Mixed Farm Model for the Economic Impact Assessment of Climate Change and Extremes

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Abstract

With greater certainty of a climate change occurring, there is a need for developing information on its impacts on agricultural production, particularly on farms with mixed enterprises. This paper outlines a farm simulation model developed to assess the impact of climate change and extremes on a mixed farm in the Canadian Prairies. The model is named MF-CCE -- Mixed Farm Model for the Economic Impact Assessment of Climate Change and Extremes. The model integrates the production models such as agronomic crop simulation model, cattle herd simulation model, and pasture yield model for the simulation of crops and hay, livestock production, and pasture production, respectively. The model also includes liner-programming models for the economic decisions such as crop selections for feed rations and the crop mix for market sales. The outputs from these biological and economic models are inputs needed for simulation of farm level economic indicators. This model is applied to a mixed farm operation in Pincher Creek region of Alberta. The impacts of climate change and extremes are simulated through yield effects measured by biological models under an assumed climate change scenario. The simulation results indicate that the modelled farm is viable business for the planning horizon of 30 years under both the baseline and future scenario. In terms of future climate change impacts, both the crop and beef cattle activities will benefit in the future taking account of both the average climate change as well as weather extreme events. However, the farm will be impacted severely during the period of extremes weather as indicated by negative returns at crop production and farm levels.

Keywords

Mixed Farm Model; Climate Change and Extremes; Bio-Economic Farm Model; Canadian Prairies

Introduction

Agricultural system represents a complex combination of biophysical components and economic decision-making. Assessment of agricultural system, therefore, requires information from both biophysical factors represented by site-specific climate and environment conditions and economic factors (including market conditions) that shape farm owner’s management decisions. Modeling of any representative agriculture system combining biophysical factors of production and economic decision of farm management are commonly referred as Bio-economic farm modeling [1, 2]. A variety of such farm models have been used for the different scenario analysis, including effect of policy change, price...
change, environmental change and other external shock to optimal farm plan, economic returns, and environmental performance in Canada [3]. A number of farm models have also been constructed for the purposes of climate change impact assessment; however, most of these models are built with very specific aim and seldom applicable for the use in other studies [4]. More specifically, there are very few choices to model the mixed farm that has crops, livestock and forage components and that can simulate the effect of normal climate change as well as climate extremes.

The Canadian Prairies, comprise the provinces of Alberta, Saskatchewan, and Manitoba, as they are partially covered by prairie (grasslands), are agriculture based regions as it occupies more than 80% of total agricultural land in Canada with about 50% of total Canadian farms operating in the region [5-7]. Prairie agriculture production is heavily dominated by grain, oilseed and beef cattle production activities [8]. However, dry and moisture-deficit conditions in most part of the year poses limitation in agriculture production. Besides, the Prairies has been hard hit by droughts in the past and climatological studies projects increased frequency of extreme weather events in the future [9-11]. To estimate the vulnerability of representative agriculture to climate change, the modeling approach should be flexible enough to accommodate major agricultural production activities as well as extreme climate events. This paper outlines a whole farm simulation model called Mixed Farm Model for the Economic Impact Assessment of Climate Change and Extremes (MF-CCE) that integrates all possible farm activities on a mixed farm including crops, cattle and forage production activities under assumed climate change extremes. A case study of a mixed farm operation in Pincher Creek region of Alberta is simulated to test the applicability of the model.

Review of Farm Models

Farm modeling approach is a tool for integrated assessment of farming system, which can simulate the variety of shocks at the farm level. Such models can be used for impact assessment of scenarios at farm production level. The modeled farm in this approach can be a single real farm, hypothetical/synthetic or representative farm with mean or median characteristics in the region, or can be an aggregate farm by aggregating individual farm data in the region of interest. This type of farm generates farm income under given (or estimated) values for land use, crop mix or other variables of interest. These outcomes may be varied by altering the input or coefficient in the farm model; for example, changes of climate can be input, and the farm-level response in output and income simulated therein [12]. Farm modeling approach is quite flexible in the use of methodologies that it can be a single technique or can be a mix of different techniques, such as biological simulation model for production component, simulation or mathematical programming model/s for economic behavior with the flexibility in incorporating many techniques in an integrated framework [4]. Most commonly used farm models are reviewed in this section.

