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The application of agricultural land rating and crop models to CO_2 and climate change issues in Northern regions: the Mackenzie Basin case study

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The Mackenzie Basin in northwestern Canada covers approximately 1.8 million km^2 and extends from 52°N to 70°N. Much of the Basin is currently too cool and remote from markets to support a viable agricultural sector, but the southern portion of the Basin has the physical potential to support commercial agriculture. This case study employed agricultural land rating and crop models to estimate the degree to which a CO_2-induced global warming might alter the physical potential for commercial agriculture throughout the Basin. The two climate change scenarios considered in this analysis would relax the current constraints imposed by a short and cool frost-free season, but without adaptive measures, drier conditions and accelerated crop development rates were estimated to offset potential gains stemming from elevated CO_2 levels and warmer temperatures. In addition to striving for a better understanding of the extent to which physical constraints on agriculture might be modified by climate change, there is a need to expand the research context and to consider the capacity of agriculture to adapt to altered climates.

Key words: agricultural land suitability, wheat yields, Northern Canada

Introduction

Research into the potential impacts of global climate change on human activities has flourished over the last decade, and the relationships between agriculture and climate change have received considerable attention. (For reviews of the effects of global climate change on world agriculture see Reilly et al. 1996, and Parry 1990. Studies on the sensitivity of Canadian agriculture to climate change are presented in Arthur 1988, Bootsma et al. 1984, Brklacich and Stewart 1995, Singh and Stewart 1991, Smit et al. 1989, Williams et al. 1988).

In retrospect, agriculture was well-positioned to respond to the challenges that might accompany global climate change for at least three reasons. First, weather is an important input to agricultural production on an annual basis and long-term climate trends exert considerable influence over the location of agriculture. These indisputable linkages underpin the sensitivity of food production systems to a global climate change and have become part of the rationale for investigating the potential bio-

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physical impacts of climate change on agriculture.

Second, many of the climate change scenarios that were advanced throughout the 1980s and early 1990s suggested a less favourable climate for agricultural production (eg: drier conditions, greater variability) (IPCC 1990) and often contributed to a general conclusion that climate change would result in a less secure global food supply. This potential decline in food security in combination with other concerns regarding the long-term potential for meeting planetary food requirements led to a reframing of global climate change concerns, and contributed to an explicit recognition of the economic, social and political dimensions of climate change impacts research (Brown et al. 1989, World Resources Institute 1990).

Third, agricultural research has investigated the relationships among food production, weather and climate for many decades, and as a result addressing the agricultural impacts of climate change did not hinge upon the development of new scientific methods. Existing agricultural research frameworks and methods were able to incorporate climate change scenarios, and agriculture became one of the first sectors to examine impacts which might stem from global climate change.

Overall, agriculture and agricultural research were and continue to be well-positioned to investigate the physical, biological, economic and social impacts stemming from global climate change. Much of this research into the agricultural impacts of climate change has, to a large extent, evolved from conventional agricultural research and it embraces the assumptions and context which underpin agricultural research in the major food producing regions. For example, agricultural research often draws upon reliable soils and weather data, well-documented crop trials, and high quality farm management data. However, reliable and complete biophysical and socio-economic data bases do not exist for many regions which are near or beyond the current climate margin for commercial agriculture. As a result conventional approaches for gauging the agricultural impacts of rising CO_2 levels and global climate change can be difficult to implement in northern regions.

This paper focuses on assessing the impacts of a potential global climate change on agricultural opportunities in northern regions. It draws upon a case study in the Mackenzie Basin, Canada, and examines issues relating to:

- model applications near and beyond the current climate frontier for commercial agriculture,
- sparse data coverage, and
- linking biophysical and socio-economic assessments.

The Mackenzie Basin context

An overview of the Mackenzie Basin

The Mackenzie Basin (Figure 1) is the world's twelfth largest watershed with a drainage area of about 1.8 million km^2. The main trunk of the Mackenzie River is the dominant feature, and the Liard, Athabasca and Peace River watersheds represent significant areas in the southern half of the Basin. The Basin extends from 52°N to 70°N, and includes portions of the Arctic, Boreal and Grasslands ecoclimate regions (Statistics Canada 1986).

Much of the Basin is currently too cool and remote from markets to support a viable agricultural sector, but the southern portion of the Basin has the physical potential to support commercial agriculture. Commercial agricultural production occurs primarily in the Peace River region. Wheat and barley are the key cash crops, but canola (rapeseed) has become increasingly important in the last 10 years. During the 1980s an average of 335 800 ha of barley and 383 100 ha of wheat were seeded in the Peace River region. Forage production and pasture are the other main agricultural land uses. About 1.2 million ha of land in the Peace River region is currently used for commercial agricultural production (Agriculture Canada 1986, 1990).

