

IMPACTS OF GLOBAL WARMING ON CROPPING PRACTICES IN ALBERTA

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Abstract

A Target MOTAD farm-level model was developed to assess the expected impacts from global warming on representative grain and oilseed farms in Alberta. It was found that a warmer climate would increase crop yields and length of the cropping season. Net returns and shadow values of land would increase substantially.

Introduction

Increased concern for the environment in the past decade has resulted in a greater awareness of mankind's interrelationships with the environment. On one front, it has become quite widely accepted that "human activities have the potential to cause climate change." (Goodess and Palutikof (1992) p. 34). Significant research has focused on how increasing emissions of carbon dioxide and other trace gases contribute to the greenhouse effect. Most climate warming scenarios predict that the average annual global temperature will rise 1.5 to 4.5 °C and that some climatic factors, such as precipitation, will become increasingly variable.

The purpose of the following study is to address the issue of farm level adaptation to climate change and regional climate variability in the agricultural regions of Alberta. The climate scenarios used in this study were developed in the first of multiple components of a multi-disciplinary project. Other components estimated the impact of climate change on drought and other climatic indices which affect agriculture in Alberta along with the effects on plant growth. The study presented here, is part of the economic component of that project.

Climate Change and Agriculture

Due to increasing levels of CO₂ and other trace gases, the global concentration of which is expected to double by the early part of the 21st century, global climate change models (GCMs) are predicting significant surface warming and changes in precipitation and other climatic variables. Many climate change studies have predicted negative effects on yields of most agricultural crops throughout the world, particularly in areas already experiencing low levels of precipitation (mostly developing countries). See for example Rosenzweig and Parry (1993), Woodward (1992), Carter, Porter, and Parry, (1992), and Smit (1989).

In Alberta, Wong *et al.* (1989) predicted that a doubling of CO₂ concentration would result in a 3 to 7 °C increase in surface temperature and between 7 and 32% increase in precipitation. The higher temperature translates into longer growing seasons (see McGinn, Akinremi, and Barr (1995)). However, in the semi-arid regions of Alberta where soil moisture

content is often the limiting factor in plant growth, additional growing degree days may not be important to crop growth. In addition, the higher temperatures result in greater evapotranspiration and the increase in precipitation is not likely to offset this effect.

Stewart *et al.*(1988) indicated that a doubling of CO₂ would result in an increase in mean surface temperature of 4.7 °C and an increase in precipitation of 18% for Saskatchewan. The result would be an increase in the growing season of 5-15% but a decline in crop yields of 6-15% and an increase in the probability of drought. In another Saskatchewan study by Williams *et al.* (1988) similar results were obtained. These effects translated into a 12% fall in farm level income and a reduction in expenditures by agriculture of Can\$277 million.

Arthur and Abizadeh (1988) (see also Arthur (1988)) assessed the economic impacts of climate change on prairie agriculture. They determined that due to slight increases in precipitation and earlier seeding dates, which result in a new crop growth time scale relative to historical pattern, most of the negative effects on crop production could be mitigated.

Climate Data

The results of McGinn, Akinremi, and Barr (1995); and Saunders and Byrne (1994) were used as input information for farm level models. Saunders and Byrne (1994) and Byrne examined the output from the Canadian Climate Centre Circulation Model (CCC-GCM) and determined that a doubling of CO₂ would likely translate into a 5 to 7°C rise in surface temperature and a 15% increase in precipitation for the Canadian prairies.

McGinn, Akinremi, and Barr (1995) developed four climate change scenarios based on historical data. Their results suggested: 1) a shift in vegetation classification with most scenarios indicating a reduction in the size of the semi-arid; 2) the seeding date for spring wheat would be advanced by 10-20 days in the northern part of the province and greater than 27 days in the southern part of the province; 3) there would be an advancement of the harvest date by between 22 and 37 days depending on the region; and 4) growing degree days (GDD) would increase across the province with a 50% increase expected in most regions.

