exp(X_{it}\beta_k)}{1 + \exp(X_{it}\beta_k)} \quad (4)$$

Thus:

$$Y_{it} = \frac{\exp(X_{it}\beta_k)}{1 + \exp(X_{it}\beta_k)} + \varepsilon_{it} \quad (5)$$

Where  $\beta_k$  is a coefficient vector and  $\varepsilon_{it}$  is the independently and identically distributed error term. The asymptotic analysis is carried out as  $N \rightarrow \infty$  and for all of  $i$ ;

$$E(Y_{it}|x_{it}) = G(x_{it}\beta) \quad (6)$$

Where  $G(\bullet)$  ( $i=1;2; \dots ; J$ ) is a predetermined function whose properties ensure that the predicted fraction will lie in the interval (0;1) and will sum to one across all  $i$  [34].

The most common cumulative distribution function chose for  $G(\bullet)$  is the logistic function. This can be estimated using nonlinear least squares (NLS); however heteroscedasticity is likely to be present since the variance of  $Y_{it}$  conditional on  $x_{it}$  is unlikely to be constant when  $0 \leq y_{it} \leq 1$ . Therefore the NLS estimates will not have any efficiency properties [29]. The estimation procedure proposed by Papke and Wooldridge is quasi-likelihood method adapted from Gourieroux et al. [35] and McCullagh and Nelder [36]. The log-likelihood function can be expressed as follows:

$$l_i(\mathbf{b}) = Y_i \log[G(\mathbf{x}_i\mathbf{b})] + (1-Y_i) \log[1-G(\mathbf{x}_i\mathbf{b})] \quad (7)$$

Maximizing this equation is straightforward and because it is a member of the linear exponential family (LEF) the  $\beta$ 's obtained in estimations are consistent and asymptotic normality distributed.

A fractional logit equation needs to be established for each dependent variable; to ensure the identification of these equations; only  $k-1$  equations are estimated. The equation that is not estimated serves as the base or comparison; with results from each estimated equation representing the choice over the base. The effect of the explanatory variables on the base choice equals one minus the sum of the effects on the other  $k-1$  equations.

### Analytical Model

Using the theory behind FMNL model and literature review; a basic functional form was constructed for this study; as shown in equation (8).

$$CHOICE_{irt} = f(CL_{irt}; EC_{irt}; SE_{irt}; SR_{irt}) \quad (8)$$

Where; CHOICE is selection of  $i^{th}$  crop in region  $r$  during period  $t$ ;

CL represents climate related variables affecting choice of crop;

EC represents economic variables affecting choice of a crop;

SE represents socio-economic (policy) variables affecting choice of a crop; and;

SR represents geographical (spatially related) variables affecting choice of a crop.

Producers in different parts of Saskatchewan face different agricultural conditions. For this reason; analysis was undertaken for three regions of Saskatchewan (expressed in terms of subscript ' $r$ ');

based on soil type. These were: Brown soil zone; dark brown soil zone and Black soil zone. Data were collected by a crop district (CD) and sub-divided into the three regions.

A given farmer can have a choice of a large number of crops. However; the commodities that make up a large portion of provincial production are traditional crops; such as wheat and canola. In this study the most dominant crops grown were selected and grouped into seven categories; as shown in Table 1. The dependent variable was measured as a percentage or share of total cropped area within the CD during a period t.

Since wheat is one of the major crops produced in the province; it was used to represent the first crop group. This group included both durum and spring wheat grown in Saskatchewan. The second group consisted solely of canola. Canola was; until recently; was one of the only cash crops available to producers; since it was marketed through open market channels; thus it provided a good substitute for wheat. The pulse crops represented the third group; which included peas; lentils and chickpeas. Although lentils and chickpeas have been grown since the early 1980's; their production was minimal and was limited to particular areas of the province. Therefore in the early years of the study period the pulse group was represented only by peas and a small amount by lentils in each CD.

The fourth crop group was oilseeds; made up of flax; mustard and canary seed. The fifth group was represented by five crops that are grown for feed. Most of these crops were sold either through the Canadian Wheat Board (CWB) or through the open market; but all of these were intended for on-farm animal feed. Crops included: barley; oats; two types of rye; and winter wheat. Oats have lost some significance since its removal from the CWB.

The last two groups represented area that is allocated to summerfallow and that to for ages. Summerfallow is leaving the filed idle for one cropping season to restore moisture for the next period crop; and is an important rotation tool. The practice of summerfallowing has been steadily declining over the past 30 years; partly due to adoption of conservation tillage methods. The last group was represented by area that is seeded for hay production or to pastureland for grazing. This group makes up a significant portion of the total area; since both improved and unimproved pastures are included.