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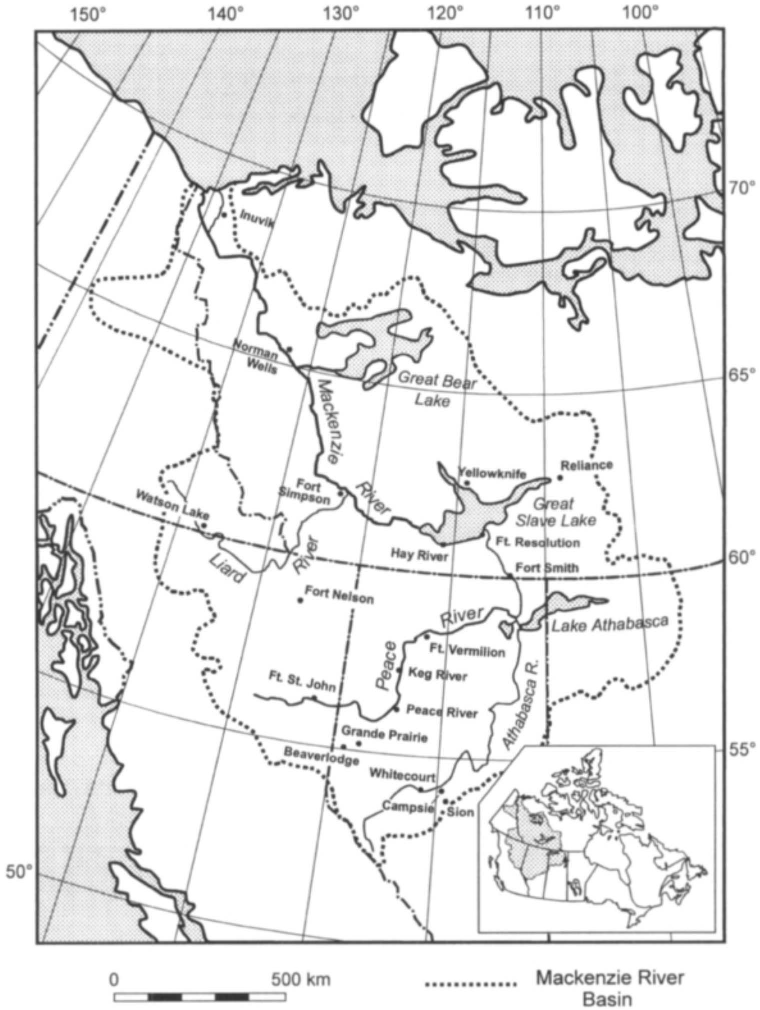

Fig. 1. The Mackenzie Basin.

The Mackenzie Basin case study

With the Mackenzie Basin covering a vast area, much of which is beyond the current climate boundary for agriculture, it should not be surprising that existing data bases impose constraints on the opportunity to assess the agricultural impacts of climate change.

For example, detailed, high resolution soils maps have been compiled for only a limited number of sites within the Basin, and do not provide a foundation for exploring the Basin's agricultural prospects. Basin-wide coverage of basic soils data is not available below the scale of 1:1 million. At this scale, the smallest recognizable land parcel is about 4000 ha and provides a foundation for reconnaissance level assessments.

There were 567 weather stations operating in the Mackenzie Basin between 1951 and 1980. Since the study presented in this paper represents one component of a multi-sector assessment of climate change impacts on the Mackenzie Basin (Cohen 1992), for consistency, all sectoral studies contributing to the Mackenzie Basin project utilize the 1951–80 climate base line. For many of the weather stations, the record has been compiled for a relatively short period (i.e. less than a decade), and lengthy gaps in the record and/or observation of a limited number of weather properties limit their utility. A comparison of the data requirements of the current generation of crop models to the observed weather records revealed that the data required to implement these models could be satisfied at less than 20 sites throughout the Basin. Given this level of coverage, it is feasible to conduct assessments of crop yield sensitivities to climate change for selected indicator sites, but clearly it is not possible to extrapolate from these selected assessments and draw conclusions about the Basin in general.

Crop trials supported by detailed weather, soils and management data are required to calibrate crop models to local conditions. Data from crop trials are available for limited areas, and all are within the southern reaches of the Basin. Under these restrictions, full calibration of crop models is simply not feasible.

The research framework developed for the Mackenzie Basin study recognized the limitations imposed by the available information base, and was designed to make the best use of the available information. The assessment began with a Basin-wide assessment of the extent to which possible changes in long-term climate averages might alter agroclimate constraints and land suitability for commercial production of spring-seeded cereal grains. Regions identified as having a physical potential to support commercial agriculture under this initial assessment were targeted for more intensive investigations into the effects of a CO_2-induced climate change on annual spring wheat yields.

An agricultural resource potential perspective

Resource rating scheme overview

The primary analytical tool used to estimate the climate change impacts on agricultural land potential was the Land Suitability Rating System for Spring-Seeded Small Grains (LSRS) (Agronomic Interpretations Working Group 1992). This rating scheme was selected for two reasons. Firstly, climate properties are considered explicitly by the rating scheme and therefore it could be applied to climate change issues. Secondly, implementation of the LSRS requires routinely collected soils, climate and landscape data and therefore it can be applied to broad regions.

The LSRS is based on rating the extent to which soil, climate and landscape represent limitations for the production of common spring-seeded grains (e.g. wheat, oats, barley). Each of the components is rated separately and assigned an initial value of 100. Then the extent to which a range of factors (e.g. effective growing degree days, drainage class, topography) impair crop production is determined and points are deducted to reflect the severity of the limitation. The overall land suitability rating ranges from 0 to 100, and is based on the most limiting component. An overview of the analytical units upon which the land suitability assessments are founded and a brief description of each component and the data used to implement each component follows.

Units of analysis

The polygons defined for the Soil Carbon Data Base (Soil Carbon Base Working Group 1992) are compiled at a 1:1 million scale and represent the analytical units used in this assessment. These polygons are not necessarily homogeneous and can include a Dominant Soil which exceeds 40% of the polygon's surface area, and a Subdominant Soil accounting for between 10% and 40% of the polygon area. About 1800 polygons containing mineral soils were extracted for further analysis and account for about 57% of the Basin's land area.

Climate component

The climate component considered the extent to which accumulated heat and moisture limit

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spring-seeded cereal growth and development. Growing degree days above 5°C was the prime indicator of heat accumulation during the frost-free season. The May through September moisture supply, estimated as the difference between accumulated precipitation and potential evapotranspiration, was used to calculate the seasonal moisture supply. The LSRS can consider the impacts of earlier than average fall frosts on land suitability for commercial crop production, but insufficient data prohibited the use of this component of the rating scheme. Details on point deductions associated with each of the climate parameters are described in Agronomic Interpretations Working Group (1992).