We considered only the worst case scenario developed by McGinn, Akinremi, and Barr (1995), a change in temperature accompanied by historical precipitation. In addition, we used the historical scenario in order to obtain a base case to validate the economic model. Finally, the

CCC-GCM scenario from Saunders and Byrne (1995) was also incorporated as a more moderate climate change scenario.

We assumed that the effects of climate change, world wide, will be neutral. This assumption enabled us to assume further that world agricultural input and output prices would maintain their historical pattern.

Model Formulation: Crop Growth Simulation Model

There are numerous crop growth simulation models available for most major crops like wheat and maize (for example see Toure and Major (1995), Toure *et al* (1995), and Global Climate and Terrestrial Ecosystems (1992)). The crop growth simulation model selected for this study was the Erosion Productivity Impact Calculator (EPIC) developed by Williams *et al.* (1989) with the USDA at Temple, TX, as calibrated by Toure and Major (1995). This choice was based upon an evaluation of simulation models in southern Alberta (Toure and Major (1995)). The EPIC model gave the best simulation results over all rotations and the most accurate predictions of mean yields during droughts. In another study, Toure *et al* (1995) found that wheat growth simulated by EPIC had correlations of 0.77 to 0.39 with actual yields. Given the semi-arid region of southern Alberta and the risk effects of droughts, EPIC provided a logical choice.

In addition, EPIC can be used to simulate growth of a variety of crops and attempts to account for the physiological processes that govern crop growth and development. Toure and Major (1995), and Williams *et al* (1988) give a more detailed description of EPIC.

Model Formulation: Farm-Level Economic Model

A Target MOTAD (Tauer) model was developed. Given EPIC's strength for simulating drought years and moderate to high correlation with actual yields, it more effectively captures bottom-side risk. Thus, when coupled with a farm-level model which has a Target MOTAD objective function, the best approximation of the weather-induced risk faced by farm operators in Alberta will be obtained.

The Target MOTAD model has a linear objective. The objective function maximizes expected net revenue minus a risk term which captures only the variability in income below a specified target level. The risk term is discounted by the risk aversion coefficient. The greater is risk aversion, the greater is the risk aversion coefficient.

The objective function is:

$$\text{maximize: } E - r \sum d_i \quad (1)$$

where E is expected income, r is the risk aversion coefficient, and d_i is the negative deviation (in net income in state i) from the specified target level.

Expected income equals the hectares planted times the yield times the price, less the costs of production. The risk aversion coefficient is specific to the farm operator. Negative absolute deviations occur when net income in any state of nature (yield-price combination) results in a net income that's below a specified target level.

Decision Variables

Although dryland farmers can plant a number of different crops in the harsh climate of southern Alberta, a rather small number of crops tend to dominate agricultural production, no doubt reflecting their relative profitability: hard red spring wheat, winter wheat, barley, corn, canola, and forages (represented in the model by crested wheatgrass). The farm-level model allows the selection of any combination of these crops when making planting decisions (subject to certain constraints discussed below).

As moisture is generally a concern to crop producers in southern Alberta, large portions of these crops generally are planted on summerfallow rather than stubble (to conserve soil moisture). The model incorporates this choice, where all the crops (except crested wheatgrass which is a perennial forage crop) can be planted on either stubble or summerfallow. The choices include the number of hectares of each crop to plant, whether to plant on stubble or summerfallow and when to plant. The optimal levels of each are determined on the basis of relative costs of each crop, prices, yields, crop rotation constraints, and the variability of net returns which occur as a result of climatic factors and output prices.

The present form of the model assumes that only conventional tillage operations are performed: a crop-fallow choice simultaneously chooses the type and amount of tillage, as well as chemical (herbicide and insecticide) use. Fertilizer use in this in this version of the model has been pre-set for each crop-fallow combination. Yield depends on the weather, planting date, and whether the crop is planted on stubble or summerfallow.

Resource Constraints

The resource constraints include land area, labour hours, machine hours, and financial capital availability. The number of hours required to perform a given operation is determined by the size and efficiency of operation for each farm machine. The farm operator may face financial constraints in operation of the farm. The model includes constraints on cash flow, taxes, and requires that short, intermediate, and long term debt (interest) payments be made.