The explanatory variables included four sets of variables. The first set included climatic variables; temperature and precipitation regimes in various sub-regions of the study. To avoid the multicollinearity problems associated with using consecutive months; the climate variables were represented by four seasons – January; April; July and October. The winter months (represented by January) are important to include because the crop groupings include two crops seeded in the fall-winter wheat and fall rye. Snowfall in the winter months also influences the soil moisture for spring seeding; thus influencing crop choice. These months also capture the extremes of each season and

the length of the growing season [17]. Average monthly temperature in degrees celsius and precipitation<sup>5</sup> in millimeters was used as appropriate measure of these variables in Canada [37]. Environment Canada has various weather stations across the province and data from each station are available as monthly averages for every month of the year. Although there are several weather stations in each crop district; data were collected from one centrally located weather station for each crop district. In the case of missing observations; either nearby station data was used or Olympic<sup>6</sup> averages were estimated<sup>7</sup>.

The economic set of variables included two sub-sets of variables: (1); those affecting demand for forages and feed; and (2); those affecting profitability of a crop in a given crop year. Demand for forages and feed is a strong incentive for a farmer to plant more forage crops. One of the major determinants for forage and feed demand is the on-farm inventory of hogs and cattle. This variable included the total number of these animals on farms as of July 1<sup>st</sup> of each year. The specified model included prices of the commodities in estimation. Due to the large time frame covered; most prices were represented by the average farm price for the year (or first transaction price<sup>8</sup>) [39]. This farm price represents the final market price that farmers receive less all the deduction; such as freight rates; elevator rates; etc. It also represents both the initial and final payments for CWB commodities. Because the crops are grouped together; the yearly average of each crop were summed and averaged to represent the entire group. For example; the feed group was represented by the average farm price of winter wheat; rye; barley<sup>9</sup> and oats. A common measure of price that has been used in various studies is a simple one or two period lag or moving average of past prices [18,28,38]<sup>10</sup>. Therefore; a three year moving average of past prices was calculated to best represent the expected price for these crop groups.

The next set of variables represents important policy changes that have occurred over the study period. These policy changes were included through binary variables. The policy was related to change in rail transportation policy that occurred in 1983. This was the change in grain freight rate by producers for export grains. This change in policy was significant because it changed the prices that farmers received for exports of major commodities; specifically the prices for grains such as those marketed through the CWB (i.e. durum; spring wheat; barley; etc.). Another policy change included in the model was the change in the status of oats marketing. In 1989; oats were removed from sales to the CWB. This had a large impact on the demand for oats and thus; on the area devoted to it. A third policy change variable included was the

<sup>5</sup>Precipitation as defined by Environment Canada is: any and all forms of water, liquid or solid, that falls from clouds and reaches the ground. This includes drizzle, freezing drizzle, freezing rain, hail, ice crystals, ice pellets, rain, snow, snow pellets, and snow grains [37].

<sup>6</sup>Olympic averages omit the highest and lowest value and average the remaining. In historical weather data this was done by using the surrounding four years (top and bottom) of the missing value.

<sup>7</sup>There was also an issue with some recent year's monthly data missing; this issue was addressed by summing the available daily data at the same station.

<sup>8</sup>Commodities are priced at point of first transaction, where the fees deducted before a producer is paid are excluded, but bonuses and premiums that can be attributed to specific commodities are included [39].

<sup>9</sup>Note that both malting barley and feed barley are combined to represent total barley price.

<sup>10</sup>There are various other, more complex, measures of that have been used to represent price such as weighted averages and geometric weighted averages, however, this focus is more common when modeling the impact of expected prices and risk on area allocation.

Group	Group Name	Crops Included
1	Wheat	Spring wheat; Durum
2	Oilseeds	Canola
3	Pulses	Dry peas, Lentils, Chickpeas
4	Specialty Oilseeds	Mustard, Canary seed, Flaxseed
5	Feed crops	Winter wheat, fall rye, Spring rye, Oats, Barley
6	Forages	Tame hay, Improved pastures, Unimproved pastures
7	Summerfallow	Summerfallow

**Table 1:** Specification of study crop groups.

introduction of the permanent cover program (PCP). Producers were provided incentives to convert crop land into permanent forage area. As a result of the program; it is likely that the choice to seed tame hay would have been affected.

### Source of data

Data were collected annually over a 30-year time period from 1981 to 2010. The spatial scale used was the agriculture census districts (CDs). Climate information was collected through Environment Canada using a centrally located weather station in each CD. Area seeded of each crop group and livestock inventories were collected through various sources including: Saskatchewan Ministry of Agriculture [40,41]; Statistics Canada [42,43] and UofS (University of Saskatchewan Data Library) (Undated) [44]. Price information was obtained through Saskatchewan Ministry of Agriculture; and Statistics Canada. Table 2 outlines all variables included in the estimated model; along with the definition of the variable; unit of measure and the source.

Estimation of the model was done using the statistical software STATA using the “fmlogit” command. It fits a fractional logit model to a given set of data using quasi maximum likelihood method. This method is ideal for large; multivariate data sets. Six equations were

estimated with wheat serving as the base (comparison) equation. Therefore all results need to be interpreted as the choice between wheat and an alternative crop group. The choice of wheat was made in light of the fact that it is the most significant crop group in all CD's of the province.