The 10 km by 10 km baseline (1951–1980) of monthly mean temperatures and total precipitation compiled by Environment Canada (Smith and Cohen 1993) was augmented with monthly normals for minimum and maximum temperatures. Many of the land units (i.e. Soil Carbon Data Base polygons) used in this analysis follow natural drainage systems and therefore are delineated as relatively long narrow polygons. Several 10 km x 10 km climate grid cells intersect partially with these land units. The development of climate profiles for these land units based on an averaging of climate grid cells would have regularly included substantial areas of land outside the soil polygon and thereby contributed to unreliable estimates. To minimize the occurrence of this error source, baseline temperature and precipitation data for the land units of analysis used in this assessment were estimated as the climate associated with the 10 km by 10 km grid cell closest to the centroid of each soil polygon. The moisture supply was calculated using monthly data for the following climate properties: precipitation, maximum and minimum temperature, solar radiation at the top of the atmosphere. Solar radiation estimates at the top of the atmosphere were obtained from Russelo et. al. (1974). The Brooks (1943) method was employed to estimate daily mean temperatures from monthly climate normals, and these daily estimates were used to calculate the accumulation of growing degree days.

Scenarios for long-term climate change were derived from the application of the Canadian Climate Centre (CCC) and Geophysical Fluid Dynamics Laboratory (GFDL) GCMs to 2 x CO_2 atmosphere experiments (Boer et al. 1984 and Manabe and Wetherald 1987, respectively, as reported in Smith and Cohen 1993). Scenarios were generated by applying differences between 2 x CO_2 and 1 x CO_2 GCM model runs to the 1951–80 monthly temperature and precipitation means.

Warmer temperatures were estimated for the entire Mackenzie Basin and for all seasons under the CCC scenario, but the greatest temperature deviations were estimated for the winter months and in the northerly portions of the Basin (Fig. 2). The regional climate change scenario derived from the GFDL GCM was considerably different from the CCC scenario. Estimates under the GFDL scenario of summer temperature increases for the southern half of the Mackenzie Basin were in the 4°C to 6°C range whereas the CCC scenario estimates ranged from 1°C to 3°C. Estimated summer temperature increases for the northern half of the Mackenzie Basin were similar under the two scenarios.

The estimated changes in winter temperature also varied. The CCC-derived winter temperature increases tended to be in excess of 4°C for most of the Basin. Estimated increases under the GFDL scenario were considerably less, and in general did not exceed 3°C.

Changes in precipitation patterns were also considerably different between the two scenarios (Fig. 3). Precipitation estimates under the CCC scenario for all seasons were in the $\pm$25% range over most of the Basin. Estimated deviations from the current under the GFDL scenario were more severe, especially during the summer for which estimated precipitation changes ranged from decreases of up 25% to increases in excess of 100%.

Soils component

The rating of mineral soils was based on the extent to which moisture supply capacity, surface