Mathematical programming based farm models make use of optimization as a main technique in model building [13, 14] developed farm-level linear programming model based on Discrete Stochastic Programming method. The model, called Model of Uncertain Dryland Agricultural System (MUDAS), estimates changes to farm management practices under assumptions of climate risk. The model incorporates a discrete stochastic representation of weather and tactical response of the farmers against the risk. This approach considers the seasonal variation by considering number of discrete state of nature [15] developed a representative crop and livestock farm model using Mixed Integer Linear Programming to optimize the level of crop and number of livestock under different level of risk generated by weather variability. This class of farm model may make use of production model incorporated with an optimization model where the impacts of climate change are captured through the production model. The methodologies used in such models are a mix of different techniques like process based simulation or statistical method for production component and optimization approach for the whole farm economic decision [16, 17] combined economometric model of yield forecasting with a linear programming techniques [18-21] combined crop productivity model to a linear programming model. The base model was then simulated with the crop yield effect of future climate to see the changes in farm income and regional crop mix. A similar model for a mixed farm (simulating both crop and livestock production) was used by [2, 22, 23].

Mathematical programming based farm models can simulate the climate change impacts at the farm level as discussed above. The main analytical component of these models is optimization, which is best suited to optimize the resource allocation given the expected costs and revenues from such activities, as land use change. In mixed farm settings with integrated crops, combined with forages, and cow-calf, backgrounding and finishing beef cattle operation, an optimization model may not be a good choice because of difficulty estimating per unit cost and
return. Nonetheless, mathematical programming can be a tool in selecting crop choice and formulating the least cost ration for beef cattle combined with other tools and techniques necessary to develop a farm simulation model.

Another class of models for the integrated assessment is farm simulation models, which is generally more detailed than the optimization based farm models. Techniques used in these models range from simple simulation to combination of several tools and techniques including optimization. Such models are typically more detailed and flexible in both model construction and scenario analysis [24-26] modelled a Canadian Prairie mixed crop and beef farm using generic simulation approach. Focus[26] on estimating whole-farm Greenhouse Gas (GHGs) emissions from beef production in Alberta using The Life Cycle Assessment (LCA) approach to fully capture the GHG emission over the life cycle of a beef from the mixed farm. Models developed by [24, 25] focused mainly on economic assessment. Similar mixed farm model has been used by [27-29]. However, aim and scope of these models vary greatly.

Farm modeling approaches have been widely used in the simulation of agricultural systems for economic impact assessment. However, these models are specific to purpose and location, and are seldom used in the other studies [4] states that a number of farm programming and simulation models for farm modeling and scenario analysis exist, but no single robust model can be applied everywhere. However, basic tools and techniques from available models can be adopted to develop a farm simulation model based on the aim and scope of a study.

**Description of the MF-CCE Model**

In this study, a farm simulation approach is followed to estimate the economic impacts of climate change extremes for a mixed farm. It is called MF-CCE -- Mixed Farm Model for the economic impact assessment of Climate Change and Extremes. The model is a whole farm simulation model that combines the biological models of beef cattle herd development, agronomic crop production and pasture yield estimation with the model(s) of economic decisions. The economic decision models include feed models and a model for crop mix selection for the market sales. Feed model comprises of a linear programming based optimization of feed (grains and silage) model for the least cost way of on-farm feed production (subject to on-farm requirements) linked with hay and pasture demand and supply.

An overview of the model is presented in Figure 1. The MF-CCE contains five sub-models as shown in the boxes with bold outline: agronomic crop model, pasture yield model, beef cattle herd simulation model, crop mix linear programming model and least cost feed model. Boxes with dotted outlines indicate scenario inputs and scenario outputs.

**Figure 1:** An overview of the MF-CCE simulation model

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### Legends:

**MODEL**

**Input/Output**

**Scenario**

**Legend:**

- **Crop yields**
- **Crop area for market**
- **Crop area for beef feed**
- **Crop prices**
- **Total crop area**
- **Least cost feed model**
- **Least cost feed model output**
- **Crop yield model**
- **Crop price model**
- **Crop area model**
- **Pasture yield model**
- **Pasture area model**
- **Pasture demand model**
- **Beef herd simulation model**
- **Beef herd simulation model output**
- **Beef market model**
- **Beef market model output**

**Inlet/Outlet**

- **Crop yield**
- **Crop area**
- **Pasture yield**
- **Pasture area**
- **Pasture demand**
- **Beef demand**
- **Crop prices**
- **Crop area prices**
- **Pasture prices**
- **Beef prices**