Post-estimation commands are also available in STATA; which include marginal effects; which are the best way to interpret the results of the fractional multinomial logit model. Marginal effects are defined as the change in the predicted value of a dependent variable for a unit change in the explanatory variable; assuming that the effect does not change over that interval (i.e.; time period); calculated at the mean [45]. Fixed or random effects estimation methods are not applicable because the dependent variable is limited within the range of zero and considering fixed effects would remove time constant variables such as land characteristics. For this analysis; it was assumed that the independence of irrelevant alternatives (IIA) hypothesis holds in estimation.

After estimating the fractional multinomial logit model; the results were used to run a simple simulation showing how future climate will impact acreage allocation decisions; holding other factors constant. The estimated projections of climate were obtained from Price et al. [46]. These values were transformed into the non-linear forms of the

Variable set	Variable Name	Definition	Unit of measurement	Source of data
<b>Dependent variable</b>				
	Wheat		% of total area under wheat in a given CD	Statistics Canada (2013b); Sask. Ministry of Ag. (2012); UofS Library (Undated)
	Canola		% of total area under canola in a given CD	
	Pulses		% of total area under pulses in a given CD	
	Feed		% of total area under feed crops in a given CD	
	Specialty Oilseeds		% of total area under Spec. Oilseeds in a given CD	
	Forages		% of total area under forages in a given CD	
	Summerfallow		% of total area under summerfallow in a given CD	
<b>Independent variables</b>				
Climatic	JT	January temperature	°C	Environment Canada (2013)
	AT	April temperature	°C	
	JuT	July temperature	°C	
	OT	October temperature	°C	
	JP	January precipitation	mm	
	AP	April precipitation	mm	
	JuP	precipitation	mm	
	Op	precipitation	mm	
Economic	I <sub>beef</sub>	On-farm beef inventory	Number of head of all cattle and calves	Statistics Canada (2013b); Sask. Ministry of Ag. (2013); UofS Library (undated)
	I <sub>pg</sub>	On-farm pig inventory	Number of head of market and bred pigs, gills and boars	
	P <sub>WG</sub>	Monthly average price of wheat group	\$CAD t <sup>-1</sup>	
	P <sub>CG</sub>	Monthly average price of canola group	\$CAD t <sup>-1</sup>	
	P <sub>PG</sub>	Monthly average price of pulses group	\$CAD t <sup>-1</sup>	
	P <sub>FG</sub>	Monthly average price of feed crops group	\$CAD t <sup>-1</sup>	
	P <sub>SG</sub>	Monthly average price of specialty oilseed group	\$CAD t <sup>-1</sup>	
	P <sub>TH</sub>	Monthly average price of tame hay group	\$CAD t <sup>-1</sup>	
Policy	D <sub>CN</sub>	Binary variable for abolishment of Crowsnest pass Agreement rates	= 1 for years 1980-1983 = 0 Otherwise	--
	D <sub>OATS</sub>	Binary variable for withdrawal of oats from CWB	= 1 for years 1980-1989 = 0 Otherwise	--
	D <sub>PCP</sub>	Binary variable for introduction of PCP	= 1 for years 1989-1992 = 0 Otherwise	--
Spatial	D <sub>DBSZ</sub>	Binary variable for Dark Brown soil zone	= 1 if the crop district is in dark brown soil zone = 0 Otherwise	--
	D <sub>BRSZ</sub>	Binary variable for Brown soil zone	= 1 if the crop district is in dark brown soil zone = 0 Otherwise	--

**Table 2:** Variable definition, measurement and sources

climate variables. Simulation results were compared with the base year of 2000 and each crop group was compared to the base commodity group of wheat.

For the simulation; soil zones were used in place of the CDs for simplicity. Using CDs as the spatial scale for the simulation would result in 33 scenarios with three projected years each. There would likely be little variation using this spatial scale and interpretation would be tedious and repetitive. The simulation was undertaken for the six crop groups using the three soil zones for regional comparisons against the base year of 2000 area seeded levels. Climate projection for three time periods and three different projected climate change scenarios were obtained from Price et al. [46].

## Results

Parameter estimates for marginal change using the FMNL model are presented in Table 3; along with their standard errors for the non-binary variables. No marginal effects were calculated for the binary variables; therefore; the only interpretation they have is whether they are significant in the FMNL model estimates. Overall the model had a good fit with a Chi-square statistic of 15;229; much larger than any critical value at any significance level. Expectations of signs were based on economic logic; where applicable.

### FMNL Estimates for binary variables

As expected; the binary variables representing land characteristics were significant in six of the estimated equations; with the exception of the brown soil zone; where this variable was not significant for the pulses commodity group. However; pulses only represent 12% of total

area in this soil zone. In all equations; with the exception of the Dark Brown soil zone in the pulses group and the Brown soil zone in the summerfallow; soil zones had a negative impact on the share of wheat over another commodity group. The high significance of the soil zones indicates the heterogeneity in acreage allocation decisions that are made in regions of Saskatchewan.