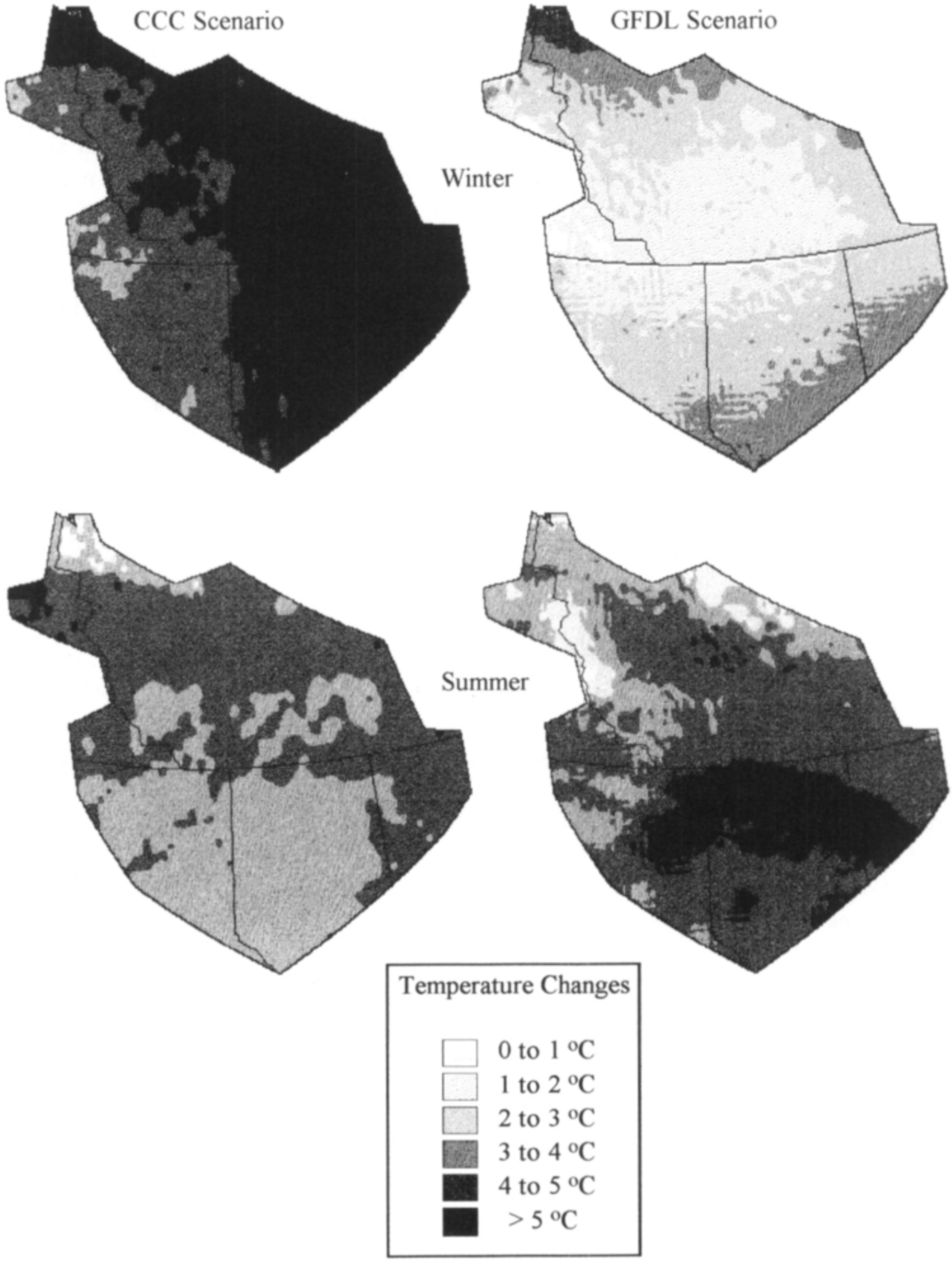

Fig. 2. Temperature changes estimated under the Canadian Climate Centre (CCC) and Geophysical Fluid Dynamics Laboratory (GFDL) model-based 2 x CO_2 scenarios.

factors, subsurface factors and drainage impose limitations on crop production. Limitations were estimated as a function of depth of top soil, texture, drainage, soil structure and consistency, organic carbon content, pH, depth to an impeding layer, and bulk density. The required data were either extracted directly from the Soil Carbon Data Base or information from the Data

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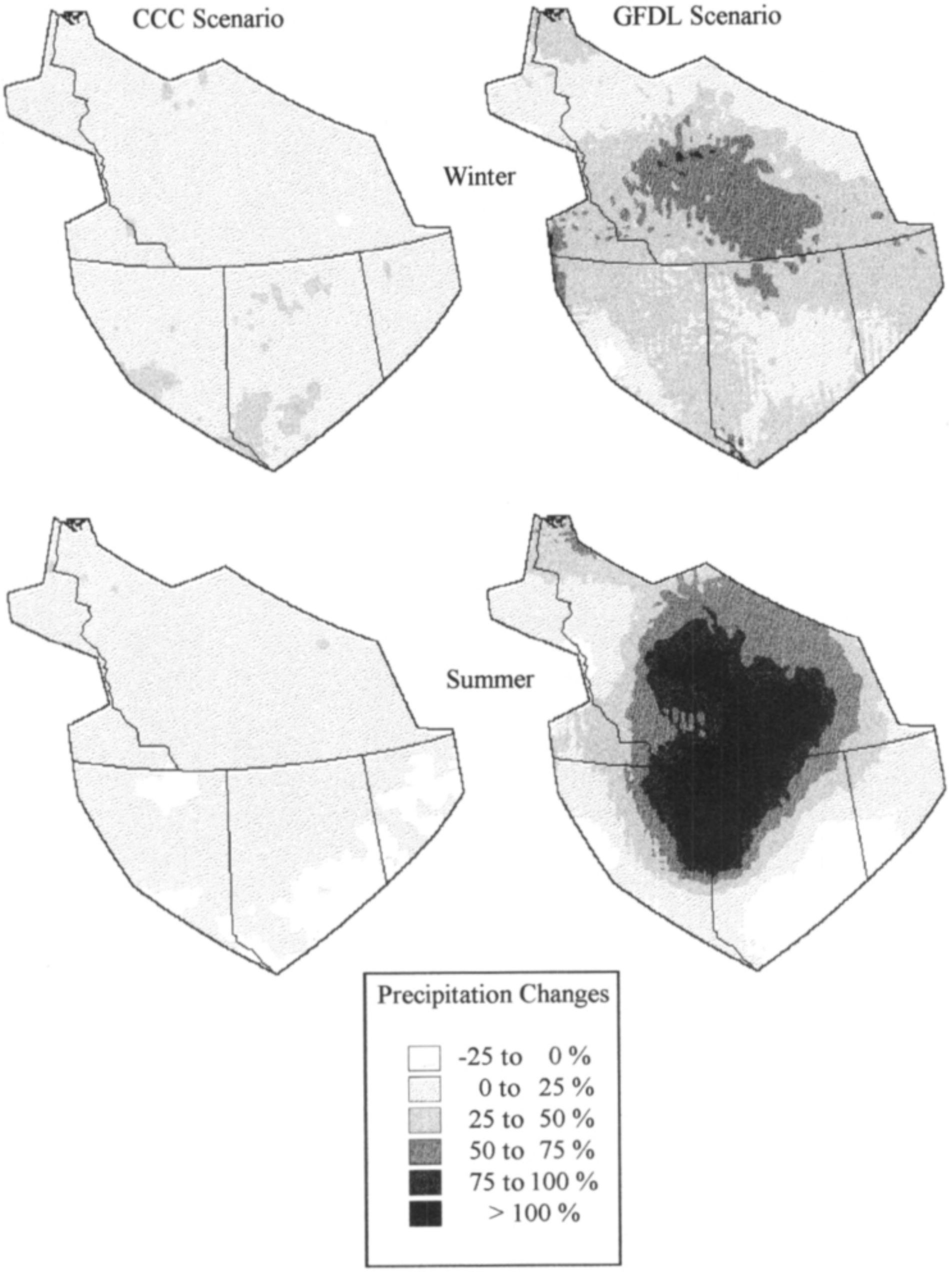

Figure 3. Precipitation changes estimated under the Canadian Climate Centre (CCC) and Geophysical Fluid Dynamics Laboratory (GFDL) model-based 2 x CO_2 scenarios.