**Scenario**

- **Scenario input**
- **Scenario output**

**Legend:**

- **Crop yield**
- **Crop area**
- **Pasture yield**
- **Pasture area**
- **Crop price**
- **Pasture price**
- **Crop area price**
- **Pasture area price**
- **Crop price model output**
- **Pasture price model output**
- **Crop area model output**
- **Pasture area model output**
- **Crop yield model output**
- **Pasture yield model output**

**Inlet/Outlet**

- **Crop yield**
- **Crop area**
- **Pasture yield**
- **Pasture area**
- **Crop price**
- **Crop area price**
- **Crop yield model output**
- **Crop area model output**
- **Pasture yield model output**
- **Pasture area model output**
- **Crop price model output**
- **Crop area price model output**
Under a given climate scenario, the crop model estimates the yields of various including hay and crop biomass for silage. The pasture model estimates the native pasture productivity under a given climate scenario. The crops and silage, hay and pasture areas are fixed throughout the simulation period. The available crop area is first used to produce feed grains, hay and silage to meet the demand of the herd. Once met, the remaining area is used to produce grain for market sales. The impact of climate change and extremes are estimated through impacts on crops and forage productivity. The impacts on beef cattle production are linked through the impacts on crops and forages, which are linked to feed availability for the beef cattle herd. The major components of the MF-CCE are described hereunder.

### Agronomic Crop Simulation Model

Agronomic crop models are generally used to simulate a crop’s response to given input and management conditions by creating controlled dynamic plant growth processes. These simulation models can be used for impact of a change in a given scenario by altering the variable of interest. Once the model is calibrated, the climate input can be altered to see the crop response against climate change. The crop models have been widely used to understand the effect of climate change on crop yield as the focus of such models is on the biological consequences of climate change on crops [12]. For this reason, the crop models are usually integrated with economic models to assess the economic impact on farm to regional and global level [23, 30-32]. This study uses Food and Agriculture Organization’s (FAO’s) Aqua Crop model (version 3) to estimate the production of various crops and hay. The Aqua Crop is a water-driven crop simulation model, termed crop water productivity (WP) model, which simulates the yield response of herbaceous crops to water availability and use. The model is believed to be superior in simulating crop yield in the conditions where water is a key limiting factor in crop production [33]. It requires daily and monthly climate data over the entire simulation period to generate annual crop yield. These data would include period of climate change extremes.

### Beef Herd Simulation Model

A beef herd simulation model contains beef cattle production activities in terms of input required and output produced. In this model, three types of beef cattle activities are included: cow-calf, backgrounding and finishing cattle. The farm produces calves, which pass through on the same farm, through backgrounding and finishing phases, resulting in finished animals. A portion of these animals is sold to the market, as superior calves are kept for on-farm herd replacement. The model runs in a monthly time steps to complete a cattle cycle of nine calving. In the model, calving is done in late February to early March. The weaning is done at the seventh month (at the end of September). The weaned calves enter the backgrounding lot in October until February (for five months). The backgrounding animals enter the finishing lot in March and finished animals are sold for slaughtering in June. The total length of a calf prepared for market is 16 months from birth. Three months after calving, cows come into heat and conception takes place in between mid-May and mid-June. Pregnancy tests are done within three months of conception and open cows (starting old age) are culled.

After the calving season in the 28th year, the cows are kept until the weaning of calves is completed. The real world coefficients on beef cattle performance indicators required to run the simulation (such as number of calving, age at first calving, conception rate, mortality rate, daily weight gain and so on) are adopted from [24-26].

### 3.3 Pasture Yield Model

Pasture yield model estimates pasture production under given climatic conditions for baseline model calibration as well as for the scenario analysis. The native pasture yields were based Forage Calculator for Native Rangeland (FCNR) developed by the Saskatchewan Research Council [34, 35]. The FCNR estimates the yearly forage yield values for a given “forage-year-precipitation” (PPTy). Taking the average long-term production and corresponding monthly precipitation value as a reference, the calculator estimates yearly forage production using the current year’s “forage-year” precipitation. The “forage-year” precipitation is the 12-month total from the September 1st of the previous year to August 31st of the current year.