The binary variable for the removal of oats from the CWB marketing was significant in all the equations. In all groups; except summerfallow; its estimated coefficient was negative. The removal of the Crow's Nest Pass Agreement rates was only significant in pulses; specialty oilseeds and summerfallow decisions. Again the estimated coefficient was negative in all equations except in the summerfallow equation. This is consistent with expectations as the removal of the Crow's Nest Pass rates increased transportation costs of specific commodities; thereby making them more expensive to ship for export; leading to reduced demand and reduced area under them. The PCP binary variable was significant in all but the summerfallow equation; again having a negative effect on wheat acreage. Overall it can be concluded that policy changes did have an impact on the area allocation decisions for various crop groups.

### FMNL estimates for continuous variables

Table 3 shows the marginal effects (as defined in Chapter 5) of all the variables with their corresponding standard errors. Note that these estimates still maintain the sign of the estimated coefficients in the FMNL model.

Variable	Wheat		Canola		Pulses		Specialty Oilseeds		Feed		Tame Hay		Summerfallow	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
JT	0.0007	0.0032	-0.0027	0.0018	0.0009	0.0007	-0.0004	0.0011	-0.0012	0.0019	0.0021	0.0012	0.0007	0.0032
AT	0.0035	0.0039	-0.0055***	0.0019	-0.0021**	0.0009	-0.0010	0.0012	-0.0063***	0.0023	0.0013	0.0013	0.0100***	0.0039
JuT	-0.0180	0.0384	0.0189	0.0258	-0.0097	0.0084	0.0098	0.0203	-0.0462	0.0251	-0.0440***	0.0146	0.0890**	0.0447
OT	-0.0045*	0.0024	0.0026**	0.0011	0.0001	0.0006	-0.0005	0.0012	-0.0022**	0.0018	0.0019*	0.0010	0.0026	0.0026
JP	-0.0002	0.0015	-0.0003	0.0011	-0.0004	0.0003	0.0007	0.0007	0.0006	0.0009	0.0004	0.0005	-0.0007	0.0017
AP	0.0001	0.0005	-0.0001	0.0002	-0.0002*	0.0001	0.0002	0.0002	0.0000	0.0003	0.0001	0.0002	0.0000	0.0005
JuP	-0.0019	0.0010	0.0005	0.0008	-0.0002	0.0004	-0.0007	0.0005	0.0017**	0.0007	0.0000	0.0004	0.0006	0.0012
OP	-0.0008	0.0008	0.0006	0.0004	0.0001	0.0002	0.0003	0.0003	-0.0003	0.0005	0.0005	0.0003	-0.0004	0.0008
JT <sup>2</sup>	0.0000	0.0001	-0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001
AT <sup>2</sup>	-0.0002	0.0003	0.00041***	0.0001	0.000094*	0.0001	0.0000	0.0001	0.00044**	0.0002	0.0000	0.0001	-0.00065**	0.0003
JuT <sup>2</sup>	0.0003	0.0010	-0.0006	0.0007	0.0002	0.0002	-0.0003	0.0005	0.0014**	0.0006	0.0013***	0.0004	-0.0022**	0.0011
OT <sup>2</sup>	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0001	0.0000	0.0000	0.0001	0.0001
JP <sup>2</sup>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000032*	0.0000
AP <sup>2</sup>	0.0000	0.0000	0.0000	0.0000	1.6X10 <sup>-6</sup> *	0.0000	-0.33X10 <sup>-5</sup> **	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JuP <sup>2</sup>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
OP <sup>2</sup>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
JT*JP	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
AT*AP	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
JuT*JuP	0.0011*	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-8.8X10 <sup>-3</sup> **	0.0000	0.0000	0.0000	0.0000	0.0001
OT*OP	0.0001	0.0001	-0.00011***	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001
I <sub>BEEF</sub>	0.0000	0.0000	0.0000	0.0000	1.5X10 <sup>-6</sup> ***	0.0000	-7.2X10 <sup>-8</sup> ***	0.0000	4.7*10 <sup>-6</sup> ***	0.0000	8.0X10 <sup>-6</sup> ***	0.0000	-1.3X10 <sup>-5</sup> ***	0.0000
I <sub>PIG</sub>	-1.3X10 <sup>-5</sup> ***	0.0000	-1.3*10 <sup>-5</sup> ***	0.0000	0.0000	0.0000	3.6X10 <sup>-7</sup> ***	0.0000	1.9*10 <sup>-5</sup> ***	0.0000	0.0000	0.0000	-2.3X10 <sup>-5</sup> ***	0.0000
P <sub>WG</sub>	0.0001	0.0007	-0.00056**	0.0004	0.00034**	0.0002	0.0000	0.0002	0.00072*	0.0004	0.00065**	0.0003	-0.0013**	0.0007
P <sub>CG</sub>	-0.0001	0.0002	0.0001	0.0001	-0.00013**	0.0001	-0.00015*	0.0001	0.0001	0.0001	-3.8X10 <sup>-4</sup> ***	0.0001	0.00049**	0.0002
P <sub>PG</sub>	-0.00064***	0.0002	0.00034***	0.0001	0.0003***	0.0000	0.0000	0.0001	-0.00026**	0.0001	0.00019**	0.0001	0.0000	0.0002
P <sub>FG</sub>	0.00038**	0.0002	-0.0005***	0.0001	-0.0002**	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0004	0.0002
P <sub>SG</sub>	-0.0004	0.0011	0.0014	0.0006	-0.0002	0.0003	0.0003	0.0004	-0.0013**	0.0006	0.0000	0.0003	0.0002	0.0010
P <sub>TH</sub>	-0.0026	0.0008	0.0016**	0.0005	0.0015**	0.0002	0.00075**	0.0003	0.0015***	0.0004	0.00077**	0.0003	-0.0035***	0.0007