Base was used to infer the required data. Point deductions for soil factors are presented in Agronomic Interpretations Working Group (1992).

Landscape component

The landscape component considered slope and slope length, stone removal requirement and coarse fragment content. Lack of reliable information prohibited the use of the flooding factor in this analysis. The data required to rate the landscape component were taken from the Soil Carbon Data Base, and were either used directly or used as proxy data. Details on the implementation of this component are found in Agronomic Interpretations Working Group (1992).

Interpreting the overall rating

The lowest or most limiting score of the three components becomes the basis of determining the overall land suitability ranking for spring-seeded cereal crops, while the other two components are included as subfactors influencing agricultural potential. This approach provides a preliminary estimate of the combined effects of soil, climate and landscape factors on agricultural land potential.

To assist with interpretation the overall score can be grouped into three broad categories (Agronomic Interpretations Working Group, 1992). Lands with a rating ranging from 60 to 100 points are considered highly suitable for sustained crop production. Ratings from 30 to 60 points represent lands which are moderately suitable for agriculture, and scores less than 30 points designate lands which are unsuitable for commercial agriculture.

Climate change impacts on agro-climate potential

The current average frost-free period for the Basin of 132 days (Figure 4) represents a substantial constraint to the commercial production of crops. Each of the climate change scenarios implies a considerable extension of the frost-free period, with the greatest estimated increase of 29 days occurring under the GFDL scenario.

With the longer frost-free period and higher temperatures associated with the climate change scenarios, it was estimated that there would be substantial increases in effective growing degree

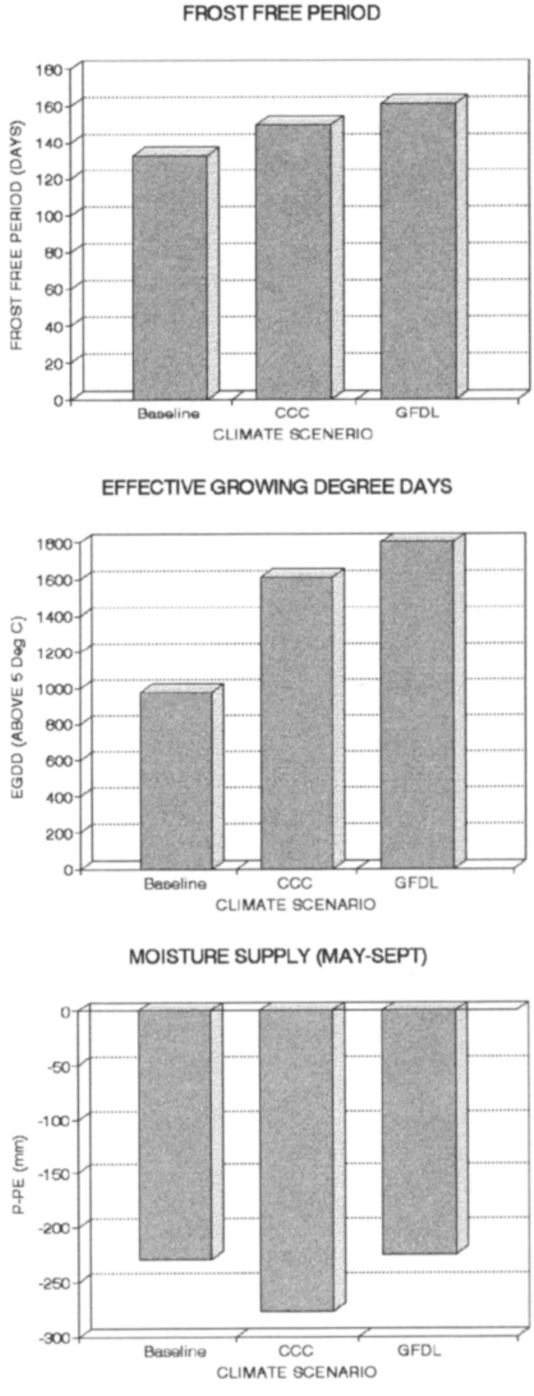

Fig. 4. Impacts of climate change on selected agroclimate properties in the Mackenzie Basin.

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days (GDD) over the duration of the frost-free period. The current Basin-wide average falls short of 1000 GDD, and represents a moderate to severe constraint to the production of spring-seeded cereals. Spring-seeded cereals typically require about 1600 GDD, and this threshold is reached on average under both of climate change scenarios considered in this study.

The estimated seasonal moisture supply, defined as the difference between precipitation and potential evaporation, was also sensitive to the climate change scenarios. Substantial precipitation increases estimated under the GFDL scenario are offset by anticipated potential evaporation increases, resulting in only minor adjustments to the estimated seasonal moisture supply. However, the CCC scenario assumes only a modest precipitation increase, and this was more than offset by the estimated potential evaporation increase. As a result, the estimated seasonal moisture supply decreased under the CCC climate change scenario.

Climate change impacts on agricultural land suitability

Figure 5 illustrates the estimated impacts of the CCC and GFDL climate change scenarios on the agricultural land suitability throughout the Mackenzie Basin. Under current conditions, it is estimated that nearly 6 million ha of mineral soils throughout the Mackenzie Basin are physically suitable for the production of spring-seeded small cereals. Moderately suitability agricultural lands account for nearly 36 million ha, while the remaining 62 million ha of mineral soils are estimated to be unsuitable for spring-seeded cereals.