Machine Sequencing Constraints

Six groups of activities must be performed in a sequential order: pre-seeding tillage, seeding, early summer weed control, late summer tillage and hay harvesting, fall harvest and post-harvest tillage. Not all crops have activities in every group; the main exceptions are winter wheat and crested wheatgrass.

Rotational Constraints

Certain cultural practices must be observed when planting canola. In particular, due to disease, canola should not be planted on the same land more than once every four or five years. The Alberta Canola Production Survey (Alberta Agriculture 1993) found that 70 percent of the best producers rotate canola with three or four crops. This practice is modelled by imposing a constraint that limits canola acreage to one-fifth of the total cultivated farm land base.

Yields and Prices

Twenty-four equally likely states of nature, based on weather and crop prices from the years 1964-87, are included in the model. Prices were deflated on the basis of the Consumer Price Index to provide a series of prices in constant 1990 dollars. Yields were obtained from EPIC and vary by seeding date.

Input Costs

The model includes the prices and quantities of chemicals and fertilizer; seeding rates; machinery needed for pre-seeding, seeding, harvest, and post-harvest activities for each crop; hired labour costs; and amounts of borrowed capital in short, intermediate, and long-term loans. Machinery requirements, sizes, prices, ages, depreciation schedules, repair schedules, fuel use, are also included. Depreciation, repairs, and machine efficiency are based on the age of the machine implement and accumulated hours of operation. Fuel use and other machine costs are tabulated for each hour of machine use.

Walburger and Klein (1998) provide a complete description of the models and validation.

Results

Four farm-level models are developed, one for each major soil zone in Alberta (Figure 1). The structure of the model was the same in all cases, only the input data was changed to reflect the costs, appropriate operation data, farm size, and etc. which are typical of the soil zone. Each of the four models were run three times in order to obtain values for each of the three climate change scenarios: historical case (SCENH), CCC-GCM prediction (SCEN1), and the worst case scenario (SCEN2).

The Historical/Base Case Scenario (SCENH)

Brown Soil Zone

In the brown soil zone, barley and spring wheat grown on stubble were found to be the most profitable crops. The profit maximizing outcome ($r=0$) resulted in 93% of the total crop hectares being planted to barley on stubble, while the remainder was planted to spring wheat on stubble. This is not at all characteristic of farmer behaviour in this region, but increasing the risk aversion coefficient as little as 0.2, obtained a solution more comparable to what occurs on average in the brown soil zone. Approximately 82% of the farm was planted to spring wheat on fallow (i.e. 41% is fallowed at a given time), while about 15% was planted to barley on stubble, and the remainder planted as a perennial forage crop. This outcome resulted in a drop in income variability (standard deviation of farm net income falls by 44%). The trade-off to such a significant decrease in variability however was a reduction in net farm income of about \$10,000.

As the risk aversion parameter was increased above 0.2, barley hectares declined and forage hectares increased. Hiley (1995) estimated, for major crops, that the average crop mix presently observed in the brown soil zone is 40% wheat, 32% fallow, 11% forages, and 9% barley and oats. This compares most closely to the results where $r=0.5$.

Dark Brown Soil Zone

The profit maximizing crops in the dark brown soil zone were spring wheat, barley, and canola, all on stubble. Canola, in fact, was the most profitable of all crops, but was constrained not to exceed the average level observed in this soil zone.

As in the brown soil zone, even a very small increase in the risk aversion coefficient

resulted in large changes in crop selection. With an $r=0.2$, spring wheat on fallow became the dominant crop at approximately 497 of the 650 hectares planted to spring wheat on fallow (76%); 102 hectares were planted to spring wheat on stubble and 46 hectares planted to barley on stubble. This small increase in risk aversion resulted in a 35% reduction in variability and a decrease in net revenue of \$13455. As risk aversion was increased further, barley exited the solution, spring wheat hectares decreased slightly, and the forage crop entered the solution, rising to 119 hectares at $r=2.0$.