Table 3: Marginal effects of continuous explanatory variables

## Effect of climatic variables

The effect of climatic variables were significant in all the estimated equations; however the specialty group had only one significant climatic related variable. The signs of the significant linear temperature coefficients suggest that increased temperatures in the spring (April) lower the share of canola; pulses and feed groups and increase the share to summerfallow. The positive temperature coefficient for January in forages and for April in the summerfallow equations indicates that warmer temperatures in these months lead to increases in the share of these two crop groups. Although warm weather is beneficial to crops; cold winters help to kill off diseases and pests and cooler springs help to make sure they do not damage seedlings. Therefore; farmers' may be taking this into account when preparing crop rotation for the following year.

July temperature was found to be a significant factor in both forages and summerfallow equations; however they had opposite signs. Increased temperatures in July decreased the share of forages by 0.044% over the study period; holding all other variables constant. In contrast; rising July temperatures increased the share of summerfallow by 0.089%; holding all other variables constant. These differing signs suggest that these two choices compete with one another for area allocation. Hot summer months are also a disadvantage to crop development; this result could indicate that farmers are switching to summerfallow in response to increases in summer temperatures over the study period.

Wheat; canola; feed and forages have significant coefficients for October temperature. For canola and forages this coefficient is positive; suggesting that a warmer fall increases the share of canola or forages. Canola area increases by 0.0026%; holding all other variables constant; and share of tame hay increases by 0.0019%; holding all variables constant over the study period. In some instances; canola can be seeded in the fall and grown through the winter; warmer Octobers open up this opportunity. Currently this practice is not common; but represents a potentially viable option given the projected changes in climate. Warm fall weather also gives the opportunity to graze cattle longer in pasture or to do a fall cut of hay. Increased temperatures in October decrease the share of wheat and feed; again this suggests that farmers may be moving away from traditional crops such as those in the wheat and feed groups in response to warmer falls.

A significant non-linear temperature effect was observed for canola; pulses; feed; forages and summerfallow. The linear and non-linear temperature coefficients for April were positive for canola; pulses and feed (increasing their respective share by 0.0004%; 0.000094% and 0.0004%; respectively; holding all other variables constant). These results indicate the importance of temperature at the beginning of the growing season. Because Saskatchewan already experiences relatively cold springs; increased temperatures in April are beneficial to crop production; and the positive nonlinear coefficient suggests that there is no maximum to this value. This finding is consistent with other studies using this measure of climate in the USA and Canada [47].

The non-linear effect of July temperature was another significant variable in the choice of feed; forages and summerfallow. Both feed and forages groups had positive coefficients indicating that there is a minimum rather than a maximum temperature where the choice of these crops would be made. These results can be defended as this particular set of crop groups are often consumed on farm and therefore detrimental yields as a result of extreme heat may not be as large of an issue compared to the damage it can do to wheat yields; thus the

economic value of the crop. Again; this could indicate that as summer temperatures begin to increase; farmers can switch to these crops as an adaptation response to climate change. The opposite is true for summerfallow. Share of summerfallow increases as July temperature increases; but only up to a certain point as given by the negative non-linear coefficient. Again; this is defensible since increased temperatures may lead to increased evapotranspiration rates and some summerfallow practices have the potential to exacerbate moisture loss in soil.

Precipitation does not have as many significant coefficients in the estimated equations. This is not as expected due to the fact that moisture is an already a limiting factor in Saskatchewan and previous studies have noted the significance of precipitation. April precipitation is only significant in the pulses equation and an increase of 1 mm of precipitation in this month decreases the share of pulses by 0.0002%; holding all other variables constant. July rainfall has a significant and positive effect on the choice of the feed group; a 1 mm increase in July precipitation increases the share of feed by 0.0017%; holding all other variables constant. Since the feed group included fall seeded crops; and as wet summer months have the ability to spread diseases and pest infestations; farmers could switch to these crops to avoid such adversities. It also guarantees that these crops are seeded into a period with adequate moisture. Similar results have been found by previous studies supporting the finding that timing of precipitation is a key factor in plant development; thus influencing crop choice [15,17,18].

A statistically significant nonlinear effect of precipitation measures was noted for pulses; specialty oilseeds and summerfallow. April precipitation had differing signs with a positive coefficient for pulses and negative for specialty oilseeds suggesting that these two groups compete for the same area. It also indicates that the share of a specialty oilseed decreases when April precipitation reaches a maximum level; while the opposite is true for pulses. Interesting to note is that both April precipitation measures are significant but with differing signs for the pulse group. This effect of April precipitation has also been found by Reinsborough. It appears that dry; cooler springs increase the choice of a pulse crop.