The largest adjustments in land suitability for agriculture stemming from global climate change are estimated under the GFDL scenario. A 41% increase in the total area of land which is either highly or moderately suitable for cereals is estimated under this scenario, and this includes an estimated 64% increase in highly suitable land.

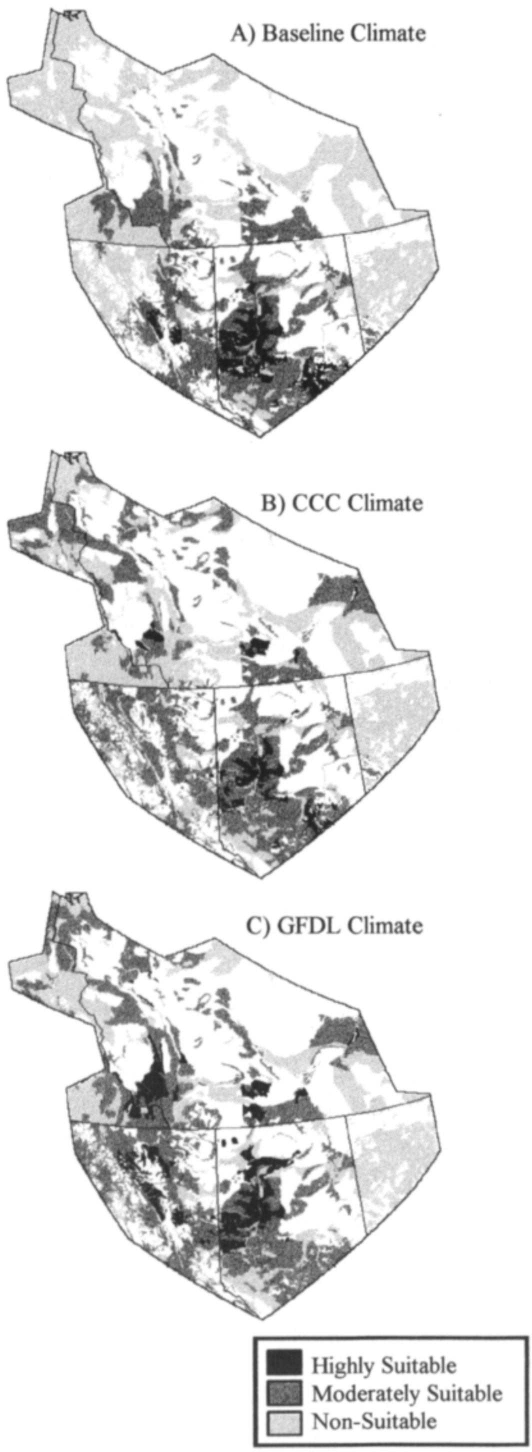

Fig. 5. Climate change impacts on agricultural land suitability.

Under the CCC scenario, the total area of lands highly and moderately suitable for spring-seeded cereals is estimated to increase by 31%. This aggregation of highly and moderately suitable lands however masks an estimated 29% decline in land which is highly suitable for agriculture. Under the CCC scenario, the estimated temperature increases relax constraints associated with the current short, cool frost-free season, but this potential benefit is offset by estimated increases in moisture deficits. As a result there was an estimated decrease in the land area with the highest potential for crop production.

A crop yield perspective

CERES-WHEAT overview

The primary analytical tool used in this component of the study was the CERES-WHEAT crop growth and productivity model. This crop model was selected as it is one of only a few models which can consider the combined effects of CO_2 and climate changes on crop yields, and the model has been applied elsewhere at higher latitudes (Brklacich and Stewart 1995).

The version of the model used in this research is described in Ritchie and Otter (1985) and Godwin et al. (1989). CERES-WHEAT predicts crop growth and yields for individual wheat varieties, and the model employs simplified functions which advance on a daily time step to estimate crop growth and yield as a function of plant genetics, daily weather (solar radiation, maximum and minimum temperature, precipitation), soil conditions, and management factors. Modelled processes include phenological development, growth of vegetative and reproductive parts, biomass production and partitioning among plant parts, and root system dynamics. The model also tracks moisture inputs and withdrawals, and estimates the impacts of soil-water deficits on photosynthesis and partitioning. For this analysis, seeding date (SD) was estimated as the first day of the frost-free season and soil moisture conditions at seeding reflected the extent to which soil moisture reserves were recharged over the winter period.

The intensive data requirements of the CERES-WHEAT crop model limited the application of the model to 16 sites scattered throughout the Mackenzie Basin. The remainder of this section summarizes the input data used in the crop yield assessment and presents selected findings for two sites. Beaverlodge at 55°N is in the Peace River region and within the area of the Basin which presently supports commercial agriculture. Hay River at 61°N is beyond the current climate frontier for agriculture (Fig. 1). This analysis focuses on isolating the sensitivity of spring wheat yields to climate change, and changes in production practices. The use of alternative crop varieties and other adaptive measures are beyond the study's scope.

Model performance

Crop development aspects of the model track well with observed conditions, and differences between the estimated and observed times from sowing to maturity are minimal (Brklacich and Stewart 1995). This indicates that the model replicates crop development processes reasonably well and therefore can be applied in climate change studies. Model estimates of crop yields however often exceed observed yields, and the models provide little insight into the effects of poor weather on crop quality. Overall, this suggests the model can be used to provide insight into the relative rather than absolute impacts of climate change on wheat yields.