At all levels of risk aversion, winter wheat on fallow was very close to entering the solution. The loss in net revenue, on average, would be less than \$0.25 per hectare. So it could easily enter the farmer's choice of crops in a year with a long fall or where there was concern of a wet spring (factors not accounted for in this model).

None of the solutions for different risk levels were particularly close to the estimated proportions of crop production provided by Hiley (1995); nevertheless, his estimate is easily contained in the set of solutions.

Black Soil Zone

The profit maximizing crops in the black soil zone were barley and canola, both on stubble. At an $r=0.2$, spring wheat on stubble, crested wheat-grass, and canola on fallow entered the solution at hectares of 102, 69, and 6 respectively. Barley remained important with 119 hectares. The reduction in income variability was 28% for a trade-off of \$4,361 in net income.

As risk aversion increased, barley and spring wheat hectares were reduced while forage hectares increased quite substantially to 57% of the total at $r=2.0$. Average production estimates from Hiley (1995) are most comparable to the model solution from $r=0.2$.

Grey Soil Zone

For the most northerly soil zone, the profit maximizing crop mix involved barley, spring wheat, and canola, all on stubble. Again canola hectares were restricted to the maximum permitted by cultural practices. Barley comprised 47% of the 250 hectare total while spring wheat was 33%, and canola made up the rest.

As risk aversion increased to 0.2, crested wheat-grass became the dominant crop at 69% while barley dropped to 11%, and spring wheat disappeared from the solution. This solution was

most comparable to Hiley's estimates, with the exception that the canola proportion is higher. Further increases in risk aversion resulted in the disappearance of barley from the solution; spring wheat re-entered to take barley's place at almost the same number of hectares.

Based on these results we concluded that SCENH reasonably represents the historical case, validating the model.

The CCC-GCM Scenario (SCEN1)

The most notable impact for all regions in Alberta was the substantial increase in farm net income. This outcome differs from earlier studies and is a direct result of the yield outcomes obtained from EPIC. By allowing earlier seeding dates, the probability that drier summers would severely damage crops was reduced (more will be said on this below). As an example, spring wheat on stubble yields increased by 34% for the province on average. As costs and output prices are held at historical levels, the yield increase goes entirely to increase net revenues. Under profit maximization, i.e., risk aversion coefficient equal to zero, the increases in net farm income of average size farms in the respective soil zones ranged from \$78,000 in the grey soil zone in the north to \$236,000 in the larger farms of the brown soil zone in the south.

Because of such large increases in average net returns, risk analysis using the Target MOTAD objective function required a larger target income. Leaving the target at an acceptable historical level resulted in little change in crop selection as risk aversion increased. We, therefore, chose to elevate the target level to the mean net return in order to capture risk effects.

In the brown soil zone, barley planted on stubble was the most profitable crop and only at the highest risk aversion level, $r=2.0$, did any other crop enter the solution. At that point, spring wheat on stubble entered the solution at around 8% of total hectares. In the black and dark brown soil zones, spring wheat on stubble was the most profitable crop and was the only crop planted regardless of risk aversion level. Finally, in the grey soil zone, spring wheat on stubble was the most profitable crop and was planted on all the farm hectares. However, a slight increase in risk aversion to $r=0.2$, resulted in an introduction of canola.

Interestingly, the most profitable crops in SCENH remain the most profitable in SCEN1. Therefore, major shifts in production from one crop to another did not result.

We were interested, not only in the change in farm welfare but also in relative riskiness of

different crops. An observation, which applies to all soil zones, requires some discussion. Unlike the SCENH, SCEN1 (and SCEN2 as discussed below) crop selections did not change very much as risk aversion increased. However, there was a much greater range of seeding dates in the climate change scenarios than in SCENH and these varied as risk aversion varied. This was likely due to the expanded seeding period in SCEN1 (and SCEN2).