### Feed Model

Daily nutritional requirement of livestock depends on the average daily gain (ADG), expected finishing weight, body weight, and age of the livestock. Nutritional recommendations by [36, 37] are adopted. Given the desired weight, age in month, and daily weight gain, nutritional requirement (in terms of dry matter, energy
and crude protein) of different type of beef animal in the herd are calculated separately and are matched with the nutritional content of the feedstuffs. Least cost feed model are used to match the grain-based nutrient requirement and supply while the amount of forages requirements are calculated by matching dry matter (DM) demand of the herd with the dry matter supply from hay and pastures.

Feed Grain/Silage Demand and Supply

Least cost feed mix linear programming (LP) was formulated to estimate the feed grain and silage requirements of the herd given the nutritional content of crops grown on farm. This is done with the aim of minimizing total feed production cost as suggested by [15]. The land used to produce animal feed competes with the land for crop production. Therefore, beef crop demand determines the amount of crop that can be sold in the market. The DM, energy and crude protein needs of each animal type per day were adopted from NRC (2000). Changing nutritional requirement of the animal with age and weight were accounted for by taking an average monthly weight and corresponding nutritional requirements. The general LP structure of the cattle feed mix problem is described in equations (1) to (5).

\[
\text{Minimize } C = \sum_{i=1}^{n} FGi * VCi \\
\text{Subject to; }
\]

\[
DMr \leq DMs; 
\]

\[
Er \leq Es; 
\]

\[
CPr \leq CPS; \text{ and} 
\]

\[
FGi \geq 0; 
\]

where, C is total feed production cost; FGi is ith type of feed grain produced on farm (i = 1..n); VCi is variable cost of production of the ith feed grains (i = 1..n); DMr, Er and CPR are the dry matter, energy and crude protein requirement of the herd, respectively; DMs, Es and CPs are the dry matter, energy and crude protein available from the feed mix.

Pasture and Hay Demand and Supply

Pasture demand of the herd is calculated based on dry matter (DM) requirements of the grazing animals. For example, the DM matter requirement of 1,300 lbs beef cattle ranges from 25-29 lbs per day depending on stages of gestations and lactations [37]. On average, a 1,000 lbs beef cow requires 26 lbs of DM a day, which is called an Animal Unit Equivalent (AUE). Therefore, total pasture requirement expressed in terms of AUM was estimated using equation (6):

\[
AUM \text{ Demand} = AUE*\text{Number of cow} * \text{ Months in grazing} 
\]

Pasture supply, also expressed in terms of AUM/acre, from a given pastureland was calculated to match the pasture demand. Pasture supply, calculated as Ecologically Sustainable Stocking Rate (ESSR), was estimated using equation (7), which uses 455 kg of dry matter in an AUM, which is recommended quantity for Alberta and that, might vary by region.

\[
ESSR(\text{AUM / acre}) = \frac{\text{Yield (kg / acre)}* \text{Utilization rate}}{455 \text{kg / AUM}} 
\]

Pastureland needed to maintain the cattle herd was then calculated using equation (8).

\[
\text{Pastureland required (acre)} = \frac{AUM \text{ Demand}}{ESSR(\text{AUM / acre})} 
\]

Hay demand was calculated to fulfill the daily DM requirement of the animal, estimating yearly demand based on total number of feeding days and number of animals. This was then matched with the hay supply as in equation (9). Correction factor of (100/85) was included to take account of feeding wastage in equation (9) to estimate total hay demand.

\[
\text{Total hay demand} = \left[ \frac{\text{Total DM demand} \times \frac{100}{\% \text{ DM content}}}{} \right] \times 100/85 
\]
Crop Mix Multi-Year Linear Programming (MLP) Model

Crop mix for market sales was determined by formulating a Multi-year Linear Programming (MLP) model for the entire simulation period with the constraints of yearly area available and area needed to feed the herd. Given the crop yield, market price of the crops and their respective variable cost of production (COP), the present value (PV) of future yearly gross margin flows were maximized. The MLP is a non-stochastic model where model parameters were assumed to be known with certainty. Parameters like cost and price were estimated using a time series model, whereas crop yield estimations were obtained from FAO’s AquaCrop model simulation. The structure of the MLP model of crop mix is described in equations (10) to (15).

\[
\text{Maximize } PV \text{ of Gross Margin } = \sum_{i=1}^{m} \left[ \left\{ \sum_{j=1}^{n} (P_i \cdot Y_j) - V_{C_i} \right\} \right] ^t (1 + r)^t
\]

(10)

This can be written as:

\[
\text{maximize } PV \text{ of Gross Margin } = \sum_{i=1}^{m} \left[ \left\{ \sum_{j=1}^{n} X_i \right\} \right] ^t (1 + r)^t
\]