Atmospheric CO_2 data

The current level of carbon dioxide in the atmosphere is assumed to be 360 ppm. Future levels are set at 555 ppm and are based upon an "equivalent of a 2 x CO_2" atmosphere. This approach has been used elsewhere in climate im-

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pact assessments (Rosenzweig and Parry 1994) and recognizes that increases in the atmospheric concentrations of other trace gases will result in a radiative forcing of the atmosphere equivalent to that due to a doubling of CO_2 but occurring prior to actual CO_2 doubling.

Climate data

Baseline climate data for the period 1951 to 1980 were derived from the observed weather record at each site. Recorded daily values for maximum and minimum temperature and precipitation were employed. Solar radiation data are not collected on a routine basis and therefore the deJong and Stewart (1993) method was used to estimate daily solar radiation values from temperature and precipitation data.

Scenarios for long-term climate change (Figs 2 and 3) were derived from the application of the CCC and GFDL GCMs to 2 x CO_2 atmosphere experiments (Smith and Cohen 1993). These climate change estimates were then superimposed onto the daily baseline climate data.

Soils data

Soil data were obtained from the Canada Soil Information System (CanSIS). The latitude-longitude position of each weather station was used to locate the corresponding CanSIS soil polygon, and the following soils data for the dominant soil in the polygon were utilized in the analysis: texture, bulk density, organic carbon, pH, coarse fractions, layer thickness, and soil classification.

Management data

Though many wheat varieties are grown in the Peace River region, this study is based upon cv. Manitou. Many of today's wheat varieties have been derived from cv. Manitou and it has been used as a representative variety in previous studies (Brklacich and Stewart 1995).

The application of fertilizer, particularly nitrogen, on commercial crops is considered very important for most agricultural regions in the Basin. The findings presented in this paper are based on 36 kg/ha N, which is consistent with recommended fertilizer application levels for wheat.

Climate change impacts on seeding date for wheat

The frost-free season in the Mackenzie Basin is relatively short and cool, and therefore the estimated seeding date (SD) for spring-seeded crops was assumed to be the first day of the frost-free period. At Beaverlodge, which is situated in the Peace River region, the estimated mean SD occurs in the last week of April (Figure 6), but can vary from mid-April to mid-May. The estimated mean spring wheat SD for Hay River, which is located beyond the current climate frontier for agriculture, was about one week later than the mean SD at Beaverlodge but the range in SDs is similar at both sites.

An earliest possible SD of mid-May represents a relatively late start to the crop season. It is rare under current climate conditions that the estimated SD at Beaverlodge occurs after this threshold, thereby reducing the risk associated with farming in a climateally marginal region. Spring conditions at Hay River are considerably more risky,.and the estimated SD occurs after mid-May about 25% of the time.

Both climate change scenarios imply an earlier SD, however the magnitude of the estimated impacts are not uniform. Mean SD is advanced to a greater extent under the CCC scenario than under the GFDL scenario. A comparison of the two climate change scenarios suggests that larger precipitation increases and less pronounced temperature increases for the winter and spring seasons under the GFDL scenario would result in wetter and cooler soil conditions in the early spring, thereby limiting the impacts on seeding dates. It should be noted, however, that both scenarios lead to a decline in production risk at Hay

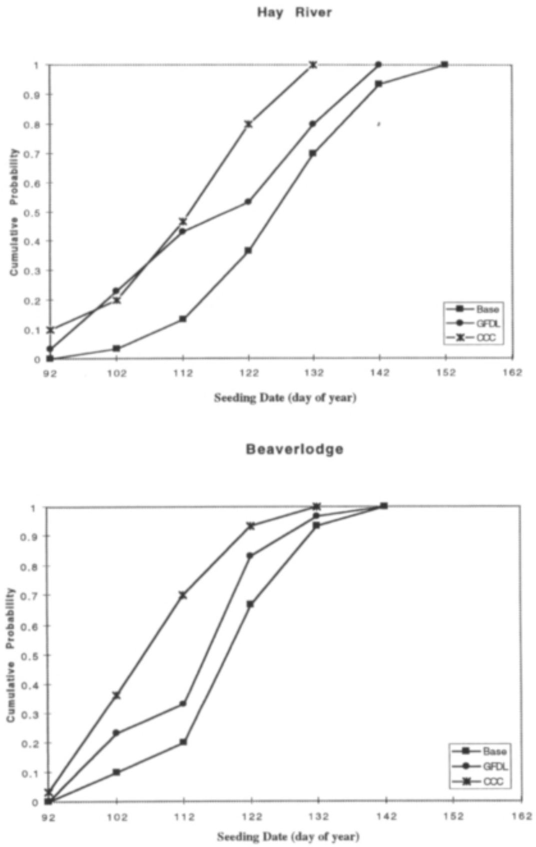

Fig. 6. Climate change impacts on estimated spring wheat seeding dates.

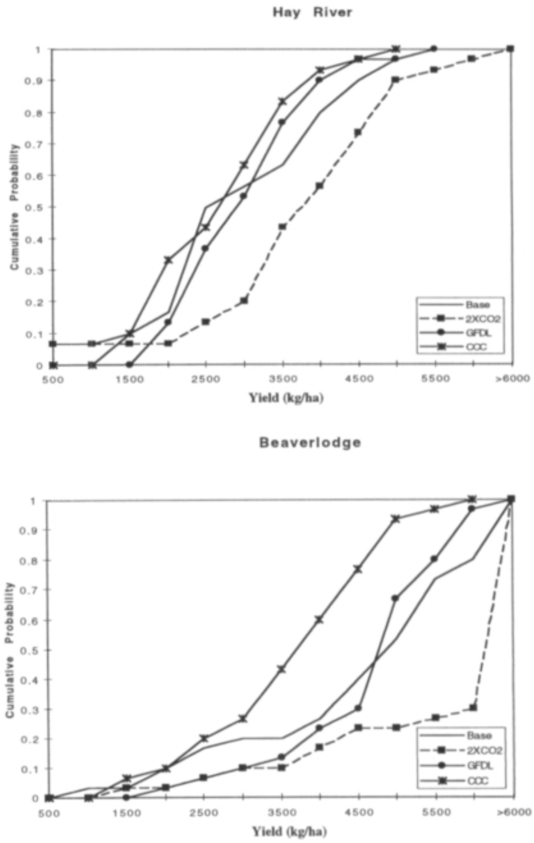

Fig. 7. Climate change impacts on estimated spring wheat yields.