The July interaction terms were significant in both wheat and feed; however they had differing signs. Increased temperatures and precipitation in this month decreased the share of wheat but increased the share of feed over the study period. Again; this is conceivable since hot; humid weather is detrimental to wheat yields; as it increases the spread of diseases and pests. The October interaction term was significant in the Canola equation; however it decreased the share of canola. It was hypothesized that warmer and wetter Octobers would be beneficial to the crop rotation as it increased the length of the growing season; therefore this could signal that farmers may be switching to different crops when trends result in weather being more suitable in the fall.

## Effect of beef and pig inventory levels

As expected the beef and pig inventory variables had at least one significant variable in each estimated equation; whereas in the feed equation both of them were positive and significant. An increase in beef inventory would lead to a  $(4.7 \times 10^{-6})\%$  increase in the share of feed crops; holding other variables constant. Similarly; an increase in pig inventory would result in an increase in the share of a feed crop by  $(1.9 \times 10^{-5})\%$ ; holding other variables constant. The specialty oilseeds group also had a significant effect on beef and pig inventory variables. This effect was positive for pig inventory; increasing the share of a specialty oilseed by  $(3.6 \times 10^{-8})$ ; holding all other variables constant; but negative

for beef inventory; decreasing the share of this group by  $(7.2 \times 10)^{-8}\%$ ; holding others constant. This difference could be explained by that fact that recent research has suggested flaxseed is beneficial to a swine diet [48]. It is also more common to feed pigs differing rations than with cattle. Summerfallow also had both livestock inventories having a significant but negative effect on the choice to leave land to fallow. On livestock farms; summerfallow may not be practiced as stringently as on grain and oilseed farms. Therefore the choice to leave fields to fallow would not be greater than the choice to use fields for feed or forage; for example.

For the wheat and canola share; pig inventory was the only variable that was significant. A 1% increase in pig inventory would decrease the share of wheat by  $(1.3 \times 10^{-5})\%$  holding all other variables constant. Similarly; this variable would increase the share of canola by the same amount; holding other variables constant. The beef inventory variable was only significant for the pulses and forages equations; with a 1% increase in beef inventory increasing the share of pulses or forages each by  $(1.5 \times 10)^{-8}\%$  and  $(8.0 \times 10)^{-8}\%$ ; respectively (for each coefficient holding other variables constant). Intuitively this makes sense as dry peas can be used in feed mix for cattle and forages can be used as pasture land to graze cattle. However; these results are quite small as dry peas command a high market price and would likely be sold for cash. The minute result for forages is not as easily explained; as it should be an important crop group for on-farm inventories of cattle [49].

### Effect of price variables

Prices play an important role in acreage allocation decisions given the high level of significance in the estimated marginal effects for all crop groups. This significance is most prominent for canola and pulses with five of the six price variables being significant in each group. Wheat; pulses; specialty oilseeds; feed and forages prices all affect the decision to grow canola. As the price of pulses increases by \$1/tonne; the share of canola increases by 0.0014%; holding all other variables constant. This same result was observed for feed and forages prices; which is expected on economic grounds. An increase of \$1/tonne for feed increases the share of canola by 0.00034%; holding other variables constant; and an increase by the same amount for forages increases share of canola by 0.0016%; holding other variables constant. This result however; is unexpected on economic grounds; although it could be explained by the fact that canola has commanded such a high price in recent years that it may have precedence over marginal crop groups such as the forages. As expected; an increase in the price of wheat reduces the share of canola by 0.00056%; holding other variables constant. Similarly; an increase in the price of specialty oilseeds decreases the share of canola by 0.00045%; holding other variables constant. Both wheat and specialty oilseed prices had signs that were expected on economic grounds. As mentioned; wheat was marketed through the CWB during the time period estimated; with initial prices announced before spring seeding and payments being virtually guaranteed. Therefore an increase in the price of wheat would negatively affect the share of any other crop that is sold on the open market where there is no guarantee of a high price. An increase in the price of other oilseeds (specialty) negatively affects the share of canola as expected; as this crop group is another viable crop rotation tool.

The share of the pulse group was influenced by the price of wheat; canola; pulses; specialty oilseeds and forages. Of these five prices; three of them increase the share of pulses-wheat; pulses and forages. As expected; an increase in the price of pulses by \$1/tonne increases the share of pulses by 0.0003%; holding other variables constant. An increase in the price of wheat and forages also increases the share of the

pulse group by 0.00034% and 0.0015% respectively (each holding other variables constant). Contrarily; and increase in canola and specialty oilseed prices decreases the share of pulses. A \$1/tonne increase in price of canola decreases share of pulses by 0.00013%; holding other variables constant [50]. Similarly, an increase in specialty oilseed prices decreases share of pulses by 0.0002%; holding other variables constant.