(11)

Subject to:

\[
\sum_{i=1}^{n} a_j \leq A, \forall m; \quad (12)
\]

\[
FG_{as} \geq FG_{ad}, \forall m; \quad (13)
\]

\[
S_{as} \geq S_{ad}, \forall m; \quad \text{and,} \quad (14)
\]

\[
X_i \geq 0 \quad \text{..........} n \geq 0 \quad (15)
\]

where, i = 1...n, are the number of crop choices; t is year of gross margin flow; m is length of simulation or total years of gross margin flow; \( Xi = (P_i \cdot Y_i) - V_{C_i} \) is gross margin per acre of ith crop activity; \( P_i \) is price of ith crop; \( Y_i \) is yield per acre of ith crop; \( V_{C_i} \) is variable COP ($/acre) of ith crop; r is discount rate; \( FG_{as} \) and \( FG_{ad} \) are area allocated to and area demanded for feed grain; and \( S_{as} \) and \( S_{ad} \) are area allocation and area demand for silage.

Case Study of a Canadian Prairie Mixed Farm

The MF-CCE was used to evaluate the impact of climate change and weather extremes on a representative mixed crop and beef farm in the Pincher Creek region of Alberta. The study farm was simulated under two climate periods of 30 years each: the baseline period of 1971 to 2000 and future period of 2041 to 2070. Data obtained from [6] for a mixed beef-crop farm in the study region were used to develop the farm characteristics. The study farm had 1700 acres of native and tamed mixed pasture, 686 acres of crop area including hay, and 307 head in the beef herd (100 cow, 88 calves, 16 replacement heifer, 6 bulls, and 97 finishing steers and heifers). Crop portfolio of the farm included four major crops grown in the region: canola, wheat, feed barley and maize.

The results of agronomic crop simulation model showed that, on average, climate change would have positive effect on crop production in the future. Under the future climate, 30-year average crop yield increases would be in the range of 55 to 127% depending on type of crop. Included within this period were periods of extreme weather events, which pose a serious effect on crop production, as no yields are recorded for these time periods. Plots of yield estimates are shown in Appendix 1.

These estimated crop yields were used as an input into the MF-CCE model to link with to beef cattle production and the resulting economic impacts of climate change extremes at the farm level. Change in crop yields affected the beef cattle activities through higher feeding cost, as per unit cost of feed production combined with the increased amount of feed purchased during the period of extreme weather events increased. The cost of total feeding during the year of extreme weather increased by more than 134% under the baseline scenario and more than 24% under the future scenario. The results are presented in Table 1.

The resulting climate change extreme impacts on economic returns of producers are summarized in Table 2.
Appendix A: Crop and hay yield estimates for the Pincher Creek study site

Figure A1: Spring wheat yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

Figure A2: Spring wheat yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

Figure A3: Barley yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Pincher Creek
Figure A4: Barley yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

Figure A5: Canola yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

Figure A6: Canola yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Pincher Creek
Figure A7: Maize yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

Figure A8: Maize yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

Figure A9: Alfalfa hay yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Pincher Creek
Figure A10: Alfalfa hay yield forecast under the future scenario, 2041-2070, under

Table 1: Costs of Beef cattle herd feeding during the simulation period.

<table>
<thead>
<tr>
<th>Feeding Costs</th>
<th>Average costs of feeding</th>
<th>Coefficient of variation</th>
<th>Maximum costs during extreme weather years</th>
<th>% increase in extreme years from the average year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of feed production</td>
<td>$16,973.98</td>
<td>0.4</td>
<td>$38,968.60</td>
<td>129.58</td>
</tr>
<tr>
<td>Cost of feed purchase</td>
<td>$2,262.03</td>
<td>1.2</td>
<td>$11,521.62</td>
<td>409.35</td>
</tr>
<tr>
<td>Total feeding cost</td>
<td>$19,236.01</td>
<td>0.4</td>
<td>$45,099.41</td>
<td>134.45</td>
</tr>
<tr>
<td><strong>Future Scenario (2041-2070)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of feed production</td>
<td>$33,916.22</td>
<td>0.1</td>
<td>$43,321.53</td>
<td>27.73</td>
</tr>
<tr>
<td>Cost of feed purchase</td>
<td>$2,373.51</td>
<td>1.0</td>
<td>$7,646.72</td>
<td>222.17</td>
</tr>
<tr>
<td>Total feeding cost</td>
<td>$36,289.73</td>
<td>0.1</td>
<td>$45,969.58</td>
<td>24.27</td>
</tr>
</tbody>
</table>
Table 2: Average and extreme weather year returns at crop, beef cattle and farm level under the baseline and future scenarios