River. The estimated SD occurs after mid-May about 25% of the time under current climate conditions, however the risk associated with this relatively late SD is removed under the CCC scenario and reduced to about 10% of the years under the GFDL scenario.

Climate change impacts on wheat yields

The short, cool frost-free seasons and the potential for crop failures at Hay River tend to suppress crop development and yields. Estimated current mean wheat yields at Hay River are about 50% of the mean yield estimated for Beaverlodge (Figure 7).

The estimated impact of the equivalent of a 2 x CO_2 atmosphere in isolation (i.e. CO_2 increases without climate change) was an increase in wheat yields of about 30%. The potential benefits of increases in atmospheric CO_2 tended to be offset by the climate changes specified under the CCC and GFDL scenarios. The warmer temperatures, especially during the later phases of crop development, shortened the time available for grain filling and therefore the climate change scenarios do not necessarily imply more favourable conditions for cereal crops. At Hay River, it is estimated under both scenarios that the combined effects of CO_2 increases and climate change would result in mean wheat yields that are similar to yields estimated under the current

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climate. For Beaverlodge, this estimated trend also applies for the GFDL scenario, but it is estimated that the expected increases in crop moisture stress associated with the CCC scenario would further reduce mean wheat yields to about 75% of the current estimated mean.

Expanding the research context

The research framework used in this study was initiated by specifying scenarios for climate change, and then the implications of these possible changes were estimated for agricultural resource potential and wheat yields in the Mackenzie Basin. This approach has been instrumental in isolating the sensitivity of particular attributes of agricultural systems to a pre-specified climate perturbation.

While the spatial displacement of conditions which are physically suitable for the production of a particular agricultural activity will undoubtedly have considerable impact on the future of agriculture, this sort of information does not directly address the vulnerability of agricultural systems to changing conditions and the capacity of agriculture to adapt to change (Carter et al. 1994; HDP 1994; Smit 1993). In order to investigate the adaptive capacity of agricultural systems to potential changes in climate and other conditions which influence agriculture, there is a need to expand the conventional research framework employed in this analysis and also consider:

- Do farmers perceive a change (in climate and/or other conditions)?
- What role does climate play in agricultural decision-making relative to other influences including other environmental, economic, political and socio-cultural factors?
- Is the farm vulnerable to the changing conditions?
- If the farm is vulnerable, what is the perceived range of adaptive responses?
- Which of these adaptive responses could be implemented?
- Which of the feasible adaptive responses comes closest to meeting the goals for farming?

Conclusions

This study provided preliminary insights into the potential effects of global climate change on agricultural prospects in the Mackenzie Basin. The relatively short and cool frost-free periods characterizing the current climate impose considerable constraints on spring-seeded cereal production in this region. The two climate change scenarios considered in this analysis would relax these constraints, but it is important to note that, the magnitude and the geographical distribution of the estimated impacts are not uniform across the region. Furthermore, it was estimated that without adaptive measures, accelerated crop growth rates and drier conditions associated with the climate change scenarios could offset potential gains associated with elevated CO_2 levels and expanded frost-free seasons.

Improving upon these preliminary assessments hinges upon advances in at least two areas. Incomplete data is clearly a substantial limitation. The available data on weather, soils, crop trials and farm management are sufficient to support reconnaissance level assessments. Creative methods for supplementing the existing data bases are required.

This assessment considered the physical potential for commercial production of cereals. Logical extensions of this research would involve considering the role of climate relative to other biophyscial and socio-economic factors which influence agricultural systems, and addressing the capacity of agricultural systems to adapt to climate change.

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SELOSTUS

Viljelyvyöhykkeiden ja kasvumallien soveltaminen ilmastonmuutoksen tutkimisessa: Mackenzien jokialue, Kanada

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Mackenzien jokialue sijaitsee Kanadan luoteisosassa ja on laajuudeltaan noin 1,8 miljoonaa km². Tällä hetkellä alue on liian viileä ja etäisyydet ovat liian pitkiä, jotta maataloutta kannattaisi harjoittaa merkittävässä määrin. Jokialueen eteläosien luonnonolot ovat kuitenkin sellaiset, että taloudellisesti kannattavalle maataloudelle on edellytyksiä. Tutkimuksessa selvitettin, miten ilmastonmuutoksesta aiheutuva maailmanlaajuisen lämpötilan nousu vaikuttaa Mackenzien jokialueen luonnonoloihin. Tutkimuksessa sovellettiin maatalousmaan luokitusta ja kasvumalleja, joiden avulla arvioitiin alueen potentiaalista maataloustuotantoa muuttuneissa olosuhteissa. Analyysissä käytetyt kaksi ilmastonmuutosta kuvaavaa skenaariota viittaavat siihen, että lämpötilan nousu lyhentää nykyisin hyvin pitkää routajaksoa. Samanaikaisesti kuitenkin kuivuus ja viljan nopeutunut kasvu vähentävät hyötyä, joka maataloustuotannolle koituu lisääntyneestä hiilidioksidista ja kohonneesta lämpötilasta.