Feed and forages groups were the next crop group with the most influence of prices with four of six price variables being statistically significant. Wheat price positively affected the share of both these crop groups; with a \$1/tonne increase in the price of wheat increasing the share of wheat or forages. An increase in the price of wheat increased the share of feed by 0.00072%; holding other variables constant. An increase in the price of forages increases the share of feed by 0.0015%; holding other variables constant. Forages had the same effect on both crop groups; with an increase in the price of forages increasing the share of feed or forages. An increase in the price for pulses and feed both decrease the share of a feed crop. As the price of pulses increases by \$1/tonne; the share of feed decreases by 0.00026%; holding other variables constant. Similarly; as feed price increases; the share of feed decreases by 0.0013%; holding other variables constant. This finding is not as expected as an increase in own price would make the crop more desirable. However; because feed crops are used and managed differently<sup>11</sup> than the other crop groups; prices could be less influential on the feed crop choice.

The wheat; specialty oilseeds and summerfallow groups had the least amount of significant price variables. For the choice of area allocated to wheat; pulses and specialty oilseed the model revealed that oilseed prices were significant. A \$1/tonne increase in the price of pulses decreases the share of wheat by 0.00064%; holding other variables constant. Alternatively; an increase in the price of specialty oilseeds increases the share of wheat by 0.00038%; holding other variables constant. The sign on prices of pulses was as expected; however the sign on specialty oilseed prices was not as expected.

The choice of a specialty oilseed was influenced by the price of canola and forages with a \$1/tonne increase in the price of canola decreasing the share of specialty oilseeds by 0.00015%; holding other variables constant; and an increase in the price of forages increasing the share of canola by 0.00075%; holding other variables constant. Again; the sign on canola price was as expected since this is a cash crop and offers a high price in the open market. Share of summerfallow was negatively influenced by the price of wheat and forages as expected. As the price of wheat increases by \$1/tonne; the share of summerfallow decreases by 0.0013%; holding other variables constant. Similarly; as the price of forages increase; the share of summerfallow decreases by 0.0035%; holding other variables constant. However; as canola price increases the share of summerfallow increases; which is not as expected.

The simulation was carried out using expected climate change data for the future from Price et al. [46]. The spatial scale used in the study split the prairies into two ecoregions: the semi-arid and the sub-humid. These two distinct ecoregions line up well with the soil zone profile of Saskatchewan; with the sub-humid region lying mostly across the black soil zone and the semi-arid on the southern brown and dark brown soil zone.

### Simulation results

Table 4 outlines the projected change in wheat area for the three

<sup>11</sup>They are consumed on farm, can be sold privately, and there are not strict grading guidelines for protein content, weight, etc.



different climate change scenarios by time period as well as total change. The trend of less area to wheat continues to decrease in each soil zone over the projected time period. Contrary to the current trend however; summerfallow area continues to increase. In fact; it is the one crop group whose area increases the most in all three soil zones and in all three future time periods. As expected; much of this area change comes from a switch to canola; which has been on the rise over the past several decades and is likely to continue. Pulses; on the other hand do not experience an increase in share in any scenario. This is not as expected since area of this crop has dramatically increased in recent years. However; pulses are a relatively new crop to Saskatchewan; especially chickpeas and lentils; therefore the use of them as an adaptation to climate change may be less attractive compared to the other crop groups.

Although pulses; feed and forages represent a negative change; this change is relatively slower in the pessimistic and medium scenarios. This could suggest that beyond 2099; given the same trend in climate change; these other crop groups may begin to be a viable option to add to the crop mix as an adaptation strategy. The optimistic scenario outlines a slightly different story. The share of a specialty oilseed over wheat has the highest percentage change than any other scenario. In the last time period; this increase reached its maximum; suggesting that a specialty oilseed may be another viable option for adaptation to climate change. Forages appear to be a poor choice for adaptation to climate change as it experiences the largest negative percentage change. Again; for the final time period in the optimistic scenario this decrease reaches a maximum of an over 10% decrease in the choice of forages. Summerfallow dominates in choice in all three scenarios and all three soil zones. As mentioned in the marginal effects discussion; farmers could chose fallow as an adaptation to climate change; and as the scenario results suggest; this choice of this continues to increase beyond most other crops.

## Conclusion

The main objective of this study was to develop a model that would assess how farmers in Saskatchewan have been adapting to climate change by switching crops. Based on choice theory; share of cropland in Saskatchewan devoted to seven specified crop groups were chosen to represent the dependent (or choice) variable. Based on extensive literature review climatic; economic; socio-economic and geographic variables were chosen as explanatory variables to model the choice made by producers. Overall; the results suggest that prices; policy

and land characteristics play an important role in a majority of crop choices. Cooler, dry springs are favorable for major crops such as wheat; canola and pulses; and when temperatures are high in the summer months the choice of summerfallow increases. Interestingly; precipitation did not have as much of an impact.