The results suggest that there are two underlying characteristics of the covariance structure. The first and simplest is that the most profitable crops also experienced the smallest variability in returns. Second, and more importantly, it doesn't appear that there was significant diversifiable risk. Alternatively, it is more effective to alter the seeding dates of the most profitable crop(s) than to introduce new crops.

The longer growing season in SCEN1 resulted in earlier planting and harvesting dates. The earliest seeding dates advanced by as much as 3 weeks in the brown soil zone to as little as two weeks in the grey soil zone. Just as important, the seeding periods in SCEN1 covered as many as 6 weeks in some combinations of soil zone and risk aversion level. The SCENH seeding period never extended beyond 3 weeks in length. This illustrates two underlying factors. First, yields varied less over a larger range of potential seeding dates; and as a result, it was unnecessary and more costly to employ extra labour or less efficient machinery than to spread seeding into later periods. Second, and similar to the first factor, it was less critical for early seeding because a longer growing season translates into less risk of frost damage.

The shadow values on land increased substantially between SCEN1 and SCENH: 213%, 106%, 114%, and 125% for the brown, dark brown, black and grey soil zones respectively.

The Worst Case Scenario (SCEN2)

Recall this scenario was developed based upon yields obtained when precipitation was held at historical levels but temperature increased according to the climate change predictions.

This scenario also generated large increases in net income, although not as large as SCEN1. Toure and Major (1995) indicated that, despite decreases in summer soil moisture, yields can increase substantially due to advanced seeding dates and more heat units early in the growing season resulting in faster maturity. Both of these factors enable significant plant growth to occur early in the season before the drier summers are able to severely impact crops.

In the farm level model, the economically optimal seeding dates were advanced by as much as 4 weeks in the dark brown soil zone and as little as 1 week in the black soil zone (seeding dates in the remaining soil zones advanced 2 weeks). The profit maximizing crop selection resulted in net revenue increases of \$141,500, \$81,700, \$45,900, and \$48,400 in the brown, dark brown, black, and grey soil zones respectively.

In the brown soil zone, barley seeded on stubble is the most profitable crop. Spring wheat on stubble and barley on fallow would reduce the net income by less than \$1.50 per hectare if forced into the solution. In the dark brown soil zone, spring wheat and canola, both seeded on stubble, were most profitable, but barley on stubble would reduce net income by only \$0.13 per hectare. The results for the black and grey soil zones were almost identical. In both cases crested wheatgrass and canola were the most profitable crops; canola is produced at the maximum permitted level and crested wheatgrass is grown on the remainder of the hectares. Spring wheat on stubble was close to entering the solution, at a reduction to net income of \$0.25 per hectare.

Only in the dark brown soil zone did risk aversion affect the crop choice solutions. At high levels of risk aversion ($r=1,2$), crested wheatgrass entered the solution at the expense of spring wheat hectares.

Shadow values on land in SCEN2 experienced increases of 125%, 40%, 46%, and 71% for the brown, dark brown, black and grey soil zones respectively.

Conclusion

The growth of all major cereal and oilseed crops grown in the four major soil zones in Alberta were simulated by EPIC for historical and two climate change scenarios. A Target MOTAD farm-level model was developed to simulate optimal crop selection for representative farms found within in each of the four major soil types.

Results indicated that under a warmer climate, crop yields would increase for all investigated crops, though by different proportions in different crop regions. Planting dates advanced by as much as 4 weeks in the brown soil zone. The seeding periods could cover as many as 6 weeks without substantial yield penalties while seeding in the historical scenario never extended beyond 3 weeks.

Increased profitability resulted due to increases in average yields. The result was increases

in shadow values on land by 114% to 213% in the scenario with precipitation increase and 40% to 125% for the scenario without increased precipitation.

References

Alberta Agriculture. 1993. Alberta canola production survey. Alberta Agriculture, Food and Rural Development, Field Crop Development Centre. Edmonton, Alberta.

Arthur, L.M.. 1988. Socio-economic impacts of climate change on prairie agriculture: the Greenhouse Effect. In Symposium on the Impact of Climate Variability and Change on the Canadian Prairies, Eds. B.L. Magill and F. Geddes. Alberta Environment: 187-203.