<table>
<thead>
<tr>
<th>Activity and farm returns</th>
<th>Average</th>
<th>% change from baseline scenario</th>
<th>Max returns (per year)</th>
<th>Min returns (per year)</th>
<th>% change average to min</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Scenario (1971-2000)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross return from crop activities</td>
<td>$31,303.58</td>
<td></td>
<td>$31,303.58</td>
<td>-$6,062.68</td>
<td>-119.37</td>
<td>0.91</td>
</tr>
<tr>
<td>Gross returns from Beef cattle activities</td>
<td>$45,747.89</td>
<td></td>
<td>$45,747.89</td>
<td>$26,412.77</td>
<td>-42.26</td>
<td>0.36</td>
</tr>
<tr>
<td>Farm Net returns</td>
<td>$71,255.01</td>
<td></td>
<td>$71,255.01</td>
<td>$15,879.65</td>
<td>-77.71</td>
<td>0.56</td>
</tr>
<tr>
<td>Future Scenario (2041-2070)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross return from crop activities</td>
<td>$66,692.08</td>
<td>113.05</td>
<td>$66,692.08</td>
<td>-$1,549.79</td>
<td>-102.3</td>
<td>0.72</td>
</tr>
<tr>
<td>Gross returns from Beef cattle activities</td>
<td>$67,326.62</td>
<td>47.17</td>
<td>$67,326.62</td>
<td>$42,036.30</td>
<td>-37.56</td>
<td>0.29</td>
</tr>
<tr>
<td>Farm Net returns</td>
<td>$107,041.57</td>
<td>50.22</td>
<td>$107,041.57</td>
<td>-$2,971.93</td>
<td>-102.78</td>
<td>0.63</td>
</tr>
</tbody>
</table>

The long-term average crop returns under the future scenario increased by 113% in comparison to the baseline scenario. However, the crop activities were seriously impacted in the year of extreme weather under both the baseline and future scenarios as decline in crop returns of up to 119% from the average return were recorded.

Similar to the crop return, the long-term average return from the beef cattle activities increased by 50% under the future scenario but the return in the year of extreme weather declined by up to 42% under the baseline and up to 38% under the future scenarios. Net return at whole farm level increased by 50% under the future scenario from the baseline level suggests that overall impact of climate change would be positive in the mixed farm settings in the Canadian Prairie; however, the farm net profit in the extreme weather year decreased by up to 77% under the baseline and up to 102% under the future scenarios. In fact, the farm is estimated to incur loss during the year of extreme weather under the future scenario as indicated by negative whole farm net returns.

Overall results indicate that the prairie representative mixed operation is a viable business under both the current climate as well as future climate. The estimated impacts on individual beef cattle production and crops as well as at whole farm level suggest that the overall gain of climate change would be positive even after considering the average future climate containing extreme events. In terms of income variability, there will not be significant difference in the beef cattle gross return between the baseline and future scenarios, but income risk in the crop enterprise was estimated to decrease sharply under the future scenario, largely due to the higher level of income resulting from increased crop area and higher crop yield.

Summary and Conclusion

The study contributes to the knowledge of climate change impact assessment at the farm level by offering a simple and flexible yet comprehensive assessment framework, MF-CCE model. The model consists of a number of integrated sub-models to assess whole farm economic returns. The model can be customized to fit any number of sub-models to represent more farm level activities or to increase its efficiency. The model can be solved for other regions and countries by using local information. The model workability was tested by applying it to a mixed farm having crops, hay, pasture and beef cattle activities in the context of the Canadian Prairies. The results of the simulation showed that both the crop and beef activities individually as well as the farm as a whole make positive and significant profit under both the present as well as future climate change scenario. The effect of climate change as well as weather extremes were captured by including inter-annual climatic variability and their effect on crops hay and pasture production. The simulation results indicate that the modelled farm is viable business for the planning horizon of 30 years under both
the baseline and future scenario. In terms of future climate change impacts, both the crop and beef cattle activities will benefit in the future taking account of both the average climate change as well as weather extreme events. However, the farm will be impacted severely during the period of extremes weather as indicated by negative returns at crop production and farm levels.

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