The major conclusion from this research are: (i) following current trends; the area devoted to spring wheat and durum wheat would continue to decline into the future; (ii) Area devoted to wheat remains a superior choice over pulses; feed and forages while specialty oilseeds represent a viable alternative choice to wheat and (iii) most significantly; summerfallow area would increase. This is in contrast to the current trend of declining summerfallow area as a result of tighter crop rotations. This finding was observed throughout all three soil zones as well as for all three climate change projection periods. The average decline in the area of wheat from the base years of 2000 in the black soil zone by 2099 is 3.5% for the pessimistic scenario and 4.6% for both the medium and optimistic scenario. In the dark brown soil zone; the decline from the base year is 2.7% under the medium scenario; while the pessimistic scenario projects a decline of 2.8% and the optimistic a decline of 2.9%. In the black soil zone; the decline in wheat area from the base year is up to 3.6% in the pessimistic scenario; 2.8% under the medium and 4% under the optimistic scenario. Overall; the projected decreases in area devoted to wheat are most prominent in the black and brown soil zones. The dark brown soil zone; experiences the least variable decreases from one time period to another. In the black soil zone; wheat area in the base year accounts for the least out of all three soil zones; however; wheat area in the brown soil zone is the highest out of all three; therefore the projected decreases in area devoted to wheat could be significant in this soil zone.

As more area is allocated to summerfallow; as simulated; one of the major implications this would have will be felt by the Saskatchewan economy. If as indicated by this modelling; summerfallow is currently the one of the few possible choice as an adaptation response to an increased climate; the repercussions for Saskatchewan could be extreme at the individual farm as well as national levels. Chapter two outlined the importance of agriculture as well as the agri-food sector to the provincial and national economy. Area devoted to summerfallow means less crop is produced; this in turn is likely to have a detrimental effect on farmers; employees of the agri-food sector; as well as the economy of Saskatchewan and Canada. There are also the welfare effects of summerfallow due to increased soil erosion and decreased carbon sequestration. This could be further exacerbated by the projected extreme climate events. Given the results of this research; it could be suggested that new crop varieties should be developed to better withstand these types of extremes. Or another crop mix all together could be introduced. Overall; more research; development and extension services would be extremely beneficial to prepare for the possibilities that are faced with a changing climate.

One of the limitations of this study was the minimal amount of previous research in agriculture using the FMNL model. Although the conceptual model drew upon many fields of research concerning climate change; agriculture; choice and adaptation; there is no solid framework strictly concerning agriculture and the fractional choice model. Another issue was the limited historical information on key variables; such as prices. Given more thorough; complete information; more key variables could have been included. Another improvement would be including a variable that would represent the cost of production. As mentioned in the previous chapter; crops such as pulses and malting barley require more stringent management practices. This

	Black SZ			TOTAL AVG .CHANGE
	2010-2039	2040-2069	2070-2099	
Pessimistic	-2.56	-4.41	-3.57	-3.51
Medium	-5.62	-4.57	-3.67	-4.62
Optimistic	-5.72	-5.27	-2.72	-4.57
	Dark Brown SZ			TOTAL AVG .CHANGE
	2010-2039	2040-2069	2070-2099	
Pessimistic	-2.53	-3.83	-2.03	-2.80
Medium	-3.55	-2.62	-2.04	-2.74
Optimistic	-3.99	-3.59	-1.10	-2.89
	Brown SZ			TOTAL AVG .CHANGE
	2010-2039	2040-2069	2070-2099	
Pessimistic	-6.11	-3.31	-1.50	-3.64
Medium	-3.57	-2.64	-2.06	-2.76
Optimistic	-3.50	-3.61	-4.85	-3.99

**Table 4:** Projected Changes in Wheat Area (acres) from base year, 2000, by Soil Zone.

is likely to factor into area allocation and production decisions. Another key variable that could improve upon the research would be a variable to represent profitability. This could be developed to gauge the effect of farmers; the agri-food sector and even the economy; depending on the construction of the variable.

Most notably; the inclusion of technology as an adaptation strategy was not included in this study. Technology is considered a long-term adaptation strategy to climate change; and would take years to take effect [10,16]. However; including the possibility of a new; robust crop group that could withstand the projected weather extremes could substantially add to this model. Examples of these crops could be the current crop mix in warmer climates of the Northern USA such as cotton; sorghum; corn and/or soybeans.

One of the major results suggesting an increase in summerfallow should be further examined in future research. Some form of tillage usually accompanies leaving land to summerfallow; however there are different summerfallow management practices that farmers can employ on these fields. Some of these practices are more beneficial to the soil than others; and some are more expensive than others such as 'chem' fallow<sup>12</sup>. Tillage methods could also be incorporated into the crop groups to account for different management practices. For example; conservation tillage leaves up to 30 percent of the previous crops soil residue on the surface; conserving moisture and lessening the possibility of erosion [51]. Others are less expensive options like zero tillage or no till. Given that historical information is available for these practices; including these in estimation could improve future research.

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<sup>12</sup>Chem fallow, or chemical fallow, involves using herbicides such as glyphosate to kill the weeds on the land, without disturbing the soil using tillage practices. However, this technique can vary to include some tillage practices (USA Environmental Protection Agency, 2013).

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