Arthur, Louise M., and Fay Abizadeh. 1988. Potential effects of climate change on agriculture in the prairie region of Canada. Western Journal of Agricultural Economics. 13(2): 216-224.

Carter, T.R., J.H. Porter, and M.L. Parry. 1992. The implications of climatic change for agriculture in Europe. Journal of Experimental Botany. 43(253): 1159-1167.

Global Climate and Terrestrial Ecosystems. 1992. Effects of global change on the wheat ecosystem. Global Change and Terrestrial Ecosystems Focus 3 Meeting, Saskatoon, SK, Canada, 22-24 July 1992. Workshop Report 60 pp. University of Oxford, Oxford, UK.

Goodess, C.M., and J.P. Palutikof. 1992. The Development of regional climate scenarios and the ecological impact of greenhouse gas warming. Advances in Ecological Research, Vol. 22. The Ecological Consequences of Global Climate Change, Ed. F.I. Woodward. Academic Press Limited, London: 33-62.

Hiley, J. 1995. Pers. Comm. Estimate of crop choice and proportion by ecoregions of Alberta.

McGinn, S.M., O.O. Akinremi, and A.G. Barr. 1995. Response of drought and agroclimatic indices to a regional change in climate. Lethbridge Research Station Publication, Agriculture and Agri-Food Canada, 87 pp.

Rosenzweig, Cynthia, and Martin L. Parry. 1993. Potential impacts of climate change on world food supply: a summary of a recent international study. In Agricultural Dimensions of Global Climate Change, Eds. Harry M. Kaiser and Thomas E. Drennen. St Lucie Press, Florida: 87-116.

Saunders, I.A., and J.M. Byrne. 1994. Annual and seasonal climate and climatic changes in the Canadian prairies simulated by the CCC GCM. Atmos. Ocean. 32(3): 621-642.

Smit, B.. 1989. Climatic Warming and Canada's comparative position in agricultural production and trade. In Climate Change Digest. Environment Canada. pp.1-9.

Stewart, R.B., K.H. Jones, and E.E. Wheaton. 1988. Estimating effects of climatic variability and change on prairie agriculture in Canada. In Symposium on the Impact of Climate Variability and Change on the Canadian Prairies, Eds. B.L. Magill and F. Geddes. Alberta Environment: 129-144.

Tauer, L.W. 1983. Target MOTAD. American Journal of Agricultural Economics 65: 403-26.

Toure, A. and D.J. Major. 1995. Impact of climate change on agroclimatic indices and crop growth. Lethbridge Research Centre Publication. Agriculture and Agri-Food Canada.

Toure, A, D.J. Major, and C.W. Lindwall. 1995. Comparison of five wheat simulation models in southern Alberta. *Canadian Journal of Plant Science*. 75: 61-68.

Walburger, A.M., K.K. Klein. 1998. Risk and crop choice in Alberta. Working paper. University of Lethbridge.

Williams, G.D.V., R.A. Fautley, K.H. Jones, R.B. Stewart, and E.E. Wheaton. 1988. Estimating effects of climate change on agriculture in Saskatchewan, Canada. In *The Impact of Climate Variations on Agriculture Volume 1: Assessments in Cool Temperate and Cold Regions*, Eds. M.L. Parry, T.R. Carter, and N.T. Konijn. Kluwer Academic Publishers, Netherlands: 221-379.

Williams, J.R., C.A. Jones, J.R. Kinery, and D.A. Spanel. 1989. The EPIC crop growth model. *American Society of Agricultural Engineers*. 32(2): 497-511.

Wong, R.K., M. English, F.D. Barlow, L. Cheng, and K.R. Tremaine. 1989. Towards a strategy for adapting to climate change in Alberta. *Alberta Research Council Report*. 79 pp.

Woodward, F.I. (editor). 1992. *Advances in Ecological Research, Volume 22. The ecological consequences of global climate change*. Academic Press Limited, London.

Figure 1. Major Soil Regions of Alberta

